(Steering) Interactive Play Behavior

Robby van Delden

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There was something sacred about this place.
No longer distracted by anything external,
he was finally able to bask in his own existence
and found it splendid.

After a while,
he almost forgot his plans and obsessions
and, indeed, might have done so altogether.

from the movie
Perfume: The Story of a Murderer (2006)

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Summary

Play is a powerful means to have an impact on the cognitive, social-emotional, and/or motor skills development. With the introduction of technology new possibilities emerge to provide engaging and entertaining whole-body play activities. Technology mediates the play activities and in this way changes how people play. We can use this to design systems that encourage wanted types of behaviors with technology.

We systematically investigated our new technologically enhanced play applications. In order to play with these applications people had to actively move. We developed several interactive systems, targeting well-founded goals, resulting in the following three systems: 1) an *interactive playground platform* tracking players and providing an interactive floor projection of about 5 by 5 meters, 2) an interactive ball responding to body movements and sounds with movement, tunes, and lights, and 3) games on an interactive pressure sensitive LED floor.

The systems included interactions that targeted to *steer* the in-game play behavior, the deliberate encouragement of particular types of targeted behavior during game play. We compared the systems and interactions to alternatives, in order to systematically investigate their effects. To indicate our fondness for this comparative approach we named this *intervention based play research*. For doing this type of research investigations we have often used the beneficial elements of automatic measurement, for which we could build on the earlier work in this project of Alejandro Moreno.

Our investigations showed we can steer interactive play behavior in different ways. We were successful in changing different types of behavior: we balanced a game, changed (in-game) occurring social interactions (picking a next target in a game), increased movement coordination between players, and changed the proxemics of players. We have also used interventions that were either more or less forceful. The way we steered the play differed between the interventions. On the one hand, we steered behavior by *forcing* game rules upon users that will quite certainly change their play behavior. For instance, creating a game mechanic that makes players score points only when they are staying close to their team mate. On the other hand, we steered behavior in a more subtle way by *enticing* players. For instance, providing non-functional embellishments for the optional collection of items. This enticing game mechanic can always be used in parallel to an already existing game. We postulate that this enticing strategy has several benefits. These enticing game mechanics are easier to disentangle from the game they have been designed for, therefore they are easier to transfer to other interactive play systems. They are less forcing, which seems to fit with a more libertarian approach, especially suitable for children. They are placed on top of a game, and therefore can be switched on and off, which makes them suitable to implement as adaptive or adaptable game mechanics.

We have included various user groups during our research. This included healthy adults/students, children, gait rehabilitants, and people with Profound Intellectual and Multiple Disabilities (PIMD). We showed several opportunities for creating technologically enhanced play activities by addressing this variety of target groups. The systems were also tested in different contexts and not only created as temporary lab prototypes to do tests with; the systems were demoed at science fairs, we did longer term testing at health care institutions, were part of an exhibition of several months at an art gallery, and even installed a system as a (permanent) daily running installation at our university.

We have seen several reoccurring aspects during our research with different methods, contexts, user groups, and targeted effects. These have led us to several insights. Personalization—in the form of adapting the input and the feedback to the capabilities and preferences of users—is often appreciated by both clients and professionals, and might further the effectiveness of reaching goals. Personalization is even more important when the target group and/or the targeted goals are heterogeneous. An interesting approach to better personalize a game to the user is to not only personalize games in an adaptable manner—with settings fitting the frame of reference of the professional—but also provide different games to chose from. Furthermore, even the evaluation might require a form of personalization. The outcome measures, and how to compare these can also require a personalized approach, both in their measurements and interpretation of outcomes. For example, idiosyncratic behavior can require personalization for annotating expressions of special target groups, and—depending on alternatives and daily behavior—successfully reaching outcomes can be more meaningful for one person than another.

Overall, we have provided a new overview. We combined intervention based play research with steering behavior—in various contexts—and targeting alternative user groups. This directed to new suggestions for both investigating and implementing interactive play systems.

Samenvatting

Het inzetten van spelen is een krachtig middel om impact te hebben op de ontwikkeling van cognitieve, sociaal-emotionele en motorische vaardigheden. Met de introductie van techniek verschijnen er nieuwe mogelijkheden voor plezierige en innemende speelactiviteiten waarbij het gehele lichaam gebruikt kan worden. Technologie medieert speelactiviteiten en hiermee verandert het hoe mensen met elkaar spelen. We kunnen dit ook gebruiken om met dergelijke technologie systemen te ontwerpen die aanzetten tot bepaalde types van gewenst gedrag.

We hebben systematisch onze nieuwe technologisch versterkte speeltoepassingen onderzocht. We ontwikkelde daarbij verschillende interactieve systemen die gericht waren op gegronde doelen waar spelers voor moesten bewegen. Deze kwamen in de volgende drie vormen: 1) een *interactief speeltuin platform* waarin mensen automatisch gedetecteerd en gevolgd werden en aan de hand waarvan een vloer projectie van ongeveer 5 bij 5 meter veranderd werd; 2) een interactieve bal die reageerde op lichaamsbewegingen en geluiden door te bewegen, deuntjes af te spelen, of lampjes te laten branden; en 3) spellen op een interactieve druk gevoelige LED vloer.

De systemen bevatte interacties met het doel het gedrag van spelers te *sturen*, het opzettelijk aanmoedigen van bepaalde types beoogd gedrag gedurende speelactiviteiten. We vergeleken de systemen en interacties met alternatieven, om daarmee systematisch de effecten te onderzoeken. Om onze voorliefde voor deze aanpak met vergelijkendonderzoek uit te spreken beschreven we dit als *interventie gebaseerd speelonderzoek*. Voor het uitvoeren van dit type onderzoek hebben we vaak gebruik gemaakt van de bevorderlijke eigenschappen van automatisch meten, waarvoor we konden bouwen op het eerdere werk in dit project van Alejandro Moreno.

Onze onderzoeken toonden dat we speelgedrag op verschillende manieren konden sturen. We waren succesvol in het veranderen van verschillende types gedrag: we balanceerden een spel, veranderde (in-het-spel) voorkomende sociale interacties (het kiezen van een volgend doelwit), verhoogde de bewegingscoördinatie tussen spelers, en veranderde proxemics van spelers – gebruik van (onderlinge) ruimte. We hebben onder andere gebruik gemaakt van sturende interventies die meer of minder *dwingend* van karakter waren. De manier waarop we stuurden verschilde tussen de interventies. Aan de ene kant stuurden we gedrag met het opdringen van spelregels die vrijwel zeker het speelgedrag veranderen. Denk hierbij bijvoorbeeld aan spelmechanismes waardoor spelers alleen punten kunnen scoren als ze dichtbij een teamgenoot blijven. Aan de andere kant stuurden we gedrag op een meer subtiele manier met het uitlokken van spelers. Door het geven van bijvoorbeeld niet functionele verfraaiingen voor het (optionele) verzamelen van virtuele objecten. Een eigenschap van deze uitlokkende strategie is dat het uitgevoerd wordt in parallel van een reeds bestaand spel. Wij postuleren dat deze uitlokkende strategie meerdere voordelen heeft. De uitlokkende spel mechanismes zijn makkelijker lost te trekken van het spel waarvoor ze ontworpen zijn, daarom is het ook makkelijker ze over te zetten op andere interactieve speelsystemen. Ze zijn minder dwingend, dit lijkt te passen bij een liberalere aanpak, naar onze mening vooral geschikt voor kinderen. Ze zijn aan een spel toegevoegd, en daarom kunnen ze makkelijker aan en uit gezet worden, dit lijkt ze geschikt te maken om ze te implementeren als adaptieve of aanpasbare spel mechanismes. We hebben verscheidene gebruikersgroepen geïncludeerd gedurende ons onderzoek. Hiertoe behoorden gezonde volwassenen/studenten, kinderen, revalidanten, en mensen met ernstige meervoudige beperkingen. Met het adresseren van deze variëteit aan gebruikersgroepen hebben we verschillende mogelijkheden getoond voor het maken van nieuwe technologisch versterkte speeltoepassingen. De systemen zijn ook getest in een verscheidenheid van situaties, dus ze zijn niet gecreëerd alleen als tijdelijke lab prototypes om tests mee te doen. In plaats daarvan zijn de systemen bijvoorbeeld gedemonstreerd op wetenschappelijk georiënteerde beurzen/bijeenkomsten, hebben we bij gezondheidsinstellingen testen gedaan over de langere termijn, waren we onderdeel van een tentoonstelling, en we hebben zelfs een systeem geïnstalleerd als een (permanente) dagelijks aanstaande installatie op onze universiteit.

We hebben verscheidene terugkerende aspecten gezien met ons onderzoek – onderzoek dat dus gebruikmaakte van verschillende methodes, contexten, gebruiksgroepen, en beoogde doelen. Dit heeft ons geleid tot de volgende inzichten. Personalisatie – in de vorm van het aanpassen van de input en feedback aan de mogelijkheden en voorkeuren van de gebruikers – wordt vaak gewaardeerd door zowel cliënten als professionals, daarmee zou het de effectiviteit kunnen bevorderen in het behalen van gestelde doelen. Personalisatie is nog meer van belang wanneer de doelgroep en/of de beoogde doelen heterogeen zijn. Een interessante aanpak om te personaliseren, is om niet alleen de spellen te personaliseren in een aanpasbare manier – met instellingen passend bij het referentiekader van de professional – maar om daarbij ook (geheel) verschillende spellen aan te bieden waaruit gekozen kan worden. Daarnaast kan zelfs de evaluatie een vorm van personalisatie vereisen. De uitkomstmaten, en hoe je deze met elkaar vergelijkt kunnen bijvoorbeeld ook een persoonlijke aanpak vereisen, zowel in de metingen als de interpretatie van de uitkomsten. Denk bijvoorbeeld aan speciale doelgroepen met idiosyncratische gedragingen – dit zijn persoonsspecifieke types van gedrag – die het vereisen om personalisatie toe te passen in hoe gedragingen worden geannoteerd, dit laatste is het gestructureerd vastleggen van observaties aan de hand van een schema. Daarnaast kan het – afhankelijk van de alternatieven en dagelijkse gedragingen – succesvol behalen van bepaalde beoogde doelen voor bepaalde dimensies voor de één meer van toegevoegde waarde zijn dan voor de ander.

Over het algemeen genomen hebben we met ons onderzoek een vernieuwend overzicht gegenereerd. We hebben interventie gebaseerd speelonderzoek gecombineerd met het sturen van gedrag, in verscheidene contexten en met verschillende gebruikersgroepen. Dit stuurt aan op potentiële nieuwe richtingen voor zowel het onderzoeken en implementeren van interactieve speelsystemen.

Acknowledgments

Because this is where we get to make a difference,
and I am so privileged to be able to do that
with each and any one of you.
–Kate Beckett, Castle s08e02 (2016)

Several times during my PhD we have written a paper which was filled up to its page limit. Then when the reviews came in we still had to address all the reviewers remarks within this page limit, so it was also hard to acknowledge people in an accurate manner in the cramped space available. Luckily for me and unfortunate for some of the readers, this thesis does not have such a page limit.... enjoy!

We always had the obligation to acknowledge the support of our research project COMMIT/, each time I was thus hoping it would fit within the page limit, sometimes requiring creative solutions of negative vspace (thanks Ronald), using a footnote, or other dirty layout tricks. Anyway, for once it is my pleasure to start with writing that this ~~publication~~ thesis was supported by the Dutch national program COMMIT/.

People that know me well, know my communications skills for: (–at least in my opinion– according to their 'opinion') every now and then getting off-track, using punctuation marks in confusing ways, and in the process have the urge to produce a beautiful food (for thought) providing garden (sentence). So Dennis, thanks for keeping up with my braindump emails, and other such writings. Thanks, for always being available, I very much look back with fond memories to the 23.59/'just before deadline' final walkthrough of papers. I also appreciated your recognition of life beyond work, and not only sharing research insights but also sharing some of your personal insights into life, you might have steered me in both. You also provided a framework from which I could never feel to be overly busy. A framework suggesting: *'No matter what I will probably manage after all, just try why not?'*. After all, what am I worrying about, if someone can manage to in one month simultaneously rebuild an old house, while organizing an international conference, coordinating a course, welcoming a lovely daughter into the world, and still being able to respond to all his emails accurately and in time. Dennis, thanks a million!

Now that I got started to thank specific people I should also do this for those that got me here to HMI some years ago. First of all, thanks Betsy, for giving an entertaining course with a well organized, interesting use case, going beyond your standard duties as always, sharing your enthusiasm, which made me realize that I also share a passion in the development of engaging interactive products. Thanks, for tutoring me, helping write my first real scientific paper, and for welcoming me to HMI –before I actually knew I was hired for sure.

Ronald, thanks for having no patience and not listening to me! For not having patience and listening to me when I was finishing my Masters', and instead sending an email to Anton directly, so that the same week I was introduced to the COMMIT/ project, and not much later I became part of HMI. Thanks for your ideas, pushing us when needed, and to-the-point feedback on papers even on extremely short notice. It often felt that I had not one co-supervisor but two. Besides work I am glad that you together with Bram, Jan, Merijn, and Gijs provided such a nice atmosphere where colleagues also became close friends and do-it-yourself (beer) brewers.

Dirk thanks for being you, fitting sort of the negation of one of the propositions, as a certain man once said –my source would in general opinion lack the prestigious origin–: *'it is nice to be important but it is more important to be nice'*. Besides being important as my promotor, you have definitely been pretty nice, I very much liked the discussion about directions for my life (and sometimes work), your unpredictable remarks when entering into our office, and the various occasions that we shared good beers, wine, food, and stories.

Alejandro (Moreno) thanks for helping out with everything. I had the pleasure to enjoy many things also outside work with you, thanks for all your help and all these moments: being at your place with Merijn at the seldom occasion where you cooked/prepared a brilliant dinner during Christmas, watching a 'match' together with you and Mafer in the Arena, or watching hundreds of kids getting tagged. It is nice seeing people getting tired... so I also very much liked the memory of you being stuck and paddling to the metal on the Amsterdam canals. I was lucky to play PhD with you.

My time as a PhD student was actually filled with many nice memories, many of those originate from the month spent at Lisbon for the eNTERFACE'13 project with Aduén, Alejandro, Dirk, Gijs, Jan, Jan, Ronald, and Merel. It was a great time, smart people say the best time, also with Goncalo and Carlos –the latter most notably introducing a quite memorable driving skill at around 7 AM. Thanks for providing so many interesting experiences: driving 'on my own' for the first time, eating horrible salty oily but also some delicious food, figuring out incomprehensible old technology by chance, failing at navigation for surfing, and experiencing Bairro Alto together.

Some months after eNTERFACE, when I heard Dirk talking about a project call with something along the lines *'the wilder the better'*, Merijn and I looked at each other and nodded, which meant not much later we successfully started a project. Merijn thanks for that nod (and project), and for not only nodding in our office upon my constant attempts to keep you from working by asking you to provide feedback on all kinds of things. Jered, thanks for the help in StarBot, your baking 'flaws', translating my thoughts into comprehensible stories every now and then, and for your entertaining stories during lunch.

The same kind of appreciation goes out to many colleagues, such as my other (ex-) office mates –Bart, Danish, Dong, Merijn, Thijs, Thomas, and Jelte (thanks for always listening and trying to help out, for example, informing those impatient students on my whereabouts and let me know me that they were waiting and that I should really hurry. Some colleagues also provided other kinds of help that I want to mention. Daniel thanks for arranging a way to get kids. Jeroen thanks for many things, and, although a long time ago, most entertainingly for being Iwan and my native guide to a particular foreign feeling southern area of the Netherlands. Vanessa, thanks for getting the ball rolling, both in BLOX and in the DesignLab. Without the help of

Lynn for this chapter I am not sure ~~if and~~ to what exten~~d~~t this combination requiring some balls actually works, as a ‘word-play’, in English, writing of~~f~~ Lynn: thanks for livening up HMI in general and pointing out the necessary ~~amount of~~ improvements in this thesis, e.g. fairly similar to these in this sentence. Thomas, looking back at my thesis: thanks for helping making two parts of my thesis possible, by both pointing me towards LedGo and suggesting our work to Ella at Tetem. Alejandro C. I enjoyed doing several BKO courses with you and I like how you are truly kind and honestly share your thoughts. Roelof and Randy I liked working together on the workshop, and the other persuasive stuff we did. Charlotte, Alice, and Wies without all your work HMI would probably collapse, I appreciate your hard work very much. Jan, a friendly but recognizably long warning: perhaps after all your wishes get fulfilled in the coming time it might turn out not to be entirely what you expected of it ;), in the way that you already manage to do a lot at HMI. Thanks for fixing a lot of seemingly simple (often Unity) things that might have taken me ages to fix otherwise. More importantly, thanks for providing fun and sharing your ‘weet je wat we proberen het gewoon’ attitude. It is great, not it is even awesome, to work with everyone at HMI: thanks Christian, Angelika, Michiel, Mariët, Mannes, Rieks, Jorge, Jaebok, Bob, Khiet, Daphne, and Gwenn. And to those (now) outside HMI: Hendri, Alfred, and Erik thanks for arranging things and helping out with the technical equipment.

Besides colleagues there are also many students that I had the pleasure to work together with, sometimes only as a proxy. David, Martijn, Fedor, Simon, and Kasper you successfully explored interesting topics that I hope to build further upon. Steven, Silke, and Wouter you even contributed tremendously to my work in a way it could be implemented as an important part of my thesis, thanks!

There are also many people from outside the UT I worked with that went out and beyond to help me out. Thanks to everybody at KITT, in particular Andries, Peter, Thomas, for making the envisioned ball become reality. Sophie, thanks for keeping the weeks of doing studies together both entertaining and streamlined. Besides being a fun person to have around when having to be 4 weeks in a room doing mostly nothing but observing clients, I am also grateful for your hours of annotation work, and all your other contributions to the project. Wietske thanks for all your contributions, and showing how insightful it can be to work together with truly different disciplines. Dankje Gerryjan Huys voor het starten van dit project vanuit Dichterbij en ons daarbij te benaderen. Jan Jacobs en Carla Ooms we waarderen het zeer hoe jullie ons verder geholpen hebben het project mogelijk te maken. We hebben vaak extra werk van verzogers gevraagd, met het bijwonen van sessies, doen van interviews, en bijhouden van vragenlijsten. Dat alles kwam vaak boven op de toch al vrij strak volgeplande en zware werkdagen, dus hartelijk dank voor al die moeite. Ik zal nooit vergeten hoe jullie elke cliënt op een voor zijn of haar passende manier benaderen en met zoveel liefde en passie het beste ervan maken (regelmatig ook buiten de werkdag om). Ik ben overtuigd dat we ook andere mensen die werken met EMBers hebben kunnen inspireren en overtuigen dat deze doelgroep meer ‘snuffelen’ in hun leven verdient, waar nieuwe technologie best wel eens een mooie rol in kan spelen. Dank aan iedereeen die er bij betrokken was vanuit Dichterbij!

Joep and Winnie, I won’t spend much words on our fruitful collaboration, as if it is up to us we are merely starting! As you both probably already know, we much appreciate the way we work together. A word of gratitude also goes out to the other people at de Hoogstraat and LedGo that helped out at several occasions.

No tests without subjects, thanks for making time to all the children, parents, clients, teammates, colleagues, rehabilitants, flatmates, and students, especially the IAers (Rien, Jan Harm, Stijn, Paul, Ruben etc.).

No interactive products without great (technological) ideas and examples. Daniel, Richard, Peter, and Michel: Anemone is awesome! Parlevision worked great, and the first interactive playground demo from Daniel provided a fun way to show where I worked on. Thanks for giving me a nice (eco)system to start with.

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Rick, Ivar, and Behrouz thanks for all the nice moments over the years, including festivals, playing a self-invented card game, going on holidays (lake slappy, verottenetie, mooi man) , and 'jahjahjah' imprinting expressions that stick, like now related to this thesis 'wat lait lait'. I am looking forward to much more of these things, here, in Canada, or wherever.

Lukke, Mark, and Jan-Willem I enjoy(ed) all the fun evenings, the talks, and the nice (cycling) trips to Maastricht. Now that Mark and I both have a nice home in Utrecht I look forward to continue doing it more regularly for years to come.

Duurt lang! A statement that for some reason I seem to have heard quite often in my old student flat. For a change giving a reasonable answer.... yes, it did definitely take long, not only this Acknowledgements section, but also the duration of my PhD. Similar to dr. 'Dré' I am somewhat positively surprised by the number of (former) PhD students that I have lived with in this flat [265]. I am very proud to now finally follow the house doctors Harold, Hendri, Andre, Joost, and Joris. At least it didn't take so long that JW, Tim, and Ruben obtained their degree before me. It was actually coming quite close, and JW I am going to miss the Tuesday evening talks we had about our PhD projects, but I am sure we can find enough other stuff in the world that provides ample opportunity to share a drink over while discussing this. I think a lot of where I am today is because of these friends, including those I made in our flat. In particular those people with which I went to skiing trips, football festivities, sailing, Southampton, and Sziget. Thanks for the awesome memories Ard (in min of meer jou woorden: de flat heerschtte de pannen van het dak), Andre, Cornelis, Geert, Hendrik, Ivan, Joost, Joos(d)t, Joris, Julius, Jurjen, Tara, en Tom; .... en ook vooral aan jullie 'de beste wensen!' Astrid, Bart, JW, Klijs, Ruben, Tim, Tom, and Tony, thanks all for making the flat feel like home, and now bringing that joy and feeling wherever we meet.

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Niet op zijn minst wil ik jullie bedanken lieve ouders! Voor een mooie prachtige jeugd, gezellige huissfeer, de juiste motivatie, en lieve zorgen. Zelfs vorig jaar stonden jullie meteen weer klaar om me op de been te helpen. Bedankt voor alles! Sander, Anne, Frank, Rixt, Bendt, en Lys, dank voor al jullie hulp; delen van ervaringen, momenten, feedback, hulp, en andere bijdragen; jullie steun; en vooral al de leuke gezellige gezamelijk momenten!

Contents

1
Introduction

Yesterday my life was heading in one direction.
Today it is headed in another.
Yesterday I believe I would never have done
what I did today.
These forces that often remake time and space,
they can shape and alter who we imagine ourselves to be,
begin long before we are born
and continue after we perish
– Isaac Saachs, Cloud Atlas (2012)

It seems like yesterday that I, as an eight-year-old, was ‘playing’ Larry and other mainly text based games on a monochromatic CRT monitor. I was not yet capable of writing proper English, nor did I know the goals of the games, and—luckily for my parents—nor did I fully understand the adult context of such a game. Simply the attractiveness of this interactive environment was enough reward for me to keep looking for new English words. Looking at a road I was soon steered to search for the English word for a cab, and this got me started on a journey in this ‘virtual’ world.

Interactive play revolves around using the attractiveness of technology while tapping into our natural instinct and urge to play. Play is used as an umbrella term here. It includes both play as in ‘playing games’ and play without rules, the performative frivolous unbounded explorations in an imaginary world [95, 241]. More specifically, in our description of interactive play it revolves around playing games by movement of the body in a room sized space with interactive elements (and other people).

Technology is everywhere, it is ubiquitous, and becoming more and more affordable, leading to more and more people playing with it. We are long past merely text based monochromatic games. Students play games with people at the other side of the world, children play with their bodies as a controller using Kinects, and we are getting used to robotic interactive moving balls that can be remote controlled (e.g. the BB-8 Sphero). Technology tends to enter into more and more contexts and aspects of everyone’s life. Technology is part of our daily entertainment, our social interactions, our physical activities, and it plays a part in other health related activities. Not only ‘we’ (healthy adults, children, or students) could benefit from the technological improvements in entertainment. Current day technology could be beneficial for everyone, even the mentally and/or physically disabled [88, 130, 282, 283]. In several contexts we might be able to trigger certain types of desirable behavior, and we might be able to do this by incorporating game elements into interactive play systems that steer people towards other playing styles or interactions. This combination of systematic research into interactive elements, play, and steering (desirable) behavior—focusing on a variety of users—are the elements central to this thesis.

1.1 Focus of the Thesis and Approach

This thesis deals with a plethora of contexts and technologies fitting interactive play with our bodies. This variety of contexts fits the research project this work is part of (COMMIT/ Interaction for Universal Access[1]) and the nature of the rapidly growing field but perhaps most importantly also my own interests and educational background.

In my attempts to research different aspects of interactive play I (mainly) use a (within subject) A/B testing approach: people interact with two (or more) versions of an activity and I measure outcomes that I set out to achieve beforehand, which I introduce in the next chapter more elaborately as *intervention based play research*. The measures I use include both quantitative (semi-)automatic measures based on positions of players and more qualitative measures based on interviews, questionnaires, and observations.

This thesis focuses on what I want to steer/achieve and how I approached this. The development, use, and applicability of automatic measurements in interactive play has been the topic of research and thesis of my colleague and friend: dr. Alejandro Moreno [153]. He played an important role in the creation of the Interactive Tag Playground (ITP), an interactive projection augmenting the game of tag, as he created the software for automatic tracking of players. This use case provided a context for investigating interactive play that forms a main part of the contribution of this thesis.

The rationale and origin for researching aspects of play differs from chapter to chapter. I work on systems that encourage physical and social interactions for children, because of the obesity epidemic and the apparent changes in the amount and quality of social interactions [254, 264]. I address our efforts to those that are left behind in entertainment so often, people with profound intellectual and multiple disabilities, which is not a superficial issue as entertainment can form an important part of a meaningful life [261, 262]. I also work on motivating and creating an enjoyable experience during gait rehabilitation.

As I describe in more detail in the remainder of this thesis these topics are indeed worthy of investigation. At the same time, the variation of topics results in other interesting questions being dealt with in less detail than they would deserve in another type of thesis. For instance, the description of play used in the first paragraph suffices to read this thesis without debating about it too much from a philosophical point of view. Instead I refer to Stenros' elaborate review of definitions and positions in the spectrum that I see as ranging from *static rule based games* to the *frivolous imaginative non-deterministic open-ended play* [241]. In his work he also explains that it can be seen as a spectrum, and based on the interests of the developer or researcher one might want to focus on certain parts.

[1] `iuall.nl`, last accessed 1-3-2017

In order to improve the quality of my work on the different topics (as included in this thesis) I work together with several other researchers and students, besides my (co-)promoters (Dennis Reidsma and Dirk Heylen). In the next paragraphs I will give a short explanation of the content/outline of the four parts of this thesis, and explain which collaborations are part of the research.

1.2 Outline

1.2.1 Part 0 - Introduction to the Playing Field

After finishing this description of the thesis outline, I start the thesis with Chapter 2. This gives an overview of existing work into pervasive play spaces. The overview includes categorizing the argumentation for creating interactive play systems, categorizing a variety of interactive play systems, and summarizing several methods for evaluation. It mentions specific types of systems and I introduce our research interests and main identified opportunities. I address those interests and opportunities in the following four parts.

1.2.2 Part 1 - Steering Behavior in Interactive Play Spaces

Part 1 deals with Interactive Play Spaces, focusing on entertainment via embodied interaction in (mainly) room sized interactive spaces where players play together.

In Chapter 3 I introduce the *Interactive Playground Platform*: a camera-projection system creating an interactive floor projection of approximately 5 by 6 meters. The projections respond to the position of four players that are automatically tracked while moving around in the interactive space. The creation of the platform and topics of research surrounding this platform included working intensively together with Alejandro Moreno and his co-supervisor Ronald Poppe.

I describe the first use case in Chapter 4, a *distributed interactive pong playground (DIPP)* involving forms of concurrent co-located and distributed team play. With this use case I address social aspects (presence) and physical movement (coordination between players) in a distributed interactive playground. The distributed version of the playground is the result of closely working together with former master's student Steven Gerritsen. This collaboration also helped in creating the survey for Chapter 2 that I report in 'Part 0' after this outline.

My second use case is the *Interactive Tag Playground (ITP)*, which forms an important part of this thesis. The playground platform, with tracking of players and the projection of circles around players, allows us to mediate the traditional game of tag. In Chapter 5 I show (with student players) that it is possible to balance a game of tag and to steer play behavior during the game. For instance, I steered game play behavior as the choice of the tagger regarding his/her next target (person being tagged) by introducing game elements in the form of virtual arrows. This was, again, done in close cooperation with Alejandro Moreno and Ronald Poppe.

In Chapter 6 I show that we can also steer the play behavior of children, and that we can do this in a more subtle way than 'pointing arrows'. In this chapter I use non-functional rewards in the form of embellishments to change the proxemics of players, which I call an enticing strategy for steering behavior. I show that we can successfully steer the physical distance between the tagger and runners during the game, with only the introduction of in-game aesthetic improvements as a reward for collecting items. In the chapter I argue that such a strategy has benefits regarding transfer to other playgrounds, is more subtle, and can be more easily included as an adaptive feature. For this research I worked together with art gallery Tetem, which allowed us to place the ITP in a real-life environment for over two months. This made it possible to have over six hundred different children playing with the ITP, and make several changes to our playground. I also worked together with other PhD students from our department, for instance with with Daniel Davison to setup primary school field trips. This setting allowed us to do a more controlled study with children. This chapter concludes Part 1.

1.2.3 Part 2 - Play for People with Profound Disabilities

Part 2 of this thesis moves to a category of users more challenging than students, and even more challenging than (healthy) children. I turn to the opportunities of play for people with profound intellectual and multiple disabilities (PIMD). I will discuss applying interactive embodied play for those people who do not have many alternative means for entertainment [43, 130, 262].

In Chapter 7 I describe why this is an important topic. I explain how we set out to improve alertness, affective behavior, and the amount of movement for people with PIMD. I describe our concept of a new form of interactive entertainment that targets these dimensions: an *interactive ball*. Based on a pilot study I made changes to the ball and designed an exploratory follow-up effect study into the effects of this ball. Together with the company KITT, this interactive remote controlled ball was designed and implemented. The research of this part was initiated by health care company Dichterbij. They came to our university as they were also interested in combining the power of play with new technology, in order to allow for meaningful entertainment for their clients that were missing out on such experiences.

Chapter 8 forms the core of Part 2, it contains the description of the exploratory effect study in which I investigate the effects of the interactions with the interactive ball on this user group. For this measurement of the effect, mainly based on manual observations, I worked together with researchers related to the Tilburg University.

1.2.4 Part 3 - Interactive Play for Gait Rehabilitation

Part 3, containing only Chapter 9, is about a more practical application of playgrounds: *games for gait rehabilitation on an interactive LED floor*. In that Chapter, I focus on the benefits of such interactive games that allow the therapist to tailor the interaction to the capabilities and preferences of the rehabilitant. The research process included close cooperation with Joep Janssen, researcher and physical therapist at de Hoogstraat Revalidatie and Winnie Meijer, managing director of LedGo.

1.2.5 Part 4 - Conclusion

The final part concludes the thesis. Here I start with a discussion in Chapter 10. I discuss what I see as the added value of the work we did, and discuss some of the limitations. In Chapter 11 I present some preliminary 'further work' we did with students into several topics that can be an interesting starting point for future work. I end with Chapter 12 that contains a short conclusion summarizing the outcome of this thesis work.

2

The Playing Field

To be is to be perceived.
And so to know thyself
is only possible through the eyes of the other.
– Somni, Cloud Atlas (2013)

This chapter presents an overview of existing work into interactive play systems. The systems central to this Chapter concern technologically enhanced forms of social and bodily play. We present a variety of research topics, directions, outcomes, and approaches that are part of this field. We do this by explaining the types of systems people have made, the goals they had with regard to the influence on end-users, the evaluation methods they used to analyze the (interactions with their) systems, and the type of research contributions they made. We end this chapter by elaborating on the usefulness of an intervention based research approach for this kind of work. This forms a firm starting point for the subsequent parts of this thesis.

2.1 Play and Interactive Play

We look at pervasive play-spaces, or interactive play systems—we will use these terms interchangeably. The systems center around providing forms of social and bodily play in a technologically enhanced space. In this manuscript we focus more on room-sized spaces than urban play, and focus on systems that target play for multiple players. With the rapid growth of technological possibilities we have seen a variety of new types of pervasive play-spaces. These environments are used to specifically target the cognitive, social-emotional, and/or motor skill (development) domains [23, 207]. We will give an up-to-date overview of this research field.

We are not the first to give an overview of pervasive play-spaces: previously Magerkurth et al. described various Pervasive Games [139], Sturm et al. described various Interactive Playgrounds [242], Nijholt et al. described various Ambient Intelligence Environments [185], Stach et al. classified different Active Games based on

This Chapter is based on work that is under review:
R. W. van Delden, S. Gerritsen, D. Reidsma and D. K. J. Heylen, “Pervasive Play-spaces: Past, Present and Perspectives”. It includes references to work presented in later chapters of this thesis.

the input [239], Schouten et al. described various Ambient Games [227], Poppe et al. also described various Interactive Playgrounds [207], and Malinverni and Parés specifically created a systematic review regarding learning through Full-Body Interaction [141]. The authors and papers had different foci but all contained some examples of what we call interactive play. They also mentioned key issues for the design of and research into playgrounds. We build on these works, extend, and bring together related work, where we also borrow part of their lexicon.

The featured literature was collected during a research project on Ambient Entertainment that started in 2011. Google Scholar, ACM Digital Library, and Springer Link were used as primary search environments. Google, Vimeo, and YouTube were used as well, to also familiarize ourselves with non-scientific work. We contacted and communicated with several companies working in this field to broaden this knowledge. Search terms included, but were not limited to: interactive playgrounds, interactive play, ambient entertainment, and embodied interaction. Several students were assigned to perform additional searches to related topics, which provided us with a broader view on the field, and also pointed us to relevant research. We did specific searches into questionnaires, recurring authors and research groups, and we performed directed snowball sampling, that is to say we looked into referenced work filtered on title, familiarity, and citation. This resulted in collection of 435 research papers, 5 books, 4 PhD theses, 4 technical reports, and several movies, leaflets, and websites. The literature included in this survey was selected based on a mix of their fit to the themes, the structure of this survey, and the recurrence of citations.

This survey is structured as follows. We finish the introduction of this survey by elaborating on play and interactive play. We then start with discussing several goals that have been targeted with the introduction of the systems (Section 2.2). This is followed by an overview of the kind of systems that are out there (Section 2.3). We then discuss several ways in which evaluation of these systems has been performed (Section 2.4). The next step is to categorize the types of research contributions that resulted from designing and investigating these systems (Section 2.5). We finish the manuscript with a section on explaining what we see as promising directions for future research in this field, an *intervention based play research* approach, a direction that we think could better bring together these different aspects of interactive play (Section 2.6).

2.1.1 Play

In this survey we refer to *play* as a social, bodily activity that people (partially or primarily) engage in for fun and entertainment. Play in that sense has been researched for decades. Best known are the early works based on analysis of (human) cultures, language and practices by Roger Caillois, and by Johan Huizinga. Both authors explain that there are many different types of play including but not limited to goal-oriented outcome games, cultural performances, and games that simply stimulate the senses [42, 95]. Both authors view play as being omnipresent in our nature and culture. Both the developmental psychologist Lev Vygotsky and Jean Piaget referred to play as being an important element in the way children develop, although the two have different views/theories on (the stages in) children's development [202, 271]. Iona and Peter Opie also did essential work in researching play in the second half of the 20th century, with the archiving, collecting, recording, and analysis of children's play and tradition in the UK. We refer the interested reader to [41] in which the

Opies' work is compared to current day play in the UK. Recently Jaakos Stenros wrote a thesis on the spectrum of playfulness, play, and games, with an elaborate review of definitions and positions of these and other authors [241]. Based on this work, from our focus and point-of-view, we see play as ranging from structured play with *non-changing rule-based games* to open-ended play which is more *frivolous, imaginative, and non-deterministic*. Both ends of the spectrum have their benefits and downsides with regard to what effects play can have outside the activity itself, for example, stimulating creativity, improving cognitive development, learning social skills, or (better) enhancing physical skills.

2.1.2 Interactive Play

Interactive play allows for enhanced play experiences by combining traditional play with advances in technology [23, 246]. We think that true interactivity is more than simply turning a product on or off and instead requires a dialogue of actions and reactions [43, 130, 262]. Interactive play is more than electronic toys such as remote controlled objects (drones, cars, and balls), light sabers, and walkie-talkies. Although such electronic toys also combine technology with playful activities, we see these electronic toys as inherently different from interactive play systems. Looking at the field of interactive play, we see 4 elements that together separate interactive play from this type of electronic toys. First and foremost, all systems that we include in our defenition explicitly require body movement for interaction, creating an *embodied interaction* that is different from the interaction required by computer games played with a joystick, mouse or touchscreen [27, 66]. The systems respond to this movement-based type of input. Second, the *feedback* is enhanced, more than just the physical impact of the movement, the feedback is 'direct', and the feedback is offered in gradual forms, for example, lights/visuals in different colors, a variety of sounds, and movement/vibrations in various intensities [130, 262]. Third, there is some *history of state*, for example, the system remembers where a player was standing a few seconds ago in order to switch between the states or to keep a score [62]. Fourth and optional, depending on the type of device and the goals, systems can be made more interactive by sending and *comparing the states of multiple devices/players* (between devices) and this provides more opportunities for play with multiple players, for example, turning on the lights around another goal once a player has past a defender and has scored[1] [58].

Besides promoting interactions and providing pleasing forms of feedback, interactive play systems can sense, detect, and observe behavior of the user, this allows us to intervene during play and adapt the game based on their interaction and performance [128, 154, 207, 260].

2.2 Argumentation for Interactive Play

Now that we have introduced the elements of interactive play that were derived from the literature, we will further explain goals that are targeted with interactive play. Systems often target several of these aspects simultaneously. These are the goals that can be linked to an *end-user perspective*, answering questions such as: What positive effects can the system have for the end-user? Why do we as a field work on this

[1] Rosales et al. argue/explain this is not always beneficial or necessary for a proper experience [218], and it is therefore not (always) a core element

topic? Later, in Section 2.5, we will focus on what the contribution can be from a *research perspective*, describing several kinds of contributions that studies and papers added to the body of knowledge. The set of goals from an end-user perspective is similar to that mentioned by Poppe et al. [207]. We revised it to mention stimulating (distributed) social interactions and (sport) skill development in a more prominent way, we excluded ‘behavior change’ as we view this as a means to promote goals, not an end in itself. We also omit diagnosis, as we have not yet seen playful interactive systems doing this, although we agree that this might form a new and promising direction for interactive play systems and we are currently starting first explorations in that direction.

2.2.1 Stimulate Physically Active Behavior and Sport Skills

Children are used to playing with digital entertainment, which also leads to children spending more time with digital games [139][1]. This trend has caused people on average to adopt a more sedentary lifestyle[2] [229, 274]. Introducing technology to make active playful activities more appealing could help to (partially) counter this trend [137] as it seems to be a promising way to encourage children [24, 128, 228], teenagers [249], adults [213], and elderly people [136] to move more at least on a short-term basis [113].

A second type of stimulation of physical active behavior is focusing on physical skill development. In Japan it has been shown that some types of physical ability have been declining in the last decades as well [229]. This skill development can be stimulated with simulation of sport elements, adding motivation with game elements, incorporating ways for improved reflection on performance, and quantifying player progression [24, 74, 107, 108, 133]. A goal of interactive play systems can also be to create a motivating activity in the rehabilitation process, where the systems help players to (re)gain skills that declined from health problems [32, 257].

2.2.2 Stimulate Social Interactions

Besides leading to more sedentary behavior, digital entertainment compared to traditional play might lead to fewer social interactions - more children are interacting through and with their technology (e.g. mobile phones) at the same time being together but alone: ‘*Alone together*’ [254]. Turning technology from a problem into the solution, well-designed interactive play could instead also increase social interactions by stimulating player interactions directly with giving players different roles [89, 260] or by starting discussions about games, sharing interpretations of interactive elements, and stimulating negotiations regarding resources or rules [23, 150, 151, 246].

A subclass of stimulating social interactions is to stimulate social interactions of people that are geographically separated. Often this is combined with exertion in-

[1]On average there was a measured average increase of 1.2 hours of gaming per week by US gamers (13+ yrs) from 2011 (5.1h) to 2013/2014 (6.3h), according to a survey by Nielsen Company `http://goo.gl/ejd2Y4` an increase was also reported for UK children by Ofcom `http://goo.gl/ubccZd`, last accessed 3-1-2017.

[2]Senda and the WHO report mention that this trend is combined with safety concerns leading children to play less outside; the fact that for the adults there are more service, clerical or desk jobs that require less energy expenditure than the traditional labor intensive jobs; and the increased use of cars that—combined with safety concerns—diminish the energy expenditure on cycling and walking as a means of transportation. All of these factors together are deemed to be responsible for the obesity epidemic but are outside the scope of this manuscript.

terfaces, *'an interface that deliberately requires intense physical effort'* [164, p1], often based on sports. Combined with the distribution this becomes *Sports over a Distance*, a category of systems that attempt to break away from social isolation and sedentary behavior that seems to be supported by traditional digital games [175]. Such systems include technological ways to provide augmented sports, such as joint jogging [3, 170], kicking/throwing a ball against a wall [163], (kick) boxing [172], and table tennis [175]. Some systems also provide ways for haptic feedback, such as a game of tug-of-war [19] or arm wrestling[1]. This is primarily a different goal than the previously mentioned stimulation of actual sports movement, as it uses sports to get people to interact socially over a distance, instead of being focused on training certain abilities. Nonetheless, it is important to realize that many pervasive play-spaces often target several of these goals simultaneously.

2.2.3 Improve (Children's) Cognitive Development

Play is important for the development of children in the physical, social-emotional and cognitive domains [46, 272]. By interacting with other children, they train negotiation and social skills. Cognitive skills are often achieved by creating and adapting game rules, scenarios, and characters [46, 221, 272]. It seems that introducing technology into traditional play could also aid in children's development. Various design strategies for creating interactive play systems fit quite well with current psychological models about learning [141]. Some installations explicitly build on these models to create interactive playgrounds that explain mathematical notions such as bar-charts [52] or algorithms [86, 286]. The installations can also be applied for explaining other educational topics such as geometry, physics, geography, music concepts, and language, or for understanding more moral topics such as environmental issues, cultural diversity, and social justice [79, 141]. Furthermore, they can be used to show the relation between educational elements, for instance showing that science is a network of knowledge [49]. A variety of interactive play systems also try to stimulate creativity. A well known approach is open-ended play or emergent games, in which interactive elements provide an emergent space in which players are stimulated to create their own goals, games, and adapt rules; instead of strictly prescribing games and how they should be played by their rules [23, 185]. This is an approach that is related to open-ended interactive art works, which are not completely defined by an Author/Artist but rely on the interpretation of the reader/visitor [159].

2.2.4 Provide Joyful Experiences

A fourth reason that is mentioned is hedonistic, a focus on applying interactive play in order to provide a (new) fun experience, perhaps improving well-being (indirectly) with positive effects for the general health of the players, or simply for commercial reasons [185].

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[1] We also refer the reader to several papers that mention such systems [160, 161, 162, 167]. The wrestling over a telephone line was probably the first system, created in 1986 by Doug Black and Norman White, interestingly due to the technology at that time the game could end up with winners at both ends `http://v2.nl/archive/works/telephonic-arm-wrestling`, last accessed 3-8-2016

2.3 Types of Interactive Play Systems

A variety of interactive play systems have been developed in the last two decades[1]. Other papers mention such systems with categories based on the type of input including physical characteristics (e.g. type of action or controllers and (physiological) sensors) [227, 239][2], game genre (e.g. affective computing) [139], goals and hardware capabilities [207], or devices, scale and interaction [185]. We organized the systems according to the *physical characteristics*, similar to Sturm et al. [242], where we extend the description of the categories and include more (recent) systems.

Roughly we see two main lines in research on interactive play that do fit our focus. *Interactive toys*, where objects are augmented with interactive elements, and *interactive environments*, in which the surrounding playground is also equipped with additional sensors or additional means of providing feedback. This split is not a dichotomy but a somewhat blurry distinction, where some interactive toys might rely on sensors in the environment and some toys can be introduced into interactive environments. In general the toys allow for more mobility of the installation and can be cheaper, the environments often seem to be more expensive but could allow for a more *easy stepping in and out of the game* [153, 243] or a *'show up [..] and play' approach* [175, p3] in public spaces. Besides these two main lines there is the topic of geo-location games that we only touch upon. This topic is quite different because it does not require colocated social play. For an overview with 3 described examples per category see Figure 2.1.

We exclude certain things and focus less on certain topics, even if they are interesting, because they do not fit into the core of this thesis. We only include a few interactive art installations and interactive play systems intended for museums. The body of work on these is much larger than represented in this survey, some do not fit the core of this thesis because of the lack of gradual input and feedback, others focus on providing a message instead of providing active embodied play. We also only include a few *active video games*, 'this form of game integrates the entertainment of playing games with the physical interaction of the user to control the game play' [6, p21]. This term is used mainly in health related domains [189], and the games are (often variations on) movement-based console games for existing systems such as the Wii, XBox Kinect, and Playstation Move. These games only to a limited extent require movements in a small physical space. Still, they share much of what is discussed in this survey so far, and they can provide relevant results when incorporated in studies [6, 27], which is why several papers are included in Sections 2.4 and 2.5. We exclude most (interactive) fitness equipment as they are also not made for colocated social interactions with different types of bodily interaction. We also exclude interactive pedometer systems and physical activity apps such as *Strava* and *Runkeeper*, and related game-like research attempts that include persuasive elements (e.g. [45]). Some of these activity-trackers might largely adhere to our description of interactive play systems and future systems might even fall within the domain. Nonetheless, they are forming a quite different area of research as many only provide 'feedback' before or afterwards [170], are less playful, and do not contain the earlier mentioned gradual ways of input and output.

[1] Immersive environments (stimulating play) around a narrative can be seen as some of the first systems [68], including the well known Kidsroom [31]

[2] Stach et al., based on analyses of 107 active games, proposed 6 forms of input: gesture, stance, point, power, continuous control (including position), and tap.

2

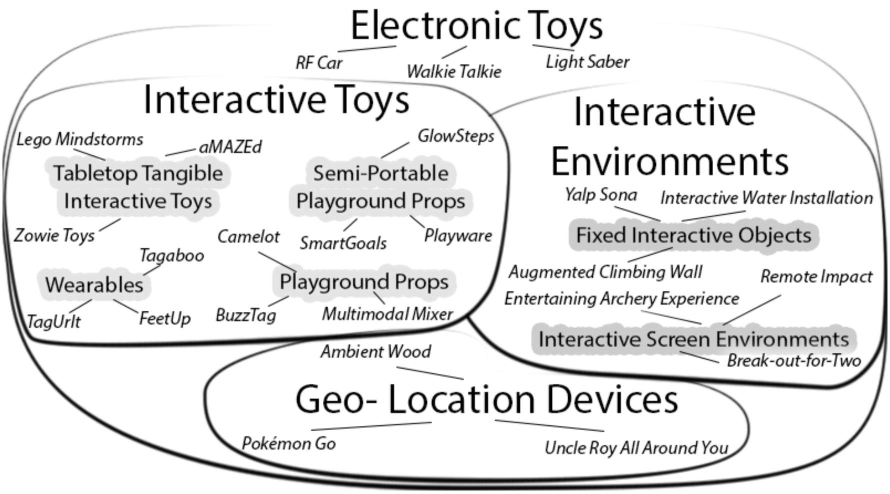

Figure 2.1: An overview of categories of electronic toys, with a focus on the three types of interactive play systems: 1) interactive toys, transportable devices with included sensors, 2) interactive environments, larger environments equipped with various sensors, and 3) geo-location devices often mobile phones, with which games are played that are not constricted to a space, collocation, and can be played asynchronously. Some examples of games/systems are close to another (sub-)category. We placed those systems close to the borders. For this categorization we included the so called head-up games in the playground props category.

Below we will provide an overview of the type of systems we encountered in the literature[1]. Before doing this, we deem it necessary, although it is not the focus of this thesis, to provide a short overview of ways that people used to measure input in embodied types of play and of several ways that people used for output in the systems discussed.

2.3.1 Hardware for Input in Interactive Play Systems

For all of the following systems it is important to either track the position or action of users. This can be complicated by the fact that there might be no physical devices to track actions with. One solution is to use (infrared) cameras or depth sensors. Using the infrared spectrum prevents feedback loops due to changing animations. Such a sensor system can be mounted to the ceiling to provide an easy means for tracking the players [128, 156, 232]. The camera can also be mounted inside the floor with a semi-transparent floor to track the feet of users [79]. Alternatively, pressure sensors [257, 283] or piezo-electric (audio-based detection) [101, 175] can be embedded in the floor/screen to provide a means to track players or a ball. These tracking systems can also be combined with a microphone to include audio/voice input [93]. Ishii et al. concluded (in 1999) that the use of sound based tracking can be beneficial if computer vision is too slow, complicated, or computationally too expensive [101]. Cameras, a laser scanner, or other sensors can also be facing the user (interaction area), similar to an Xbox Kinect game setup, which could also allow for using posture

[1] For a more elaborate description of the individual systems we refer to an extended draft of that Section `http://robbyvd.com/play-systems-extended.pdf`.

information (or record the 'shadows' themselves [159, 172, 232]) but might introduce more issues as players can easily obscure the camera [172], or other players. All these kinds of solutions, sensing with some distance to the user, can be preferred for systems in public spaces, as they allow the technology to be kept out of reach of the public [123].

There are also several sensors that measure force, bending, acceleration, rotational motion, or (related to earlier mentioned accoustic piezo electrics) vibration [219]. Some forms of lineair positions, angles, and rotation can also be measured directly when applied relative between objects, for example, with knobs and a magnetoresistive rotational (speed) sensor[1] or several reed sensors [74]. Such sensors are often embedded in (wearable) mobile solutions, or in (standing) equipment/devices, and can be applied to augment fitness exercise equipment [239].

In Section 2.4 we will also explain some other means of measuring activity (such as motion capture suits, and galvanic skin response) but we view these to be more suitable for evaluation purposes than for use for input for the interactive play systems explained here, as they require more setup time, and in some cases very extensive calibration.

2.3.2 Hardware for Output in Interactive Play Systems

Many interactive toys rely on LEDs for their main form of output, but can also use vibrations and sounds [23, 218]. In the last few years LEDs have become bright enough to also be visible in outdoor situations. Small (LED) low resolution displays (that can sometimes even bend) can be implemented in clothing or a hat and can therefore also be incorporated into interactive play systems [55, 179]. Some toys apply force feedback or actual movement instead of simple vibrations [19, 74, 130, 173]. Sounds can come in many different ways, including recorded sounds (e.g. animal sounds), sound effects, musical tones, pieces of music, and in some commercial systems spoken instructions or feedback. When several speakers are placed in an environment, or when the players wear headphones, sounds can have a 'virtual' point of origin, hearing friends or opponents coming from the front/back and left/right [82, 176]. Sounds can also be produced in the non-audible spectrum which might provide an infrasonic haptic feedback, as was done in an interactive *WaterBed* by Larsen [130]. Many interactive play environments make use of screens or projections on one or more surfaces. It has become easier to combine multiple projectors to create one larger projection space. Some systems where players have to wear Head Mounted Displays (HMD) and are able to interact in a virtual environment using their bodies could also be seen as interactive play systems [201]. However, most HMD systems and applications are currently not fitting for the domain, perhaps new systems allowing for more natural forms of embodied interaction, such as the HTC Vive, will bring it closer to the interactive play domain as we defined it.

2.3.3 Interactive Toys

There is a variety of interactive toys, objects that can be carried and which are enhanced with interactive elements. Due to the differences between them there is also a variety of terms to describe them. We will use the following set to categorize the

[1] `nxp.com/products/sensors/rotational-sensors:MC_16761`, last accessed 3-8-2016

interactive toys: tabletop tangible interactive toys [139], handheld playground props [23, 242], wearables [218], and semi-portable playground props [62, 228].

2.3.3.1 Tabletop Tangible Interactive Toys

Various commercial toys have been created that in one way or another can sense their own state, can be interacted with directly, or, are coupled to a computer [139]. What we view as tabletop tangibles interactive toys (including several types of smart toys) are often restricted to interaction on a table or on a small platform. Magerkurth et al. mention various (commercial) smart toys [139]. We will describe such a system as an example of these kinds of toys: *Zowie toy* has the form of a pirate ship or an enhanced garden that senses the rotation and presence of objects that are linked to interaction on a computer screen. Recently, the combination of games that make use of detected physical objects got a boost with the introduction of Lego Dimensions and Skylanders[1]. For these games Lego also makes use of popular movies/'brands' such as the Simpsons, building upon existing fantasy worlds and introducing these to other types of media, a powerful strategy described as 'transmedia worlds' by Henry Jenkins [226]. There are many other tabletop toys and systems, often making use of RFID technology [63, 124, 284].

There is a variety of commercially available smart building blocks that children can assemble and that are actuated, such as *ATOMS, Lego Mindstorms, Makeblock, Cubelets and Moss*[2]. These (robotic) smart block systems seem mainly to focus on the cognitive domain (sometimes dexterity) but less on the other goals we mentioned in the last Section.

There are also affective dolls [92, 139], dolls with screens [2], and commercial dolls such as *Furby* or *Baby Born*, which are on the edge of what we called non-interactive electronic games. Furthermore, there are team-based tabletop games with tracked objects [4] or even objects providing haptic feedback [19].

2.3.3.2 Playground Props

Playground props as we view them are similar to tabletop tangibles (and smart toys) but are meant to be used in a larger play-space as part of a room-sized game (or larger). They are often handheld devices with technology embedded for recognition and feedback. For instance, Bekker et al. developed *LedBall*, a device that can be held in a child's hand and that responds to movement by emitting different colors of light, either once it is shaken or rolled [23]. This was later called *LedTube* and resulted in several follow-up concepts.

Similar to such systems there are also interactive bats [51, 69] and interactive art props [159]. Furthermore, other playful objects for children with Profound Intellectual and Multiple Disabilities (PIMD) were created (including a button, a pillow, and a hugbag) [130].

The toy companies (e.g. Hasbro, Mattel, Toys"R"us) also sell commercially available interactive toys which are handheld and do not remain on the table, including an

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[1] `https://www.lego.com/dimensions/`, `https://skylanders.com`, last accessed 4-1-2017

[2] `myatoms.com/your-atoms/sets/`, `www.lego.com/mindstorms/`, `makeblock.com`, `www.modrobotics.com/`, last accessed 13-7-2016

interactive ball [250][1], and multi-modal party toys with sequential instructions and sounds[2].

Commercial platforms as the *Wii* make use of accelerometers, infrared, bluetooth, vibration motors, LEDs, and a speaker in their handheld device to trigger whole-body movement. A variety of games have been created for such a platform, including many music related games such as Rock Band, Donkey Konga, and Guitar Hero, and sports related games that rely on arm movements such as boxing, bowling, tennis, yoga, and many more.

Soute and Markopoulos introduced the term *Head Up Games* (HUG) as a subcategory of playground props where players do not need to focus and turn their head to the devices/mobile screens during an outdoor play activity, which in turn should have positive effects on the social interactions [235, 236]. For instance, *Save the safe* is a game that is played with a belt with a few LEDs and a vibration motor, where one player has a virtual key that is automatically passed when another player comes close, the burglars need to open a safe with the key in order to win [234]. Several other HUGs with accompanying handheld devices are mentioned/created, where players tag, shoot, collect, or hide someone/something [14, 97, 140, 266]. Others have made use of the LEDs and accelerometer of the Sony Move controller. *Johann Sebastian Joust*, is a game where the Sony Move controller has to be held still within a certain threshold (depending on the tempo of music playing), players are triggered to physically try to push or unbalance ('joust') the other players and be the last one standing. A similar game is *Idiots attack the top noodle* where a mobile EEG device is added to influence this threshold of allowed movement. *Jelly Stomp* is a game where players have to submerge another move controller under water [3]. Several researchers have also created interesting games with these Move Controllers [71, 179].

2.3.3.3 Wearables

Interactive wearables can also be used as playground props. For example, Bekker and Eggen, as well as Rosales, proposed an idea for an interactive *glove* [24, 216]. The glove sends and receives an infrared signal as if passing a ball around between players, allowing other players to block or intercept it, a similar glove or wearable display could also be used to play new forms of the game of tag [55, 119]. Rosales et al. created several technologically enhanced wearable systems with which children could play by jumping, 'freezing', and dancing, using shoes, fanny packs, and wearable sound kits [216, 217, 219],

In *Jogging over a Distance* players wear a headset, and either a waist pouch with a mini-computer and a GPS device [176], or a mobile phone and a heart rate monitor [170], to provide a social joint jogging experience over a distance.

The commercially available game of laser tag could also be partially included in this category, although the guns have to be held in the player's hands. Recently

[1] www.hasbro.com/common/instruct/Cosmic_Catch_Electronic_Game_42790.pdf, last accessed 1-8-2016

[2] For instance, have a look at Bop It http:/goo.gl/2Rcn6n or the Simon Swipe Game goo.gl/Tyd9pY, last accessed 15-12-2016.

[3] See jsjoust.com/ by *Die Gute Fabrik*, copenhagengamecollective.org/projects/jelly-stomp/, and copenhagengamecollective.org/projects/idiots-attack-the-top-noodle/. There is a free Unity plugin available at github.com/CopenhagenGameCollective/UniMove. All last accessed 6-8-2016.

(2015) Mattel started selling Marvel Playmation[1]. A mixed-reality wearable toy (an Iron Man glove), where physical movements influence virtual elements and in turn virtual elements influence physical elements[2].

2.3.3.4 Semi-Portable Playground Props

Another type of playground props do not need to be carried around, they are instead parts that have to be placed somewhere in the play-space. For instance, De Graaf et al. created the now commercially available *SmartGoals*[3] [58, 250]. Each goal consists of two small traffic cones that can light up when they are in their *ON* state, and only then, during this lit up phase allow scoring with a ball. The scoring is sensed automatically and the sudden change of a target could make the training more dynamic. The Swinx is a commercial device that is also placed on the ground, where players interact with placing wearable RFID tags. Several researcher used the device to investigate aspects of play including physical activity, collaborative play, and changing game rules [23, 104, 251] [4].

Seitinger et al. created an interactive pathway that was also easily transportable, containing a ladder/rail-track of pressure sensitive pads that each triggered a motor at the side, which in turn made spinners rotate [228]. Even this simple system triggered different kinds of play (fantasy, active, exploration and game building) especially after the spinners were personalized by the children themselves. Various other playgrounds and systems use interactive pressure pads. Lund et al. created one of the first with their modular *Playware* that included some networking and several LEDs [137]. It was later improved and used for soccer, rehabilitation, and more [30, 135, 136]. De Valk et al. created *FlowSteps* (later *GlowSteps*), consisting of a set of even more mobile and battery-powered mats/pads, with different colored LEDs that are capable of communicating with each other [61, 62]. These systems all provide fun interactions where players can stomp, jump, and step.

A commercial example of pressure sensitive pads is Nyoyn's *Sound tiles*[5]. Several other pressure sensitive (and portable) pads only function as a means of input but do not include any form of output or have to be combined with VR or other systems[6].

2.3.4 Interactive Environments

We now turn to the second main line of systems: *interactive environments*. This contains systems that embed the environment with sensors. It can be that sensors are put into fixed objects, a floor or a wall, or an entire room can be equipped with sensors. The systems fitting this physical characteristics mainly seem to come in two types: *fixed interactive objects* and *interactive screen environments*.

[1] `www.playmation.com/avengers`, last accessed 1-8-2016

[2] This is different from most types of physical/virtual interaction, where often the physical only influences a virtual layer, instead this seems to be a turn towards what could be called hybrid interactions, Metaxas et al. [150] created an interesting implementation of such a hybrid play system with RF cars.

[3] www.smartgoals.nl/en.php, last accessed on 29-7-2016

[4] To indicate the non-dichtonomy between categories, it can also be seen as a a Head-Up Game [251] or even as a wearable, `www.swinxs.com/gb/info/products.html`, last accessed 10-7-2016

[5] www.nyoyn.com/en/sound-tiles/, last accessed 30-7-2016

[6] Although outside the scope of this manuscript to name a few: MagicCarpet [195], Z-Tiles [212], and the open source & hardware *tacTiles* [11]

Figure 2.2: Commercial playground equipment. On the left, the Kompan Swirl, the bright red and blue objects represent the nodes, image used from Kompan (fair use). On the right, the Yalp Memo with touch-sensitive LED rings, used with permission.

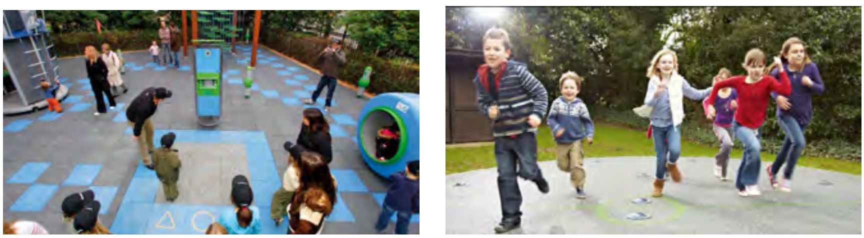

Figure 2.3: More commercial playground equipment. On the left, the Lappset Smart-us, with the tiles, the poles and the control unit. Photo courtesy: Lappset Group Ltd/Antti Kurola. On the right, a Playtop Street with their design, layout, and surfacing, with a control unit and the LED emitting satellites placed in the ground, still used from Playtop with permission.

2.3.4.1 Fixed Interactive Objects

Many examples of fixed interactive objects come from commercially available playground equipment, see Figures 2.2-2.4. Kompan is a company that makes such (interactive) playground equipment, often with a central control station and several flashing game nodes[1].

A second company that makes interactive playground equipment is Yalp[2]. Their systems vary quite a bit but include an interactive audio arch, a set of interactive touchscreen poles, and an interactive (soccer) wall.

A third company making interactive playgrounds is Lappset (this is the parent company of Yalp). Their *GameNetic* consists of a terminal that has to be electrically charged using a pedal[3]. Their SmartUS system was one of the first commercial interactive playgrounds and made use of pressure sensitive tiles, RFID cards and sensors, and several posts with buttons. It also had a control unit for game selection, high scores, and instructions[4]. It was developed in collaboration with the University of Lapland's Faculty of Education researchers, Lappset Group Ltd, and IT companies (personal communication 16-3-2017).

A fourth company that makes interactive playground equipment is PlayAlive[5]. Their systems consist of so-called satellites and a control station. Each satellite func-

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[1] `icon.kompan.com/`, last accessed 1-8-2016
[2] `www.yalpinteractive.com/`, last accessed 1-8-2016
[3] pdplay.com/product/gamenetic/, last accessed on 29-7-2016
[4] `https://www.youtube.com/watch?v=KBcptwz-d0s`, last accessed 1-8-2016
[5] `playalive.dk`, last accessed 30-7-2016

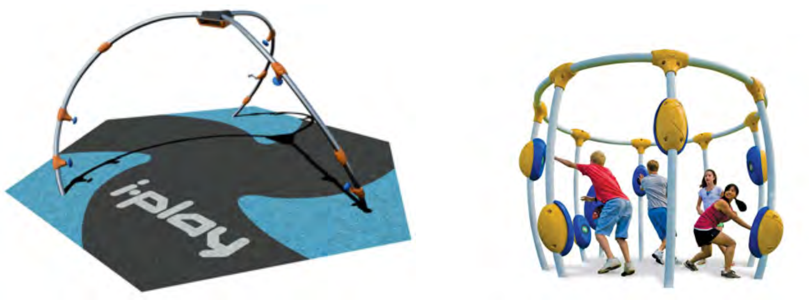

Figure 2.4: Even more commercial playground equipment. On the left, the Playdale i·Play, with activity switches that need to be pulled, pushed, or turned, image used from Playdale (fair use). On the right, the Playworld systems NEOS 360 with the central unit and several buttons in an arena setting, photo used with permission.

tions primarily as a button, has a circle of LEDs, somewhat similar to the Kompan Icon button earlier explained. In their *PlayAlive Spider* the satellites are used to create an interactive climbing frame. Their e-wall solution embeds the satellites into a wall and is intended for educational purposes[1]. Their satellites are also sold separately, where others can embed them in their playgrounds[2]. For instance, satellites can also be embedded in the ground changing the action to stomping instead of pressing[3], see Figure 2.3. Furthermore, Karoff et al. used it to create an interactive trampoline [114].

A fifth company that makes interactive playground equipment is Playdale[4]. They created i·Play consisting of an arch like structure, see Figure 2.4. It has activity switches: buttons, handles, and knobs that include LEDs and speakers.

A sixth company is Playworld®Systems that created NEOS®(360)[5]. NEOS consists of a central unit where games can be selected and that shows a high-score, combined with several poles with large buttons that have to be hit/pressed. The system also plays background music, makes sounds, and is able to emit different colored lights.

Several research papers also mention fixed interactive objects. The *Flash poles* concept consist of several poles with 3 colored rings that could be pushed/turned to change their color [242]. Ludvigsen et al. created similar poles for training handball [133]. Other systems used a bouncing frame/goal for training handball [108] or soccer [107][6]. Parés et al. created an *interactive water installation* [196, 198]. In this installation players had to create a ring of people and then move around a central fountain, to let water jet into the air in predefined sequences. Back et al. created interactive playground landscapes (including a tube and communication node). Both fixed and mobile prototypes were presented but the authors also aim for integration in a specific place [15, 16].

Marshall et al. created *Breathless*, an interactive swing ride augmenting the aware-

[1]This is actually an interactive wall but explained here for flow of reading

[2]In the US *Landscape Structures* and in Europe *Eibe*, *Wicksteed* and *Playtop* also sell/make installations with these satellites, sometimes offering a complete suite of installations.

[3]`www.playtopstreet.com`, last accessed on 31-7-2016

[4]`intelligentplay.co.uk/`, last accessed 30-7-2016

[5]`playworld.com/products/product_lines/neos`, last accessed 1-8-2016

[6]For a more detailed description of their Bouncer system see `alexandra.dk/uk/cases/thebouncer`, last accessed 22-8-2016

ness of breathing by incorporating it as the control mechanism for swinging, through the use of a gas mask coupled to the motorized swing [145]. Grønbæk et al. created the *SwingScape*, a set of permanent outdoor located swings that control sonic feedback, augmented with changing lights [78].

Rogers et al. created *the Hunt for the Snark*, an experience where children have to explore and interact with an augmented environment to get to know more about a fictional character 'the Snark' [215]. Children used PDAs to search objects (representing food), placed RFID equipped objects, stepped on pressure sensitive tiles, and flapped their arms in a wearable with gesture recognition in order 'to fly' on a large projection.

Liljedahl et al. created *DigiWall*, an interactive climbing wall [132]. It consist of climbing holds equipped with touch sensitive sensors and LEDs, in combination with a surround sound system. Several games were created for it. Ouchi et al. and Oono et al. also created an interactive climbing wall with similar holds. Their research focused more on modeling the climbing behavior of the children to inform future designs [191, 193]. Kajastila et al. instead of using interactive holds used computer vision and projections for their *Augmented Climbing Wall*, which they see being a part of the larger category of *Augmented Feedback (AFB) systems* [111, 112]. Wiehr et al. aimed to create a similar but easier to set up system called *betaCube* [275]. [1]

Furthermore, there is a variety of interactive fitness equipment such as adapted home-trainers or treadmills. Because of their adaptations they allow for gamification, or playing certain scenarios (e.g. riding through a city or up a hill). Both kinds of systems are commercially available[2] and/or designed in research settings [3]. We will leave further description out of our overview as they often respond only to intensity and not different types of input/body movements, but we do want to mention *Heart-Burn* as an example of an interesting *active game*, where people competed by cycling, where adaptive elements were used on basis of both effort (HR) and actual performance to balance the game, in order to increase the experience [240].

2.3.4.2 Interactive Screen Environments

Bobick et al. created *KidsRoom*, the first interactive play system especially tailored for immersing several children in a narrative, without them needing to wear any specific hardware [31]. It consists of a room where children are immersed in a linear narrative, that progresses depending on the players' actions and pacing thereof. It has several still-frame back-projected walls (not intended as the center of the participants' attention), computer controlled theatrical lighting, and four directionally controlled speakers that play, music, sound effects, and recorded voice narration. It contains several different worlds: a bedroom, a forest, a river, and a monster world. Each world included their own projections on the wall and required specific actions to let the story progress, this includes recognition of the positions, posture, and movement. The system intelligently exploits and controls the context of a narrative, it requires children to do actions such as shout a magic word, follow the path, walk to a chest, gather on the bed, row a boat (on the bed), and do a dance with a monster.

[1] The *Waterfall climber* is another climbing system with an interactive projection created at the RMIT Exertion Games Lab, where the climber is equipped with IR markers `http://waterfallclimber.blogspot.nl/`, another example is iOO Climb `youtube.com/watch?v=kg2uRGf_04g`, last accessed 12-8-2016.

[2] For instance, see products of SilverFit in a rehabilitation setting `silverfit.com/en/`, last accessed on 3-8-2016

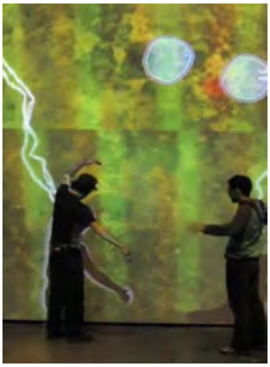

Figure 2.5: On the left, *Funky Forest*, an interactive eco system created by Theodore Watson and Emily Gobeille. You can see one person redirect the water, while others are creating trees. On the right, *Looking for Life* by Snibbe Interactive, an interactive installation representing the evolution theory. You can see two players using gestures to influence and create cells that evolve over time, still used under fair use with permission by Snibbe.

One other well-known interactive screen environment is the *PingPongPlus* by Ishii et al. [101]. It consists of a projection on a table tennis surface that responds to the position of a table tennis ball. They created several types of projection modes and games. Altimira et al. recently also created a similar projection based version for table tennis to investigate balancing a game by inducing an aggressive or defensive player style [8].

Mast and de Vries created a version of *cooperative Tetris* played on a large screen, where players had to work together to move the blocks [147]. They compared a version where players had to jump (wearing a fanny pack with an accelerometer) to one where players had to press a button[1]. One player could move a block to the right, another could move it to the left, and an action of both players simultaneously would rotate it.

Leaning towards playground props is the *Entertaining Archery Experience* [74]. It consists of a fairly realistic adapted bow and arrow, adapted with electronics (Arduino with reed switches/ sensors, IR-laser and Kinect) and a pneumatic damping system, which has to be aimed at targets on a large screen in the context of a game.

Soler-Adillon and Parés created a large *Interactive Slide* with an interactive projection on it, where children play games by sliding down over it [127, 128]. Parés et al. created *MEDIATE*, a large room with two large projection walls and 9 cameras to track behavior/attitude of the players [197]. The target group was children on the autism spectrum, low functioning and without verbal communication. Watson and Gobeille created *Funky Forest*, an interactive virtual ecosystem, including floor and wall projections, intended mainly for children, see Figure 2.5 [2].

Kick Ass Kung-Fu is an interactive martial arts game by Hämäläinen et al. [82]. It is played on a a cushioned playfield with two or more large screen(s) at the end, and the movements are tracked in this 5x1 meter area with computer vision techniques.

Mueller et al. created several (distributed) exertion games. They created *Remote*

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[1] They found no effect on social presence between the two version, they did find that participants felt less competent in the exertion version.

[2] `vimeo.com/7390684`, `theowatson.com/site_docs/work.php?id=41`, last accessed 18-8-2016

Impact, where players kick and box against the 'shadow' of a distributed opponent projected on a large mattress-like foam [172]. This is held in place with elastic bands that guide the forces which are used to measure where impact takes place. Other systems include *break-out-for-two* [164], *three-way table tennis* [175], and *airhockey-over-distance* [173]. All consisting of a non-interactive floor or table surface with a videoconferencing implementation projected on an interactive vertical wall. In the first two games, virtual areas have to be hit several times (or very hard) before *breaking*. The last hit will be rewarded with points. The ball will bounce back into the physical world. Instead, in airhockey the players have to hit (and defend) the goal. The puck will be caught, and using rotating cannons the puck will be shot in a similar direction at another location.

Laakso and Laakso created body-driven multi-player games where orientation and players' group dynamics (e.g. forming a circle) were detected with computer vision [125]. The games were shown on a large wall display accompanied with audio effects, and were interacted with by position in the space and arm gestures in a (forward) horizontal plane. Toprak et al. also created an interactive wall game where two players compete to touch bubbles on a wall [252]. Morrison et al. describe a form of an interactive wall from the domain of interactive art-works: *Space of Two Categories* by Hanna Haaslahti[1], an interactive shadow where an animation of a small girl is projected moving around in the players' shadow(s) [80, 159].

QuiQui's Giant Bounce was an early whole-body computer game that made use of both voice input and a web-cam combined with computer vision, to recognize children's movement and actions [93].

ActiveCurtain is an elastic interactive screen that can respond to touch but is different from normal touch screens, created by Larsen et al. for people with PIMD [129]. Using the Kinect's depth sensor combined with projections behind an elastic screen it can trigger interactions with a different form of bodily engagement. One might use their head or reach into the screen, by responding to such gross body movements and by providing a form of tangible interaction the system seems to be more suitable for people with profound mental and intellectual disabilities. *TouchMeDare* by van Boerdonk et al. is an elastic touch-sensitive opaque canvas that aims to explicitly elicit bodily interaction between people as a means to get to know each other [255]. It is different from all the other interactive environment play systems as the screen provides no visual feedback but is only aimed at collaborative music making.

Interactive Floors — Interactive floors have a horizontal area and often have to deal with players obscuring an image/projection for themselves or others. However, space of movement in front of a screen or wall is often more limited, and can lead to confusion in mapping movements to the screen [82].

Several interactive floor systems exist for indoor purposes, with mainly LEDs or projections as means of feedback, and using either RFID [117], pressure sensors [257, 283], or computer vision to track people [79, 102, 156]. Several target groups have participated in studies with these floors, including children [281], families [117], students [156, 256, 260], intellectually disabled people [283], rehabilitants [257], and hearing impaired people [102].

Snibbe et al. created several interactive camera projector systems [232]. *Boundary Functions* created lines between players on the floor, creating a Voronoi diagram.

[1] vimeo.com/80375243, last accessed 4-8-2016

Deep Walls records silhouettes of dancing players in front of a wall. *Three drops*, allows players to interact with water on three different scales, normal shower like, on a droplet level, and at a molecule level in front of a wall. In their *Fear* game players can collaborate and simultaneously catch fruits with their shadow shapes, but they have to stand still when a jaguar is looking at them. Snibbe Interactive also created several other interactive installations including *Looking for Life*, where the evolutionary theory is depicted on an interactive wall, see Figure 2.5. Players can influence lightning strikes and with them the cells that slowly evolve over time[1].

Parés and Parés created *Lightpools* [199]. Four players are given a lantern that tracks their position, and each player gets a circle projected underneath the lantern. Virtual abstract objects fitting a specific lantern can be found, which can be fed to/grows with the projected circle, and subsequently will move together with a player for some time, in order to be incorporated in a dance. Carreras and Parés also created *Connexions*, an interactive floor that responds to positions and contours of 8-15 players [49]. The players have to stand on a variety of nodes spread over the floor, each representing a scientific concept. When the concepts surrounding one topic are stood on and players physically link by extending their arms this topic is visualized on the floor, for example, extraterrestrial stone, atmosphere, and trajectory all belong to a meteorite object.

Palmer and Popat created *Dancing in the Streets*, an interactive projection on a public square [194]. It included flocking butterflies scared by quick movements and attracted by the players otherwise, ghostly feet following the users, and geometric shapes following and linking players in the space. *Shadowing* by Chomko and Rosier is also an (art) installation that is made part of a street or a square. It is an augmented projection of the silhouettes of earlier passersby[2].

An example of an interactive floor environment close to the fixed equipment playgrounds, is *Hanging off a Bar*. 'In which players hang off an exercise bar over a virtual river for as long as possible' [168, p1]. Underneath the player is a pressure sensitive mat with a river projected on it. Occasionally a safe zone in the form of a projected raft gives the player the opportunity to temporarily rest their hands, arms, and legs.

During the last decade many commercial implementations of camera-projection systems have been introduced, see Figure 2.6. For instance, *Lumo Play* and *MotionMagix* provide a commercial software solution both with about 100 different games that can be bought[3]. Many of these systems and games do not make use of tracking of players (using both the location and identity), instead in such games it simply suffices to detect movement on locations, for example, scaring fishes or dispersing a pile of virtual leaves. If such a system is also tracking people (position + id), it allows for even more kinds of interactions. For instance, Moreno et al. created the *interactive tag playground*, an interactive floor projection for research purposes [156]. In the tag game, each player has one circle following them, indicating their role, and children tag each other by letting their circles collide, see Figure 2.6.

2.3.5 Geo-location Devices

GEO-location devices make use of GPS (sometimes Wifi, Bluetooth, or RFID enabled locating) to respond to being located somewhere. The games played with it, geo-

[1] `snibbe.com/looking-for-life/`, last accessed 18-8-2016
[2] `playablecity.com/projects/shadowing/`, last accessed 18-8-2016
[3] `lumoplay.com/` and `MotionMagix.com/`, last accessed 30-7-2016

Figure 2.6: On the left, children are playing in the *Interactive Tag Playground* created by van Delden et al. image (re-)used with permision of authors [258]. On the right, two children are playing a soccer game on a commercial Lumo Play installation, provided by Lumo Play used with permission.

location games, clearly provide a form of interactive play. However, we do not focus on them as they differ slightly from most previous systems as they trigger moving over larger distances, are (ideally/theoretically) not confined to a certain space, nor do they need colocated social interactions, and (most) do not need to be played by people at the same time. Therefore, the following set of systems can be seen as less complete than the previous types of systems. We provide a description of several types of systems that we have encountered in this domain, mainly using the 'early' and/or famous examples.

The recent hype around *Pokémon Go* and its success clearly shows that these games have a large attraction value. One reason for this rise, besides targetting a nostalgic fantasy world [226], is probabaly the now easily available location-specific infrastructure [235][1]. The games have great attraction value, are successful in getting children to move, and could partially address the obesity epidemic. However, only the future can show us whether such games are actually suitable enough (for young children). The issue of safety, especially, could become a concern if the games could persuade children to go to unsafe zones.

Vogiazou et al. created *CitiTag*, a game where a PDA device is used to play a location based version of the traditional game of tag [269]. Björk et al. created *Pirates*, a mobile game themed around a pirate world, that uses proximity sensors to link visiting physical locations to sailing to and visiting virtual islands [29]. Feltham et al. created *Uncle Roy All Around You*, a mix between a geo-location game and theater, revolving around the concept of trust [146]. Some players have to find 'Uncle Roy' by walking around on the streets of London with handheld computers. Benford et al. also created *'Can You See Me Now'*. This is also a tag-like game where performers/actors are walking around a city with a PDA in order to chase after online (navigating) players [25]. Furthermore, Benford et al. also created *Savannah*, an educational game for six children at a time about 'the ecology of the African savannah' [26]. Rogers et al. created *Ambient Wood*, a digital augmentation of a woodland, aimed as a learning

[1]It seems *Pokémon Go* builds on verified locations submitted by players of another geo-location game *Ingress* from the same makers Niantic, showing that crowd annotation might be done with pervasive play-spaces as well, see `www.polygon.com/2016/7/7/12118576/pokemon-go-pokestop-gym-locations-map-guide`, last accessed 31-7-2016

experience for children carrying out a scientific inquiry [214]. Van Leeuwen et al. created *Beagle*, an app consisting of a 'radar' with which hospitalized children search for bluetooth tokens (Beagles) distributed throughout a hospital [263]. Piekarski and Thomas created ARQuake, which is one of the first examples of an augmented reality game in an outdoor setting [204]. They build on the Quake game in which players have to shoot monsters and can collect objects. Cheok et al. created *human Pacman*, which uses a similar setup with improved hardware, including a see-through HMD augmenting the physical world with computer graphics [56]. They also added physical interaction with Bluetooth-enabled objects, and even sensing touch of an object or player. A similar game *PacManhattan*, was created by NYU students but was less technologically enhanced. Players had no HMD and had to update their own whereabouts at each street corner[1].

2.4 Evaluation Techniques and Methods

We have seen that there are many different systems. There are also many different ways to evaluate these systems. Evaluating interactive play systems that are controlled by moving the body is often not a straightforward task [93]. It regularly involves evaluation of interactive games/systems with children, which is a topic for a text book [144], a thesis [18], a paper [210], or at least an influential column in a journal on its own [84]. Furthermore, (open-ended) play interactions do not focus on efficient interactions [159], and instead focus on (user) experience. Several more traditional HCI evaluation approaches with certain questionnaires and measures will therefore not be applicable. This Section includes a description of several methods and techniques. Many of these can be considered as 'the basics' that many readers already know. However, we think the descriptions are also suitable as an introduction for starting students, as it provides some overview. We also see an added value in showing the successful application and implementation of these methods and techniques in our field.

The experiment design is also a very important part of the evaluation. Depending on the context and extent of a learning effect, in some cases turning to a within-subject design in combination with a latin-square (controlled order) could help to appropriately deal with person-to-person differences [18, 27, 108]. However, a thorough description is outside the scope of this survey and we refer the reader to [44] for an old but comprehensive overview of (quasi-)experimental designs for educational purposes and the accompanying shortcomings and benefits regarding internal and external validity. Below we will mention the evaluation techniques and methods we have encountered that have successfully been used for the interactive play context once a proper experiment design is chosen.

2.4.1 Discussions and Notation of Utterances

A first technique for evaluation is simply listening to what people have to say during and after their play activity. It can be an important source for information during evaluations. Various techniques have been developed to stimulate people to verbalize what they experience(d). Often quotes are used as examples to describe how people experienced a method [266] or design [219].

[1] See `pacmanhattan.com`, last accessed 22-8-2016.

2.4.1.1 Thinking-aloud

Thinking-aloud protocols are often used in evaluations with adults to get more insight towards understanding into what the user is thinking. They have been applied in evaluation research with children as well, although it might be unsuitable for analyzing actions [284]. There is often a difference between the original strict guidelines/literature and practice, where in practice researchers do not keep to constant prompting every 15-60s or use different prompts than a neutral simple prompt (*Mm hm?*) [33]. When dealing with children such changes might become a deliberate choice in (future) techniques, as it can become distracting and forcing if one does need to keep on prompting non-talkative children [284].

2.4.1.2 Picture Cards

Barendregt showed that for children combining thinking-aloud with *Problem Identification Picture Cards (PIPC)* that depict frequently occurring problems can be a suitable aid to remind children what is of interest to the researcher[1]. The cards were beneficial for the number of problems indicated and was preferred by children as well. Other cards with pictures can also be used to structure an interview with children and help to keep children focused during a (semi-) structured interview [266].

2.4.1.3 (Semi-)Structured Interviews

While a structured interview always follows the same questions in the same order a semi-structured interview leaves room to jump to a related question based on a response, whether this question was already planned for later or not. Depending on the target group and context, the duration of an interview is often kept short, especially when an informal interview is done at the point that players are about to leave after playing for some time [219], while after more extensive planned tests it can take up to several hours [170]. Group discussions/interviews can also be done with multiple (child) players after a session [140, 234].

Similar to remarks made during the tests, quotes of people can be a convincing way to show how something was perceived by the players, for example, regarding the use and experience of the *Breathless* entertainment system—the gas mask swing—*'P2: it's a bit you feel like oh no I don't want to go now... but by the end you changed your mind'* [145, p132]. It is good practice to record and subsequently transcribe interviews when doing a thorough analysis, although at times it can suffice to only take notes during the interview in order to save time or to adapt to a certain context.

Grounded Coding An advantage of transcribing interviews is that it will make it easier to quickly scan through and will also help when looking for recurring elements/themes. This is a first step in grounded coding/theory, where researchers analyze their data, look for recurring elements and when and how these elements/concepts do (or do not) differ, and from there slowly build towards new theories. Such a theory is 'descriptive rather than predictive' [106, p642]. Such a method was used, for instance, in analyses of *joggin-over-a-distance* with regard to social experience to describe themes that could help to build guidelines [170]. A similar coding process was used to describe dominant themes in an interactive sport skill training with *the*

[1] The represented problems in the PIPC were: Boring, Don't know/understand, Fun, Difficult, This takes too long, Childish, Silly and Scary [18, p120].

Bouncer system [108]. This categorizing process of analyzing behavior can also be done based on (video) observations (perhaps focusing more on interaction types) or answers on open-ended questions in questionnaires.

2.4.2 Questionnaires

Most questionnaires make use of Likert scales, consisting of statements that the participant agrees or disagrees with (often on a scale of 4,5, or 7). Several statements belong to one construct, and multiple constructs can be used to investigate a certain topic of interest, for example, the perceived presence of other players. Instead of Likert scales a type of semantic differential scale can also be used, where opposite verbal anchors are at the ends [87]. The questions (or agreement with statements) measuring one construct should be answered with approximately the same scores by one person showing that indeed one construct is measured. This can be expressed with the Cronbach's alpha. The most well-know example of such a validated questionnaire is probably the big five inventory regarding personality traits [110]. Such personal traits can influence results and show interesting links between personality and the experience or use of a system. Another predictor can be the tendency to get immersed in an interaction, and it could be helpful to apply a version—revised by Berthouze et al.—of the Immersive Tendency Questionnaire ((G)ITQ) (based on Witmer and Singer's work [279]) before the interaction starts [28].

2.4.2.1 Game Experience Questionnaires (GEQ)

There are various validated questionnaires on topics regarding the perceived experience with the system that are often researched in the context of interactive play. These tend to have a sound theoretical grounding. There are questionnaires such as the *Game Experience Questionnaire (GEQ*) by IJsselsteijn et al. [98] that have been meticulously developed and can be applied easily although they are awaiting official validation [74, 98, 99, 186, 205][1].

Poels et al. also created an adapted version of the GEQ for kids, which has been applied in several studies in adapted form (reduced/extended) [21, 22, 104, 192], and seems not to have been validated yet, which limits the extent it is used in (analyses of) the results [21][2].

Questionnaires are also applied to look separately, and in more detail, into dimensions that are also part of the GEQ, such as (social) presence of other players [19, 159, 256], for example, with the Networked Minds Measure [85] or more regarding closeness [255, 256], for example, with the *Inclusion of Other in the Self scale (IOS)* [13], aspects of Flow [159], and (sensory and imaginative) immersion [200], for example, with the Immersion Questionnaire by Jenett et al. [106].

[1] There are also other 'GEQs' such as the Game Engagement Questionnaire-revised focusing on whole-body movement by Berthouze et al. [27, 28] based on the model behind an unpublished (and seemingly no longer retrievable) '[53]' *Game Engagement Questionnaire* of Chen et al. [54]. Furthermore, there is another *Game Engagement Questionnaire* by Brockmyer et al. that is built from a more pessimistic view on play related to violence in games [39, 186].

[2] It seems there is currently also no publicly available publication or list containing all the questions in this questionnaire. Other modules/categories were added to investigate besides perceived Immersion, Positive Affect, and Challenge also aspects of social interaction, creativity, and physical activity [22, 23] instead of the originally mentioned (K)GEQ dimensions, Tension, Competence, Flow, Negative Affect, and the two KGEQ modules for Social experience and Physical Experience. This many dimensions can be overwhelming but selecting those of interest only, keeps it within an acceptable number of questions [206].

2.4.2.2 Fun Toolkit

Read and MacFarlane describe the use of their *Fun Toolkit*, and other survey methods with regard to evaluations with children [210]. They explain the use and disadvantage of several tools. It includes the use of a '*Visual Analogue Scale (VAS)*, a *pictorial representation that children use to identify their feelings or opinions* [211, p83]. The *Smileyometer* can be applied [250] with such pictures creating 'a discrete Likert type scale' which were intended to be used before and after the experience[1] [211]. The *Fun Sorter* technique can be applied [140] to let children rank icons representing the items of interest on one or more constructs [211]. The *Again-Again* table can be applied [192] for one or more activities giving a reasonable measure for fun; in this table children answer if they want to do the activity again, choosing between yes/maybe/no [211]. The latter might also be adapted and applied to indicate what version they want to play [234].

2.4.2.3 Other Questionnaires

Other applied questionnaires that looked into aspects of intrinsic motivation [159, 255], for example, the *Intrinsic Motivation Inventory (IMI)* related to Deci & Ryan's Self Determination Theory [223][2], into perceived exertion [200], for example, Borg's *Rate of Physical Exertion (RPE)* [34, 35], or hedonic/pragmatic qualities [74], for example, using the aspects identified by Hassenzahl et al. [87]. The *Self-Assessment Manikin (SAM)* can be applied [200, 255] to measure human affective responses using a non-verbal pictorial assessment technique regarding pleasure, arousal, and dominance[3] [36].

2.4.2.4 Open and Less Structured Questions

Questionnaires can also leave room for less structured open comments, which—similar to noting down the utterances —can be a convincing way to represent the players experience. Open questions, sometimes combined with one or more scores (e.g. related to the 'enjoyment' of the experience), can also function as input for, or rationale for continuing a next iteration of a prototype or product [176, 188]. Even letting children draw might be an informal fun way to engage children in discussions [284]. Subsequently coding the answers to open questions into categories often provides an insightful way to present the results [112].

2.4.3 Observations/ Video Analysis

Video analysis is a method/tool often used in evaluation with children [23]. Druin et al. do mention that (in the old-days) recording children was sub-optimal, as (sound) quality was mediocre and recording could also influence the behavior as they tended to 'perform' in front of the camera [67][4]. Other studies did not observe such change in

[1] The literature and results in [211] showed that the expectations were close to their actual ratings and that young children (in their study comparing 7 and 9 to 12 and 13) have a tendency to always answer the extremely positive on the scale, and that the *Again-Again table* measures the same construct.

[2] See McAuley for a/the version of the IMI which was originally adapted for a basketball game [148]. Van Boerdonk et al. applied a dimension regarding experienced relatedness separately [255]

[3] Related to the person's sense of control relating to a stimuli

[4] This might also occur during direct observations where people act differently when they know they are being observed, which might be (partially) countered by not making them aware and let the observers be perceived as if they were just a *Fly-on-the-wall* [159]

behavior and did successfully use video analysis, perhaps due to incorporating different strategies of evaluation protocol, or perhaps due to habituation to the recording technology [93, 214]. In some cases first person view/head mounted cameras are applied [140], in others multiple cameras are needed to cover the span of the playing field [234], in order to follow several children at the same time [26], or to look from different angles [108, 250]. Making a trade-off between in-depth analysis and efficiency, to shorten the time consuming process of video analysis one could also make a pre-selection and or shorten/edit the video clips to be analyzed [219].

2.4.3.1 Peer-tutoring

Höysniemi et al. proposed to use peer-tutoring in the evaluation of interactive system for children [93]. In their peer-tutoring method a child learns the game and then instructs another child later on. These interactions are recorded and the analysis of their explanations can show what kind of problems occur, or what elements are unclear. They applied this method in their analysis of *QuiQui's Giant Bounce* and subsequently changed some controls accordingly. These changes were in turn tested and showed that children needed (significant) less time to perform the actions/controls. Verhaegh et al. used the method to decide between/evaluate two interaction styles regarding their *Camelot* game [266]. Avontuur et al. adapted such a method to a group based interaction for the evaluation of their *BuzzTag* game, although this became quite chaotic [14].

2.4.3.2 Annotation

Annotation schemes can be used to structure video analysis. These schemes consist of several constructs/dimensions of interest to the researcher, for example, physical activity levels during play. Several raters rate the behavior of a person according to what extent or what type of behavior they see a person performing, for example, sedentary behavior. Either what kind of behavior is seen during an interval, or at a specific moment in time (momentary-time sampling). Both are done with a specific time interval in mind that fits the behavior to be annotated. Some simpler forms can also be used where several observers rate behavior over the entire sequence on a scale, for example, the amount of movement 1-7 during a game of Guitar Hero [27].

Several observation schemes exist related to (interactive) play regarding social interaction and physical activity, such as the POS [222], the OPOS [17], MIPO focusing on social functioning [75], the Social Play Continuum[1], OSMOS focusing on motor skills [50], and often such schemes are adapted and then applied for interactive play evaluation purposes [104, 127, 157, 219, 246]. One often used measure for inter-observer reliability is Cohen's κ. Some aspects of play such as engagement or social interaction seem hard to quantify with video observations, especially for children [234, 266].

Real-time observation is sometimes performed as well but is often too hard to perform reliably for interactive play evaluations, especially if one wishes to follow all children individually.

[1] Broadhead's scheme can be found at cw.routledge.com/textbooks/0415303397/resources/pdf/side1and2.pdf, last accessed 27-7-2016

2.4.3.3 Occurrence of Behavioral Cues

Video analyses or direct observations without pre-defined annotation schemes can also (but in a more qualitative manner) provide information on what kind of behavior occurs with certain users (e.g. making a distinction between age or gender) when a certain (interaction) design/system is chosen and whether this fits the expectations. Such findings are often not seen as thorough proof but either show that the evaluation held to the theory or show fruitful directions for future research on such theories. For instance, in a study with the *WSK*, besides more thorough quantitative analyses with a pre-defined annotation scheme, Rosales et al. compared the type of movements, fantasies, and explorative efforts between boys and girls. Their observations indicated more gun-play from boys, and more play related to birds and bubbles and a longer exploration phase for girls [219]. Morrison et al. used the descriptions of their observations to show that different types of play (related to those they found in literature) occurred in their open-ended interactive art works [159]. Bekker and Sturm used video observations to count the number and (count and categorize) the type of games played with the ColorFlare [22]. Back et al. used coding observations in a qualitative way, where they looked at play types and locations [16]

2.4.4 Automatic Measurements

One of the measurements related to fun is the time participants spend on an activity out of own volition. Commercial platforms from both Kompan and Yalp include web interfaces that can be used to see how often their equipment is used and which games are played. It seems this would also allow for long-term testing in real-life settings. Various systems can also make use of logs of the system regarding interactions speeding up the evaluation process, for example, time-played [112, 168] or use [112, 263], the performed movements/actions[201], and positions of players [154, 260].

2.4.4.1 Activity

Another dimension that is interesting for evaluation is a measure for the level of activity during play. In some studies Heart Rate (HR) sensors have been used to this end [128, 153, 240] [1]. HR provides an indication of physical effort, in order to estimate a percentage with regard to effort they do need to be related to age, a personal optimum, or recorded maximum heart rate.

Another way to measure movement is to use Computer Vision. The amount of movement can be tracked based on recording using simple methods such Motion Energy Analysis which essentially subtracts subsequent video frames from each other and sums the pixels that have been 'moved' [208]. Such a method has been used to show the amount of movement of groups of players in an interactive playground [128]. Instead of using the information based on all players, computer vision also allows researchers to track movement and position of players which can be used for more detailed evaluation purposes as well [154].

A Motion Capture suit can also be used to track the activity including the type of movement of the players automatically. For instance, allowing analysis of personality and the type of movements players make during whole body gaming with interactive play systems [200] or between different conditions [27]. Some systems make use

[1] HR sensors have also been used as an input in a Head-up Game to generate suspensive elements [236] and as a means to automatically adapt to players' performance in exergames [170, 240].

of multiple cameras, computer vision software, and infrared reflectors[1], others use inertial gyroscopic technology[2].

Handheld devices could use their GPS data [170], or accelerometers to indicate amount of movement which is an aspect of activity, or use the GPS data and logs to analyze technology performance and players' actions [25].

2.4.4.2 Physiological Measures of Affect

Besides activity, arousal can also be an interesting feature to measure. *Galvanic Skin Reponse (GSR)* measures conductivity related to sweat 'production', and is used as a means to measure arousal [57, 143]. Mandryk and Inkpen used GSR measurements during game play of a traditional controlled video game: NHL 2003 [143]. They also combined this with electrocardiography (ECG which measures heart rate related parameters), respiratory measures (increase respiration also indicates heightened arousal) and electromyography (EMG, to measure muscle activity which applied on the face can be related to positive/negative emotions or tension, frustration, or concentration levels). Although these biometrics seem to be highly objective, in our experience interpretation is not always as straightforward or objective as it seems. Properly recording skin conductance can also be an issue in combination with energetic movement [285]. Yannakakis et al. also used such biosignals (skin reductance, blood volume pulse and heart rate) in their interactive playware research (evaluations) to link them to entertainment preferences, which after machine learning could estimate/model/account for about 80% correctly [285].

2.5 Type of Research Contributions

The argumentation that motivates the interest in research on interactive play, the end-user perspective (the higher end goals), is often different from what is targeted with an individual study or paper, the research perspective. In this Section we explain some of the contributions as we have seen them in research papers regarding interactive play. These contributions answer questions such as: What does this study show us? What can others learn from our research efforts? How can others apply the gathered insights?

2.5.1 Structuring the Design Process by Sharing Challenges and Experience

To aid in the design of interactive play systems many researchers share their insights in the form of guidelines, frameworks, taxonomies, or lenses.

2.5.1.1 Guidelines and Lenses for the Design Process

Several guidelines and methods for designing and evaluating embodied interactive play systems have been introduced, we refer the reader to [100, 165, 166] for a few of the most comprehensive sets of guidelines related to exertion games. Furthermore, guidelines provided for game design are certainly worthwhile considering during the design process of pervasive play-spaces. Although they have not been based explicitly on interactive play, we refer the reader to [73, 120, 225, 226]. Soute and

[1] For example, OptiTrack `optitrack.com/` or Vicon `www.vicon.com/`, last accessed 13-7-2016

[2] e.g. XSense `https://www.xsens.com/`, IGS-190, or Gypsy `metamotion.com/`, last accessed 13-7-2016

Markopolous propose to merge the aspects of traditional outdoor play with computer games and for their HUGs mention that technology should be simple, easy to bring along, trigger imagination (instead of unambiguous visualization), and trigger social interactions [235]. Bekker and Sturm examined how successful non-interactive play objects can be translated into open-ended play objects [22]. Building on this, Tetteroo et al. proposed a method to design interactive playgrounds in a systematic manner based on dimensions seen in traditional playground games [246]. Konkel et al. had built on the games memory, tag, and hide-and-seek for their *Tagaboo* system [119]. Similarly, Moreno et al. as well as Rosales explained how they designed their interactive systems based on observations of traditional play sessions and games [156, 216]. We have seen that commercial systems also build on the power of 'traditional' games such as memory, tag, and freeze dance (stopping when music ends), making music, or playing sports such as soccer. However, Soute and Markopolous also remark it seems important early on in the design process to realize what the benefits might be of technologically enhancing traditional play (i.e. random allocation of teams, hidden actions, balancing etc.) [236].

De Valk et al. proposed a model to design for open-ended play [59]. Tiemstra et al. also provided a set of guidelines regarding the design of open-ended play systems based on their experience and observations of interaction with the *SmartGoals* [250]. Bekker et al. also included this open-endedness to use as one of four different lenses for the design of interactive play systems: (1) open-ended play, (2) forms of play, (3) stages (phases) of play, and (4) playful experiences [20]. Wyeth et al. created guidelines and urged developers and researchers to address fulfilling psychological needs with the design of pervasive play-spaces for people with intellectual disabilities [282].

Furthermore, many papers only mention a few lines about the rationale behind certain design choices which could be seen as guidelines as well. For instance, using a fairly abstract shape to prevent a focus on the aesthetics (and prevent games depending on it), and instead letting the children focus on types of feedback but still making the interaction possibilities clear [21]. Another example is the rationale of Ishii et al. behind creating a variety of modes for PingPongPlus, that were chosen to span two identified dimensions: competition-collaboration and augmentation-transformation [101].

Another type of contribution is to describe the entire design process, mentioning certain techniques applied in a certain step of the design process and their applicability for that particular project. For instance, the authors of the *Entertaining Archery Experience*, before identifying guidelines and hints for best-practice, mention how they applied known methods [74], similarly Brederode et al. describe the applied design process for their *pOwerball* [37].

2.5.1.2 Frameworks

Frameworks can be developed, in order to understand new research directions and map out the opportunities and issues. These are the result of thorough analyses of a certain topic with design cases, and are often related to or based on psychological models and other existing theories. In contrast to guidelines they do not describe straightforward rules on *how* it should or should not be designed, instead they provide perspectives: focus on *what* could or should be investigated or designed, how elements relate to each other, or in what way a system can be described. Mueller et al. described their sports framework as a design vocabulary, a tool for discussions and setting goals and aspirations, and 'as a way to think and talk about it' [174]. Examples of (preliminary/simple) frameworks are the Tangible Interaction Framework by Wyeth et al. which relates design of playful tangibles (e.g. Wii) to engagement, specifying a dimension of representation and control [280], a framework for evaluation of persuasion in games [1], or a framework for developing playful persuasion systems linking four levels of a design: transformation (the intention, to let a player jump), experience (triggering a need, for self-expression), interaction (jump triggers sounds), and system (a musical staircase) [220]. The 'sensitising terms' of Morrison et al. can also be seen as a framework of open-ended interactive art installations that require whole-body interactions [158]. Carreras and Parés created a framework for a similar topic, designing full-body interactive experiences [49].

2.5.1.3 Designing with Inclusion of Users - Participatory Design

An important aspect in the development of interactive systems (for children) is participatory design, in which the end-users are part of development throughout the entire process, benefit directly, and get a fair say in the design directions. Many research contributions regarding interactive play and development (and evaluation) of interactive systems for children concern guidelines and techniques for such an approach. Several guidelines and techniques for doing participatory design have been proposed and adapted to use with children, such as contextual inquiry with additional note-takers, self-reflection discussions on behavior and preliminary research findings, technology immersion, and guidelines regarding group composition/age [67].

Related to extensive participatory design practices, is the somewhat limited but still iterative involvement of children, for example see [37]. One could also start with analyses of children's play behavior [154]. Which can be followed by an iterative process of testing (low-fi) prototypes to make decisions regarding the design [127].

2.5.2 Fit for Purpose

Besides showing how to design through examples of the design cases, it can be good practice to show whether the design suits the context of use. Senda mentioned a broad distinction of four physical categories of contexts where children could play: 1) streets, 2) parks, 3) schools and education facilities including museums and libraries, 4) public spaces [229]. Many of the papers and systems mentioned do indeed target one of these settings. The suitability in this physical context for the intended target group forms an important factor to show that a system is fit for the purpose. Some systems target an older target group in a context of art galleries [158], exhibitions, and trade fairs [74]. Games such *airhockey over a distance* are envisioned to be more appropriate for (employee) gathering areas (canteens, reception areas), arcades, airports, youth clubs, and children's hospitals [173].

These examples show that a wide variety of contexts can be targeted and some authors show tests regarding the applicability in their envisioned environment, or they do their actual tests in the appropriate context to make their results applicable to such a realistic context. For instance, this was exemplified with the high throughput of people interacting with a water fountain, tested at the 'Universal Forum of Cultures' [198]. Morrison et al. did most of their investigations during art exhibitions [159]. Kajastila et al. placed their *Augmented Climbing Wall* in a commercial climbing center [112]. Mast et al. and van Boerdonk et al. performed their user studies with respectively *cooperative Tetris* and *TouchMeDare* during a large music festival[1]. Lund et al. showed qualitative and prelimanry results with a pilot for home rehabilitation with their interactive *Playware* tiles [136]. Van Delden et al. placed their playground in an art-gallery for several months, where children enjoyed playing in it and came back to play with it again [258]. Hof et al. did their testing in an after-school care centre to deal with the influence of the environment and to provide known physical objects stimulating creativity [192]. To address the fairly specific context of disabled people, Larsen recorded numerous interaction sessions of this target group and their caregivers with his interactive play systems in the real-life setting of a care center [130]. Van Delden et al. tested their personalized interactive gait rehabilitation games with therapists and rehabilitants during actual sessions at a rehabilitation center [257].

2.5.3 Showing Effect of Design(-Elements)

Besides the focus on structuring the design process, we have also seen a large amount of research into interactive play that focused on investigating certain design elements. This kind of research answered questions like *'If a system contains element X does this help to satisfy goal Y?'*. This is often related to the generation or verification of guidelines, or a small part of showing fit for purpose. We cannot report all of these influences but they do give a good impression of this type of contribution and to this end we highlight some that had impact on our own work as examples.

2.5.3.1 Embodiment vs Traditional Controller

Requiring the involvement of body movement can have a significant effect on players' experience [165]. For instance, Berthouze et al. showed significantly higher engagement when comparing Guitar Hero played with a guitar to a DualShock controller [27]. A significant positive effect on engagement and on movement was also found when players played with the guitar including the performance-like 'star power' movement (heavily tilting it) compared to playing without it. Furthermore, they indicate that such a fantasy rich game element involves/triggers a different type of engagement than the hard fun/desire to win. Their results also indicate a significant effect on affect where playing with a guitar seemed to result in more high-valence/high-arousal. Similarly, comparing playing two-player Donkey Konga with a bongo controller, to playing with a GameCube controller, resulted in higher engagement and more social interaction: more utterances, more instrumental gestures, and more emphatic gestures.

Exertion games compared to non-embodied interaction styles can also change competition [165] and can have a positive effect on connectedness/bonding and perceived video-conferencing quality [164].

Beelen et al. showed that adding haptic feedback of the other player instead of a constant force added to the social presence of the other players [19].

2.5.3.2 Multimodal Output

Bekker et al. investigated their Multimodal Mixer to see what the impact was of adding modalities with sound and vibration feedback [21]. The number of games

[1] Although such a study might show some shortcomings regarding suitability for the context [255]

that were played in a session did not seem to differ much. The reported experience (enjoyment, fantasy, game creation abilities) did not seem to change either. The type of interactions with the device did change, where the richer feedback led to implementing more of the functionality into the games. Furthermore, it seems that available modality can also influence the type of games played, for example, vibration allows for secretive games, where visual cues trigger games like tag in which the devices also have to be looked at [23].

2.5.3.3 Open-ended vs Predefined Games

Bekker et al. compared open-ended play to a pre-defined game with their LEDtubes but they found no significant effect on perceived social interactions (talking and collaboration), although the children did appreciate the open-ended version more [23]. Furthermore, provided with an open-ended play system, children will turn to their creativity and create various games, and once the device had added functionality (creating the *ColorFlare*) it appeared that more diverse games were created. A blend between the two can also be created where players are able to change the rules of the game in the system itself during play [14, 251, 276].

2.5.3.4 Shared Object or a Personal Object in Order to Encourage Social Interaction

Based on their analyses of traditional playground games Tetteroo et al. state that shared/individual items can lead to in-game 'status' and as such could stimulate social interactions [246]. Rosales et al. debate whether this is true as they were more successful with an individual object, and also managed to trigger social interactions [218]. With their Swinxbee games Jansen and Bekker more convincingly showed by comparison that in their case shared objects in a collaborative setting did indeed stimulate forms of social interaction [104]. Nonetheless, one game with such an object that also triggered intense physical activity actually had a diminishing effect on social activity. They concluded that stimulating creativity and mimicking could also have a positive effect on the amount of social interaction without the introduction of shared objects. Following their conclusions, it seems that interactive play could either focus on 1) a fast paced competitive game / stimulating physical activity, or 2) stimulating creativity and social interactions [4, 104]. Such decisions and goals also influence other choices, such as the role assigned to an artificial referee [276].

2.6 Towards Intervention Based Play Research

In this survey we see two perspectives. There are many novel and exciting systems for interactive play. These often originate from a *user perspective*: we want to achieve something new and worthwhile for the user. These 'argumentations for play' are discussed in Section 2.2. Subsequently, studies are carried out with the resulting systems, from a *research perspective*, as discussed in Section 2.5.

When these two perspectives are well integrated, the user studies are well controlled and are meant to show effects that support, or contribute to, the aim and justification of the system from the user perspective. This yields what we call *intervention based play research*. In this section we discuss some characteristics of examples of successful intervention based play research in our survey. The remainder of the section then discusses some promising directions for this type of research.

2.6.1 Experimental Research

Intervention based play research includes a focus on doing 'experimental research'. There is a difference between A) showing the possibility of a new technology, exploring the design space, or investigating specifics of an interaction, and B) showing the effect of certain concepts, choices, or designs. While for the former it suffices to make one design, discuss some of its hypothetical possibilities with reporting successful user experiences but refraining from any conclusion on causality of design elements (e.g. [37]), for the latter more advanced experimental research should be done.

Claims regarding a certain guideline, fit for purpose, or design element, are made more powerful when there is a comparative study between such a choice and an alternative. It is important to actually evaluate and compare multiple design options in order to show that a suggested design decision was indeed of influence.

To use Campbell and Stanley's somewhat harsh conclusion:

> *'a design in which a single group is studied only once, subsequent to some agent or treatment presumed to cause change [..] such studies have such a total absence of control as to be of almost no scientific value. [..] Yet because of the continued investment in such studies and the drawing of causal inferences from them, some comment is required. Basic to scientific evidence [..] is the process of comparison, of recording differences, or of contrast.*
>
> *Any appearance of absolute knowledge, or intrinsic knowledge about singular isolated objects, is found to be illusory upon analysis. Securing scientific evidence involves making at least one comparison. For such a comparison to be useful, both sides of the comparison should be made with similar care and precision." [44, p6]*

We noticed that a comparative experimental design of evaluation is targeted by many in this field, for instance in a *research through design approach* [22]. It is also shown in use cases where physical play behavior is deliberately changed with design elements [127, 128, 260], with HUGs regarding incorporating HR or not [140] and incorporating physical or virtual objects [234], and regarding the effect of embodied interaction on social presence, social interactions and bonding [27, 147, 164], on video quality [164], and on engagement [27] and excitement[1] [56].

In other words, in many lines of research related to pervasive play-spaces, we see a focus on making a difference between intentions and effect. This focus makes a difference between design options allowing for certain behavior to occur and 'proofing' it actually encourages, promotes, or elicits it. Luckily for us all, it is also easier to compare two relative experimental variables than it is to prove that a single one works [44]. Therefore, we emphasize the importance to use an appropriate experimental design in *Intervention Based Play Research*. By investigating interventions (e.g. design options, user characteristics, or a certain context) in a well-structured comparative experimental design with randomized control groups or 'randomly' assigned conditions, we exclude that the encouragement of the wanted behavior is not merely the effect of context or the very nature of the players during evaluation (testing, instrumentation, etc.). This provides us with comparative results. Unfortunately this

[1] This was shown in a study with *human PacMan*, in their comparison they also changed from arcade game to the physical and HMD version.

also often requires a controlled study set-up which results in a less 'holistic picture of how children [or players in general] play' [192].

We have also seen that many researchers show that their research fits their underlying argumentation for developing certain kinds of systems. For example, the effects that they measure in experiments relate to the impact that they set out to achieve. Their motivation and argumentation can focus on the research contributions, or focus more towards end-user related goals. In order to work towards achieving the underlying argumentation, it seems good to also actively promote certain kinds of behavior. We can, and probably should, investigate what elements of a design elicit such positive effects. We can make use of the possibilities introduced with the introduction of interactive technology during play. For instance, the introduction of a controller that requires embodied interaction can have positive effects on goals such as increasing physical activity and social interaction [27]. These kinds of interventions, when chosen well and evaluated appropriately, fit into intervention based play research.

Obviously, one should take care not to over generalize and to be 'reading too much into the data', especially when a single group of children is involved in combination with statistical methods [211]. Furthermore, there are important formative evaluations that often require more qualitative insights, that might benefit from being investigated in a more efficient manner. These formative evaluations are necessary to get to a good design, and sharing such findings can also be informative for others. Therefore, our suggestion for doing intervention based research approach focuses more on 'end' evaluations.

We will now mention opportunities of interactive play that fit the intervention based play research approach, and could help to bring the researcher perspective and the end-user perspective closer together.

2.6.2 Adaptive, Balancing, and Steering Interactions

Poppe et al. mentioned that stimulating behavior change during play and incorporating *adaptive systems* can be fruitful directions for interactive play research [207]. Smart solutions that balance based on the players' effort seem to be promising for allowing people with different physical skills play together [169, 240]. Properly functioning adaptive (balancing) systems are often an ideological and unrealistic dream of the starting game designer [226]. Simple solutions like the race game *rubber band systems* or handicapping do not usually suffice [7]. Instead more sophisticated and play tested solutions are required.

Play can also be actively *steered* to temporarily increase or decrease activity [128, 153]. *Steering* refers to reaching goals by the deliberate introduction of interactions that change in-game physical play behavior in desired directions [258]. This steering is closely related to what Altimira et al. called *inducing behavior* and might allow us to improve the experience during longer lasting sessions, balance a game, and cause people to move more or interact more [8, 153]. Furthermore, some players might not (be expected to) be as socially involved in the game as the others. This could be sensed or set by a facilitator, and subsequently the game could give this player another role and/or have them lured into the play by others [89, 260]. This creates an opportunity to influence children's play in desired directions while they are playing. This *steering* of interactive play behavior during the game is triggering a change of behavior in wanted directions with playful elements. It also seems to be slightly different from most 'traditional' persuasion and nudging activities. It does not primarily aim to change long-term lifestyle behaviors outside the game, such as smoking, (un)healthy diets, medication intake, or daily level of physical activity. It is different from constraining behavior [31], or manipulation and deception [231], even if the participant might not perceive this as such the first time: it does not deliberately hide options or enforce a way of interaction by making it the only means of input. Instead, and similar to using different ways to explain suggested use to people [255] or explicitly leaving it out for intended ambiguity [276], it tries to change the play interaction itself: influence the players' activity, performance, or role, change the interactions between players, the locations players visit, or the type of interaction players perform [89, 128, 260]. Further investigation of such techniques might bring us closer to successfully addressing the goals we have mentioned as argumentation.

2.6.3 Beyond First Time Use

Many studies on pervasive play-spaces focus on first time use [23]. Due to the novelty of interactions such studies are often heavily influenced by first time use; in the longer run behavior might change. This could also mean that the effect of design elements can change on a longer term, and children might become less inclined to play again after several sessions [192]. For instance, sounds might be of added value in the beginning but could annoy people (especially adults, neighbors or bystanders) if they are monotonic, uniform and are played over and over again with limited variations [78]. Bekker and Sturm already suggested in 2009 that showing the true promise of interactive play(-objects) also requires longitudinal studies [22]. At the same time, Hof et al. noticed that performing a user test several times (three times, once each week) with observations and questionnaires with the same groups of children is already very difficult to arrange [192].

The use of automatic measurements might aid in such play analyses in the longer term. The commercial systems of Kompan and Yalp provide logs of how long which game is played, they can also be updated from a distance. With the increasing number of playgrounds sold around the world (over a 100 for some systems), it could become interesting to start scientific research with these systems, and long term tests using A/B testing, investigating certain game elements and design pattern, and then evaluate if it effects the game play in order to inform future design.[1]

The ability to update the systems over a distance also allows for changing the content in order to keep it up-to-date following contemporary trends, and regarding to some aspects (e.g. a quiz) keep it unpredictable. Both features, the automatic logging of game play and structurally changing interesting game-elements similar to the ones mentioned earlier, allow for studies on a longer term leading to interesting insights, seemingly providing an interesting way to bring the research perspective closer to the end-user's perspective.

2.6.4 Three Possible Directions for Steering Play Behavior

So far in this Section we have focused on some of the specifics, opportunities, and challenges of an intervention based research approach. Here we will point to three

[1] A nice example of how A/B testing can and in some cases should not be applied is provided by Booking.com. They have a large number of visitors each day, which has allowed them to do such tests for over a decade `http://blog.booking.com/concept-dne-execution.html`, last accessed 1-8-2016

concrete directions which are suitable for further investigations into (steering) interactive play behavior.

2.6.4.1 Distributed Team Play

Incorporating team play can be appealing for colocated interactive play systems [266]. Following the line of thought from Mueller et al. it could help to let geographically divided people bond/collaborate/familiarize by playing/sporting/exerting together [162, 164]. During studies with their *break-out-for-two* system they went slightly further in order to improve throughput. They encouraged multiple players per location to play together (as a team) and take turns shooting or throwing the ball against the wall while they were competing against another (team) over a distance [161]. They also mention doing similar investigations into adding colocated teammates for their table-tennis-for-three game [175]. One interactive pong-playground (a camera-projection playground) was even specifically created for distributed play with colocated team play in different configurations [256]. It could be interesting to see more exertion based systems or to further investigate what the effects would be of different configurations on social presence and movement coordination between team members, and this will be one aspect of Chapter 4 using the latter playground: what configuration would be more beneficial, having colocated team members with a team of distributed opponents, or colocated opponents with distributed team members?

2.6.4.2 Alternative User Groups

Interactive play is often targeted at the typical user groups: children, students, adults, or elderly people. There are several exceptions to this tendency: one is Stomp, by Wyeth et al. that was created for people with intellectual disabilities [282, 283]. Another is the use of the PlayAlive satellites to help people with dementia and in the in-space project to help train and motivate people with mental disabilities[1]. Similarly, Yalp has been involved in projects with people with dementia. Also they, as well as Playworld, explicitly mention that (some of) their interactive systems can be accessed by people in a wheelchair[2]. Brederode et al. created their *pOwerball* game for people with mixed abilities [37]. Van Leeuwen et al. created *Beagle* especially for hospitalized and segregated adolescents [263]. A very challenging target group to design for consists of people that have PIMD. Explorations into building interactive play systems for this target group show the possibilities of addressing needs that would otherwise be hard to target [129, 130, 262]. So it seems very worthwhile to also address such a user group, and this will be the focus of Part 2.

2.6.4.3 Alternative Goals

Most interactive play systems target stimulation of physical activity and/or social interaction in combination with stimulation of creativity or educational goals. Other (abstract) goals could be targeted as well. We could turn to fundamental (psychological) needs that people have to fulfill to lead a worthwhile life. For instance, Roozendal et al. use psychological needs as a layer in their playful persuasion framework,

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[1] www.playalive.dk/en/forskning-og-innovation/netvaerk/i-space/ and playalive.dk/en/forskning-og-innovation/netvaerk/demens-i-hjemmet/, last accessed on 30-7-2016

[2] www.yalpinteractive.com/?file=15978 (whitepaper) and goo.gl/Fc4FZC (brochure), last accessed 2-8-2016

and van Delden and Reidsma showed how entertainment can help to fulfill a variety of other needs related to autonomy, efficacy, purpose, safety/security, self-esteem, self-expression, or values [220, 261].

Instead of looking at needs we could also look at professional activities related to children. Several systems seem suitable for rehabilitation purposes [257] but one aspect (interactive) play seems especially suitable for is the *diagnosis* of physical, social, emotional, or cognitive limitations [75]. Poppe et al. also mentioned that for example regarding diagnoses, automatic analyses of play sessions could be a fruitful direction for interactive play systems [207]. It could reduce the time needed for analyses, give various insightful quantitative results, and provide an interesting activity for the children at the same time. To our knowledge no such systems exist yet in the interactive play research domain, perhaps due the need of expert domain knowledge and the sensitive nature of the diagnosis process. Nonetheless, the effort might be worthwhile for creating interactive play systems with societal impact.

Besides diagnosis there are many professional activities that relate to performing repetitive tasks, especially in a rehabilitation setting such as gait rehabilitation. These tasks address certain specific goals (balance, performing dual-tasks, etc.) and might benefit from providing similar tasks in a more motivating and enjoyable interactive experience. Doing this in a rather personalized way is the focus of Part 3.

2.7 Conclusion

Our survey shows that research into pervasive play-spaces or interactive play systems contains a variety of research topics, directions, outcomes and approaches. With this manuscript we have summarized several aspects that can be of interest for researchers in this field, perhaps inspiring new combinations of work.

We have also reiterated a possible way to further research in the field, a way used by many scientific researchers: intervention based play research. We mention two approaches that seem to fit well with this approach: 1) turning to longer term use probably making use of automatic measurements and existing commercially available playground installations, and 2) making use of the mediating powers of interactive play in order to adapt or steer play to better satisfy the envisioned end goals we try to fulfill for the users.

The overview might function as a guide for a new generation of PhDs and researchers as it puts together various core works and researchers of this field. We invite others to broaden the research perspective and expand the playing field.

Outro Interactive Play Spaces

I have introduced the interesting playing field of research into interactive playgrounds and similar systems. I have already described what the contents of this thesis will be, and I have discussed several interesting directions for research into interactive play behavior that contain a large overlap.

This Section concludes 'Part 0' and the thesis has three remaining parts with systematically investigated use cases and a fourth concluding part. Part I contains four chapters. In these chapters I address several of the indicated possibilities of steering behavior. I explain how we try to influence several aspects of play behavior: coordination between players, a players' choice of whom to target in a game, the (skill) balance of the game, the locations of players and especially their proxemics. I start with Chapter 3 which introduces the *interactive playground platform* (IPP) that I will use throughout Part I. I then introduce a *distributed interactive pong playground* (DIPP) in Chapter 4, where I focus our explorations on coordination and teamplay over a distance. In Chapter 5, I start with observations of non-instrumented playgrounds, and then introduce our Interactive Tag Playground (ITP) which we use to steer game play behavior in certain directions. Chapter 6 is the last chapter of Part I, where we let children play (instead of students). I show that steering interactive play behavior can be done in a subtle way that does not need to be tightly linked to the game outcome.

In those chapters I report how we use automatic measurements and test with repeated use. However, I do not yet fully address all the possibilities as proposed in this survey to go beyond first time use. In Part II, I will target a different user group, will do a longer term study, and target alternative goals suitable for this user group. In Part III, I will focus on a more practical use case, that of gait rehabilitation and show yet another level of the goals that can be targeted in play behavior. Part IV concludes the thesis, it contains a discussion, some further work that contains interesting directions and more informal explorations with student projects, and ends with an overall conclusion of what has been done.

Part I

Steering Behavior in Interactive Play Spaces

3
The Interactive Playground Platform

Amy, technology is not intrinsically good or evil.
It's how it's used. Like the Death Ray.
– Professor, Futurama s06e08 (2010)

This first part of this thesis is about a specific interactive camera-projection platform that we created for steering interactive play. In this Chapter, we will describe this interactive playground platform.

In order to create games for embodied interactive play that allow us to investigate the attainability of steering behavior we need two things. One, an installation that can use bodily interactions as input. Two, feedback that can easily be altered into different conditions. In Chapter 2 we have shown several approaches to build such an installation. One approach is a camera-projection system: a camera recognizes a user's action and large (floor) projections provide the main feedback. For this part of the research we made use of several advantages of these systems:

- Easy stepping in and easy stepping out [243]: there is no need to calibrate to the user and no devices need to be handed out or collected afterwards

- Flexibility in feedback, having the ability to change visualizations in various ways provides an easy way to investigate the effect of various conditions/game types.

- Automatic measurements, the detected behavior of users and especially position information can provide an easy-to-use method for evaluation purposes [153, 154][1].

Parts of this chapter are based on:
A. M. Moreno, R. W. van Delden, D. Reidsma, R. W. Poppe, and D. K. J. Heylen "Augmenting Playing Spaces to Enhance the Game Experience: A Tag Game Case Study" in *Entertainment Computing* 16, pp. 67–79

[1] The advantages and importance of using automatic measurements is mentioned in this thesis but does not form its core contribution. Although I have contributed to the development of the tracker on a conceptual level, for the benefits of this platform with respect to the use of automatic measurements I refer to the work and thesis of Alejandro Moreno and our paper on player experience in the ITP [153, 154, 156]

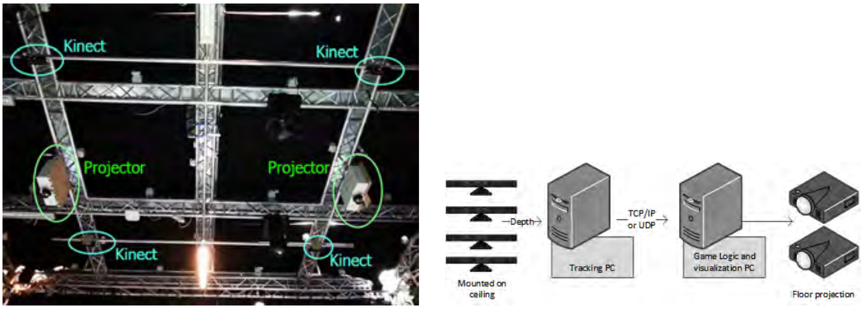


Figure 3.1: Setup of the hardware on a ceiling at one of our locations (left) and a more schematic depiction (right). The network protocol used differs between chapters.

- Anonymity, with the technology used it is also possible to do research with anonymous data. Especially when dealing with special target groups such as children this can be beneficial.

3.1 Implementation and Hardware

We developed the Interactive Playground Platform (IPP). This platform is used for the Interactive Tag Playground (ITP) that is the core of Chapters 5 and 6, and for the Distributed Interactive Pong Playground (DIPP) that forms the core of Chapter 4.

In our IPP, the activities of players take place in a large interactive floor projection, see Figure 3.2. In order to steer player interactions during the game, our IPP uses the Kinects' depth sensors to track players in the playing area, projectors to display visualizations on the floor of the playground, and PCs to process the game logic based on the players' positions, see Figure 3.1 and 3.2.

The tracking module uses four Kinects located on the ceiling of the playground. We used the first generation Kinects (XBox and Kinect for Windows) as these were affordable, available and allowed us to use multiple sensors per system. The Kinects are situated in a grid-like setup, about 4 meters apart from each other. Two projectors are also located on the ceiling in between the Kinects, about 4 meters apart (Figure 3.1). The ceiling is situated about 5 meters above the playing area, which allows us to track players in an area of up to a 7×6 meters. For the DIPP we limited this to 5.3 by 5.3 meters to have exactly the same size on two locations. With two projectors[1] we cover an area of approximately the same size, see Figure 3.2. Speakers are used to produce simple sound effects during the game, and are located either next to the playground or hanging on the ceiling.

3.2 Tracker

Our online, top-down, multi-person tracker uses the depth images from the Kinects as input to detect players. We only use the near-infrared based depth images because the game projections are better appreciated in dark environments, which would make

[1] Panasonic PT-EZ570el with ET-ELW21 0.8:1 lens, 1920x1200 px, and 5k ANSI Lumen, at another location we used a similar model with an identical lens.

Figure 3.2: Interactive projection in the setting of the ITP at the art gallery. A mother with child playing tag, this mother-child interaction is not part of the studies presented in Part 1.

the use of RGB images difficult due to the uneven and low illumination conditions, besides leading to a possible feedback loop.

The location of the players is detected by first applying a threshold to the depth images to remove the floor and small objects that might be present. With several filtering techniques the 'centre of mass' of the players is obtained per Kinect, see [156] for details. These centers of mass from Kinect-specific coordinates (pixels) are mapped to real-life coordinates, and merged with those that overlap from different Kinects' fields of view.

Once a player has been detected (detections), they are tracked in the playing area over time (tracks) in order to create player based games. To match these detections to track pairs, we use the Kuhn-Munkres algorithm. This algorithm allows us to efficiently assign the most probable combinations, in this case based on Euclidean distances.

When a new detection is found, we wait for five frames (approximately 0.25 seconds) to make sure it is an actual player and not camera noise before creating a track for it. When a track has no assigned detection in a given frame, we wait 15 frames (approximately 0.75 seconds) before deleting it, since most of the times it is a player that moves outside the field or below the threshold temporarily. By doing this, we prevent the creation of unnecessary tracks or the deletion of valid ones. We also manually limited the number of tracks to four players, preventing the creation of additional tracks. Four players seemed to be a reasonable number of players for the size of the playground.

3.3 From Tracker to Games, Logs, and Distributed Games

To simplify the process of designing and implementing interactive rules or elements, the game logic is separated from the tracking system in the IPP. This is achieved by having the game engine and the tracker on separate computers that communicate between each other over a network. The tracker PC broadcasts the position of all players to the game PC, which uses this information to drive the game interactions. We used different protocols over time. The most suitable implementation (with regard to lag), was a multicast Node.js® implementation using the UDP protocol.

The IPP can log the position and role information of all players in real time. This information can be used after the game to analyze player behavior (e.g. analyze how players moved during the game) and evaluate whether goals were met (e.g. measure the amount of physical activity), and it can be used during the game to drive certain game mechanics (e.g. display a circle underneath a player's location, or balance a game based on the players' performance). To drive the game mechanics we use the Unity 3D game engine[1] that allows for easy integration and flexibility of implementation of graphics, object movement, virtual object generation, sounds, networking, and rules. When the position data is used in post-hoc player behavior analysis, an advantage is that it can be pre-processed to account for possible tracking errors or noisy measurements.

Due to the fact that we can distribute the tasks over two separate computers, we can also use additional computers to set up a different playground elsewhere for distributed play. However, to be sure that the same game and information is shown on different locations, a slave-master approach should be used for the two game PCs. This approach means that the master collects the positions of players in both fields, and deals with the game logic. The slave computer simply receives the information necessary for visualizing the game. We will introduce such a system in Chapter 4.

[1]As the tracker and game system(s) are separated it is quite easy to use another engine or language for the game mechanics. Some students successfully implemented a Space Invader game on the IPP in Java and another student implemented interactive visualizations with openFrameworks on the IPP.

4

Steering Coordination in Distributed Team Play

Look at yourselves.
Unplug from your chairs, get up and look in the mirror.
What you see is how God made you.
We're not meant to experience the world through a machine.
– The Prophet, Surrogates (2009)

In this chapter we look at our first game for the IPP. Together with several others we created a game akin to pong and airhockey. Players have a paddle projected around their physical position, and with it attempt to bounce a ball into the opponents' goal by walking or running around. This also introduces my first intervention, the variation in the game that is introduced to reach and demonstrate attainability of a certain goal. This first intervention targets steering *coordination* between players: letting them move and play together in a more coordinated way, even when playing over a distance. This is done by providing the players with linked paddles, instead of having their own individual paddle. Two players control a shared paddle, and will have to coordinate their movements, because when they go too far away from their teammate their paddle will disappear. Results show that this intervention (the shared paddle) leads to an increase in coordination of movement. We also explored possible effects on social presence of this shared paddle in combination with different distributions of players (having either a colocated teammate or an opponent). Results did not show a clear effect regarding social presence.

Distributed games build upon the rise of broadband internet gaming technology to let people play together. They allow computer entertainment to better include the social-relatedness factor, even when the people with whom we want to play are physically far away. *Exertion games* (or exergames) target intense physical effort to play the game [174], which can result in enjoyment but also has other benificial effects.

Parts of this chapter are based on:
R. W. van Delden, S. Gerritsen, D. Reidsma and D. K. J. Heylen "Distributed Embodied Team Play, a Distributed Interactive Pong Playground" in Proceedings of 8th International Conference on Intelligent Technologies for Interactive Entertainment (Intetain 2016), pp.140–149, 2016.

Figure 4.1: The Distributed Interactive Pong Playground. Two opposing players are colocated, playing the game with their distributed teammates. On the top of the field the goal can be seen, the ball (white circle) bounces off the paddle between the green (visible) and yellow (distributed) players towards the other side of the field.

For instance, the high prevalence of obesity in western countries could be targeted with these exergames, as these games have been proven to increase energy expenditure [245]. The combination of the two leads to *distributed exertion games* [174], which allow one to play intense physical games, together with other people, over a geographical distance. Mueller et al. created several games and sport experiences that can be enjoyed with people on the other side of the world, including *table tennis for three*, *jogging over a distance*, kicking a ball against a wall (*break out for two*) and *airhockey over a distance* [178].

The novel contribution of this chapter is the introduction of *distributed teamplay* in which both collocated and distributed players participate. Building on the work of Mueller et al. we asked ourselves how distributed teams would work in such an embodied interaction setting. In our Distributed Interactive Pong Playground (DIPP), players bounce a ball towards a goal by moving, walking, and running around in a 5.3 by 5.3 meter interactive playground. Our interest focused more on the social (presence) aspects of the games than the exertion. First, we investigated whether we could increase coordination in movement between players by changing the game to enforce teamwork. This was done by letting the players in a team control one end each of a shared paddle, as opposed to both players having separate paddles. The evaluation regarding the effect on coordination of this intervention was done based on the position data of the players. Second, we investigated whether having either a colocated opponent or teammate is most beneficial for the overall social presence and how this interacts with enforcing teamwork. The evaluation of this aspect was done with questionnaires.

4.1 Building on Benefits of Embodied (Distributed) Play

Several related systems have been used to show that (distributed) embodied gaming can have positive effects on play experience and relation between players. Playing with our *Tug of war* with physical feedback on the rope of the other player, when compared to a variation where there was no physical feedback of the other user, resulted in an increase on several dimensions of social presence of the distributed

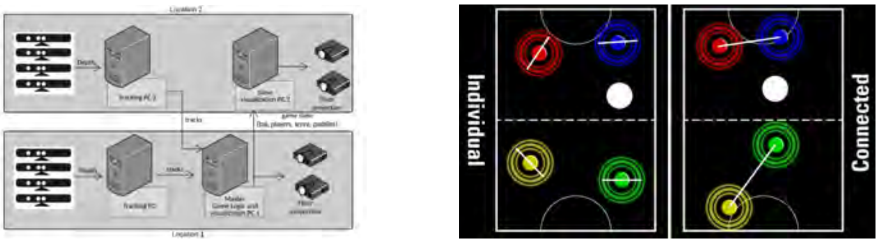


Figure 4.2: The setup of the DIPP. On the left the system layout, at 2 locations we installed 4 Kinects and 2 projectors, and we used two tracker PCs sending tracks of players (ID and position), and by processing this info a master PC sends game info (ball, players, score and paddles) to a slave PC. On the right the two game variations are shown.

player [19]. Playing with *break out for two* when compared to a keyboard alternative, made the players feel they knew one another better and became better friends. It increased fun, and unexpectedly resulted in increased perceived quality of the audio and video [167]. Participants playing with the *table tennis for three* reported that they forgot the world around them, and that they could imagine it would help to increase rapport [178]. Exertion games, also when not distributed but still compared to non-embodied interaction styles, can indeed have an effect on social interaction, trust, emotional experience, role-taking, competition, and connectedness [165].

Many benefits of existing distributed exertion games and distributed games have been linked to how players play together with another player. We have seen two players cooperatively playing a game together in *tug-of-war*. In *Breakout for two* local players were also welcome to team up during the games, taking turns to shoot the ball to increase throughput. To our knowledge there are not yet team distributed exertion games with concurrent gameplay [161, 178].

4.2 Design of DIPP

We introduce our team distributed exertion game DIPP that includes two players on each team, two four players distributed over two different locations, a virtual ball, and two virtual goals, see Figure 4.1. Each player is represented with a unique colored circle projected at their position. The players control a paddle by moving around the playfield, being restricted to their end of the field, and the paddle can be used to bounce the ball into the opponents' goal. The game is played for 7.5 minute after which it will automatically stop.

4.2.1 The System

The system consists of duplicate setups at two locations communicating over the (university's) network using the UDP protocol. As explained in Chapter 3 both setups have four top-down oriented depth sensors (Kinect), a tracker PC (transforming depth information to tracks of players), a visualization PC and two projectors, see Figure 4.2. One PC, the game-PC master, gathers the track information and transforms these to game coordinates. These game coordinates are used to run the game, the master sends the game information to another slave game PC at the second location. This second PC simply visualizes the game objects at the second location. This setup forces the game to be deterministic. This is unlike the setup of what seems to be the first distributed embodied game, arm wrestling over a phoneline, in which both players could win at their end of the game [171][1]. Mueller et al. pointed out that the audio channel is the premium communication channel (in a distributed game) [178]. In order to let players communicate verbally we set-up a Skype call between the two locations using two additional Kinects, allowing communication in the entire playing field without using wearable microphones.

4.2.2 The Variations in Game and Distribution

Our contribution focuses on cooperative team play and the mix between colocated and distributed players. We were interested to see how players would play in different distributions and whether we could increase coordination between players by changing the game play. Ideally, such an increase in coordination could also lead to an increased social presence of the other players.

We made two game variations, see Figure 4.2. In the *individual* mode players were assigned an individual paddle. They still played in a team but each paddle was controlled by one player. The paddle rotates towards the ball until the distance is below a certain threshold (approximately 1.5 meter). In this way players can bounce the ball in different directions by approaching the ball in different angles. In the *connected* mode players in a team each control one end of a connected paddle. Players can also rotate this paddle by moving around the other player. When the players are too far apart (approximately 1.5 meter, twice the size of an individual paddle) the paddle breaks (disappears). While both forms require teamwork, we tried to encourage closer coordination between players with the connected version. Especially once the game was distributed we still wanted the players to pay attention to the (other) distributed players.

We also varied the way players were distributed. Players could either have their teammate at the same location, or have their teammate distributed and have an opponent at the same location. This leads us to 5 conditions to investigate:

1. colocated$_{individual}$
2. colocated$_{connected}$
3. distributed-opponent$_{connected}$
4. distributed-team$_{individual}$
5. distributed-team$_{connected}$

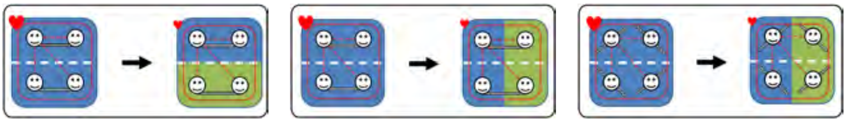
A possible sixth condition, distributed-opponent$_{individual}$, was played only once, deemed least interesting, and was omitted from analyses due to a lack of participants.

4.2.2.1 Hypothesis Coordination

We had three hypotheses regarding the coordination between players:

Hypothesis C1 The coordination will be higher if we steer towards a more connected game than with an individual game (coordination in #1 $>$ #2).

[1]Introduced in 1986, idea by Doug Black and Norman White, http://v2.nl/archive/works/telephonic-arm-wrestling, last visited 27-2-2016

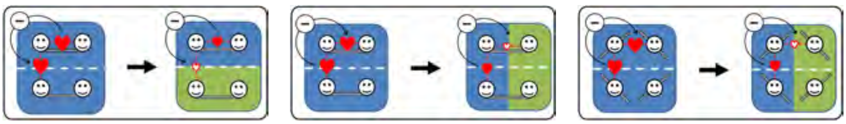


SP 1.1 In play with enforced teamwork, the average social presence between players will go down when distributing the opponents
M 1.1 SP $\frac{(Team+Opp1+Opp2)}{3}$, #3 < #2

SP 1.2 In play with enforced teamwork, the average social presence between players will go down when distributing the team members
M 1.2 SP $\frac{(Team+Opp1+Opp2)}{3}$, #5 < #2

SP 1.3 In play without enforced teamwork, the average social presence between players will go down when distributing the team members
M 1.3 SP $\frac{(Team+Opp1+Opp2)}{3}$, #4 < #1

Figure 4.3: The three sub-hypothesis from SP1 The average social presence between players will go down when distributing the game



SP 2.1 In play with enforced teamwork, when distributing the opponents the social presence of the distributed opponents will go down more
M2.1 SP $Team - \frac{(Opp1+Opp2)}{2}$, #2 < #3

SP 2.2 In play with enforced teamwork, when distributing the teammates the social presence of the distributed teammate will go down more
M 2.2 SP $`Opp1' - Team$, #2 < #5

SP 2.3 In play without enforced teamwork, when distributing the teammates the social presence of the distributed teammate will go down more than that of the opponent
M 2.3 SP $`Opp1' - Team$, #1 < #4

Figure 4.4: The three sub-hypothesis from SP2: when distributing the game, the social presence between the distributed players will go down more than the social presence between the colocated players.

SP 3.1 In distributed play with enforced/connected teammates, a remote opponent has a lesser social connection than a colocated opponent.
M 3.1 SP $`Opp1'$, #3 < #5

SP 3.2 In distributed play with enforced teamwork, remote teammates have a lesser social connection than colocated teammates
M 3.2 SP $Team$, #5 < #3

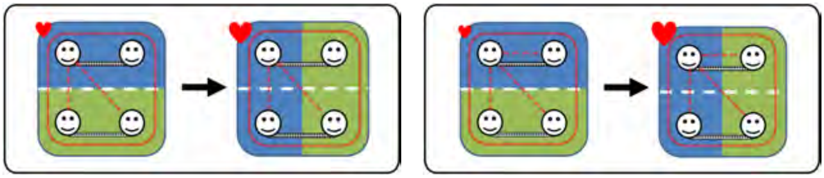
Figure 4.5: The two sub-hypothesis from SP3: in distributed play with enforced teamwork, remote players have a lesser social connection than colocated players.

Hypothesis C2 Distributing a connected team still has a detrimental effect on their coordination in movement, thus in distributed play the coordination will be higher for colocated teams than for distributed teams (coordination in #3 > #5).

Hypothesis C3 If we have distributed teams the connected version will still give a higher coordination (coordination in #5 > #4).

4.2.2.2 Hypothesis Social Presence

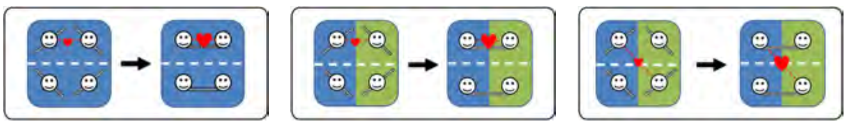
For the social presence we were performing exploratory investigations for this new type of setup. For our study regarding the effect of distributions and game variations



SP 4.1 In distributed play with enforced/connected teammates, the average social bond with the opponents improves when one opponent is colocated.
M 4.1 SP $\frac{(Opp1+Opp2)}{2}$,
#3 < #5

SP 4.2 The average social bond between all players improves when using distributed teams in the case they are connected (enforced)
M 4.2 SP $\frac{(Team+Opp1+Opp2)}{3}$,
#3 < #5

Figure 4.6: The two sub-hypothesis from SP4: in distributed play with enforced teamwork, distributing the opponents will be beneficial for the social presence..



SP 5.1 In colocated play, enforced team play between teammates improves their social presence
M 5.1 SP $Team$,
#1 < #2

SP 5.2 Enforcing team play between team members improves their social presence when they are distributed
M 5.2 SP $Team$,
#4 < #5

SP 5.3 The social bond with a remote opponent is better with physically enforced teamwork with a remote team member.
M 5.3 SP $`Opp2'$,
#4 < #5

Figure 4.7: The three sub-hypothesis from SP 5: enforcing team play between team members improves their social presence.

on the social presence we had five main hypotheses (SP 1 - SP 5) each tested partially with two or three sub-hypotheses resulting in 13 hypotheses (SP 1.1 - 5.3). We visualized these hypotheses, and also describe the comparison of social presence between players. Note that in these comparisons the suggested directions are not part of the hypotheses (2-tailed tests), and that the direction was always ordered with smaller expected condition value on the left, so often not corresponding to the order of the pictures. For some comparisons we could compare two players in one condition to only one available player in the other condition. To deal with this situation, if there were two players available in one condition and two in the other: we only selected the one colocated player starting diagonally across the field. We prefer this over averaging, as averaging would effect the statistics of the comparison. We use the term 'Opp1' (abbreviation for opponent 1) in the description of measures for these cases. The images show the version (either individual or connected), the distribution (green and blue) and the expected values of self-reported social presence values (three sizes of hearts depicting the relative values). The position of the players in the four corners are not the physical starting locations horizontally. To prevent switches where needed (#4 and #5) we had the two colocated players positioned diagonally across the field at the start at indicated positions. For clarity of the distribution types we depict them on the same horizontal position nonetheless.

4.3 User Study

4.3.1 Procedure

The experiment consisted of groups of four participants that kneweach other, playing only one of the five conditions in order to reduce the threshold (time) to participate. The two setups were both located at our university, in different buildings 400 meters apart. Participants were recruited in groups of four players. Participants were told that they would play a game of Interactive Pong, were informed about the game and had to give written consent. Participants were then asked to fill in a digital pre-experiment questionnaire, including questions regarding familiarity with each other and a baseline for the 'including Other In the Self' (OIS) scale by Aron et al. [13]. We let the participants choose the teams, so there was no influence from us in this creation. Based on which distribution type the group had to play in, we took the participants to the associated locations.

Once the players had arrived at the other location we tested the communication channel. We had to omit the Skype connection in one game from #4 due to technical difficulties. In another game from #5 we switched to a speakerphone. We first let the participants play the game as long as they needed to get used to the game (about 1 minute). This was done in order to remove any difference in pre-knowledge people may have had in playing interactive games and/or previous versions of the pong game. We then started a 7.5 minute session where we let them play uninterrupted. At the end of the session, participants answered a questionnaire including the OIS-scale, and questions regarding the social presence of the other players including six different constructs [85]. This particular questionnaire was chosen as it fitted the intended measure, had proven internal consistency, its development based on existing theory seemed appropriate, and it was applied successfully in the context of the *Tug of war* game [13, 19]. After finishing the questionnaire we asked the participants to share their thoughts on the game.

We also saved the real-world positions of the players during the games: this data of the tracker allowed us to investigate the physical coordination between the players.

4.3.2 Participants

In total we had 80 participants, equally divided over the four conditions, 62 were male and 18 were female. All participants were between 19 and 34 years of age (23 on average), most were studying at our university. We asked all participants if there was anything that could influence the experiment. Two participants reported they had an autism spectrum disorder (in #2 and #5). Seven participants had physical discomforts/limitations (backache, motor disorder, low energy levels, etc.). Most were unnoticeable in play-behavior with our direct observations, and spread over all conditions, although 3x in #5 and 2x in #3.

4.3.3 Results

4.3.3.1 Observations and Interviews

Some players in the distributed opponent configurations thought they were part of a Turing test. We were explicitly asked this question a couple of times (seemingly more often in #3). Players immediately had several ideas how to improve the game, such as restricting the time one stands close to the goal. Nonetheless, most players indicated to us that they liked the game very much, and we heard utterances such as *'This is so strange, this is so cool!'* (in #4). During the games several players were cheering and booing, giving high fives if they scored, and some made exaggerated movements like jumping in the air when (almost) scoring. These behaviors all seemed to be qualitative indications of players being immersed in the game.

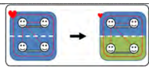
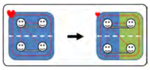
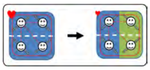
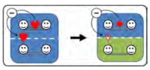
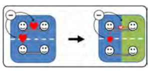
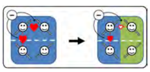
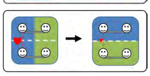
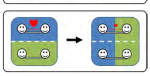
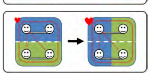
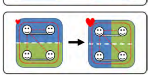
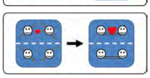
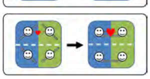
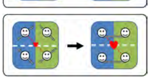
4.3.3.2 Questionnaire

Similar to Beelen et al. we performed comparisons on the social presence constructs between players in the different conditions [19]. The 6 constructs in Aron et al.'s social presence questionnaire are: Co-Presence (CP), Attentional Allocation (AA), Perceived Message Understanding (PMU), Perceived Affective Understanding (PAU), Perceived Emotional Interdependence (PEI), and Perceived Behavioral Interdependence (PBI). The analyses of the 13 hypotheses on 6 measures plus the difference in pre- and post-test in the Inclusion Other in the Self (IOS) scale, resulted in 91 comparisons, thus requiring a Bonferroni correction ($0.05/91 = 0.00054$). Reliability for the six constructs is known [85] and internal consistency for this study was good to excellent, Cronbach's α in the range of 0.74-0.92 for all player comparisons for each of the constructs. Due to non-normal distributions we used the two-tailed version of the Mann-Whitney U test and all with $n_1 = n_2 = 16$. With the uncorrected significance level only 21 of the 91 comparisons would have been significant ($p < 0.05$). For clarity we also include a condensed table with the p-values of the tests including the average and median values (with the expected smaller values on the left, e.g. for SP 1.1 values on the left are for condition 3, not condition 1 as the image would suggest), see Table 4.1. We only report more extensive information for the significant and most important results in the text. Therefore, we also limit ourselves to reporting PMU, PAU, and OIS; these are the dimensions that seem to be most (often) influenced regarding our hypotheses.

We found a significant difference regarding Hypothesis SP 2.1 for PAU. In play with enforced teamwork, there is a difference when going from colocated play (#2, Mdn = 0.17) to distributing the opponents (#3, Mdn = .67), for the difference between the distributed opponents and their teammate ($team - \frac{opp1.+opp2}{2}$), $U = 40$, $z = -3.34$, $p < \frac{0.05}{91}$). PMU was not significantly different (#2, Mdn = 0.58, and #3, Mdn = 1.08), $U = 75.5$, $z = -3.18$, $\frac{0.05}{91} < p < 0.05$), nor was OIS (#2, Mdn=1.5, and #3, Mdn = 3), $U = 87$, $z = -1.55$, $p > 0.05$). In play with enforced teamwork we also found a significant effect for Hypothesis SP 2.2 when distributing the teammate (#5, Mdn = 0) for the difference in OIS between the teammate and the colocated opposing player (#2, Mdn = -2.00) ('$opp1' - team$) the scores differ significantly, $U = 30.5$, $z = -3.72$, $p < \frac{0.05}{91}$. PMU was not significantly different (#5, Mdn = 0, #2, Mdn = -0.58), $U = 66.5$, $z = -2.33$, $p < \frac{0.05}{91} < p < 0.05$), nor was PAU (#5, Mdn = 0.25, #2, Mdn = -0.17), $U = 64$, $z = -2.44$, $\frac{0.05}{91} < p < 0.05$. All three changes are in the direction indicated for the hypotheses, a more negative difference ('$opp1' - team$) for colocated than distributed, the minus sign indicates the higher OIS scores given for the teammate. Seemingly this is a combination of somewhat increasing values for the opponent (now the only colocated player, OIS #2 Mdn = 0 to #5 = 0.5) and a decrease for the (now distributed) teammate (OIS #2, Mdn = 1 to #5, Mdn = 0).

The type of distribution had effect on the scores given to the teammate in the

Table 4.1: The p-values for the two-tailed Mann-Whitney test on social presence and the IOS, we use a corrected α of .00054 these values are marked black with white text. We also indicated non-significant low p-values. *Marks a low p-value in the opposed direction.

HYPOTHESES		val	CP	AA	PMU	PAU	PEI	PBI	OIS
SP 1.1		p	.557	.008*	.249	.002	.300	.904	.992
#3 < #2		avg	3.9 / 3.8	3.7 / 3.2	3.3 / 3.6	2.8 / 3.6	2.4 / 2.8	3.6 / 3.4	.35 / .35
		mdn	3.8 / 3.7	3.8 / 3.3	3.4 / 3.7	2.9 / 3.6	2.3 / 2.7	3.7 / 3.5	.50 / .33
SP 1.2		p	.731	.496	.010	.001	.121	.583	.093
#5 < #2		avg	3.9 / 3.8	3.3 / 3.2	3.0 / 3.6	2.7 / 3.6	2.3 / 2.8	3.4 / 3.4	-.50 / .35
		mdn	3.9 / 3.7	3.3 / 3.3	3.0 / 3.7	2.6 / 3.6	2.1 / 2.7	3.5 / 3.5	.00 / .33
SP 1.3		p	.661	.703	.744	.831	.545	.417	.187
#4 < #1		avg	3.8 / 3.9	3.3 / 3.2	3.3 / 3.3	3.3 / 3.2	2.6 / 2.8	3.6 / 3.4	-.27 / .13
		mdn	3.8 / 4.0	3.2 / 3.1	3.4 / 3.2	3.4 / 3.1	2.7 / 2.8	3.6 / 3.4	-.17 / .33
SP 2.1		p	.532	.264	.047	.000	.381	.107	.124
#2 < #3		avg	1.0 / 0.8	0.8 / 0.4	0.6 / 1.2	0.2 / 1.0	0.3 / 0.6	0.6 / 1.1	1.6 / 2.6
		mdn	1.0 / 0.9	0.7 / 0.3	0.6 / 1.1	0.2 / 0.7	0.0 / 0.2	0.7 / 1.0	1.5 / 3.0
SP 2.2		p	.004	.160	.019	.013	.040	.295	.000
#2 < #5		avg	-1.0 / -0.1	-0.8 / -0.3	-0.6 / 0.2	-0.3 / 0.4	-0.3 / 0.3	-0.6 / -0.1	-2.1 / -1.1
		mdn	-1.0 / -0.1	-0.6 / -0.3	-0.6 / 0.0	-0.2 / 0.3	0.0 / 0.1	-0.6 / 0.0	-2.0 / 0.0
SP 2.3		p	.017	.039	.153	.056	.073	.055	.489
#1 < #4		avg	-0.5 / 0.3	-0.6 / 0.2	-0.4 / 0.2	-0.1 / 0.6	-0.1 / 0.3	-0.4 / 0.4	-1.3 / -0.7
		mdn	-0.8 / 0.1	-0.6 / 0.1	-0.2 / 0.0	0.0 / 0.8	0.0 / 0.3	-0.4 / 0.4	-1.5 / -1.0
SP 3.1		p	.093	.555	.114	.049	.437	.205	.221
#3 < #5		avg	3.7 / 4.2	3.5 / 3.5	2.9 / 3.4	2.5 / 3.2	2.3 / 2.6	3.2 / 3.7	-.38 / .50
		mdn	3.6 / 4.5	3.8 / 3.4	3.0 / 3.3	2.6 / 3.1	2.2 / 2.3	3.3 / 3.5	.00 / .50
SP 3.2		p	.456	.210	.001	.020	.256	.149	.000
#5 < #3		avg	4.3 / 4.4	3.8 / 4.0	3.2 / 4.1	2.8 / 3.5	2.3 / 2.8	3.8 / 4.3	-.63 / 2.1
		mdn	4.4 / 4.6	3.8 / 4.0	3.3 / 4.2	2.3 / 3.4	2.0 / 2.9	4.0 / 4.3	.00 / 2.0
SP 4.1		p	.993	.017*	.888	.326	.786	.787	.717
#3 < #5		avg	3.7 / 3.7	3.6 / 3.1	2.9 / 3.0	2.5 / 2.7	2.2 / 2.3	3.2 / 3.2	-.50 / -.44
		mdn	3.4 / 3.6	3.7 / 3.1	3.0 / 3.0	2.6 / 2.8	2.0 / 2.2	3.3 / 3.2	-1.0 / .00
SP 4.2		p	.759	.029*	.077	.595	.816	.365	.138
#3 < #5		avg	3.9 / 3.9	3.7 / 3.3	3.3 / 3.0	2.8 / 2.7	2.4 / 2.3	3.6 / 3.4	.35 / -.50
		mdn	3.8 / 3.9	3.8 / 3.3	3.4 / 3.0	2.9 / 2.6	2.3 / 2.1	3.7 / 3.5	.50 / .00
SP 5.1		p	.352	.569	.191	.106	.978	.279	.554
#1 < #2		avg	4.3 / 4.4	3.6 / 3.7	3.7 / 4.0	3.3 / 3.8	3.0 / 3.0	3.7 / 3.8	.94 / 1.4
		mdn	4.3 / 4.4	3.6 / 3.7	3.8 / 4.1	3.3 / 3.7	2.9 / 3.1	3.7 / 4.0	2.0 / 1.0
SP 5.2		p	.094	.091	.744	.155	.416	.406	.329
#4 < #5		avg	3.8 / 4.3	3.3 / 3.8	3.3 / 3.2	3.1 / 2.8	2.6 / 2.3	3.5 / 3.8	.19 / -.63
		mdn	3.9 / 4.4	3.3 / 3.8	3.3 / 3.3	3.2 / 2.3	2.6 / 2.0	3.6 / 4.0	.00 / .00
SP 5.3		p	.282	.152	.011*	.004*	.171	.111	.091
#4 < #5		avg	3.5 / 3.1	3.1 / 2.8	3.2 / 2.6	3.0 / 2.2	2.4 / 1.9	3.3 / 2.8	-.50 / -1.4
		mdn	3.6 / 2.8	3.1 / 2.9	3.3 / 2.7	2.9 / 2.0	2.2 / 2.0	3.3 / 2.7	-.50 / -1.0

enforced team play distributed setting, but only on the OIS scale. As was expected in Hypothesis SP 3.2 and its measurement, we did find a significant difference in the reported values for the teammate during enforced distributed play between having a teammate distributed (#5, Mdn = 0.0) or colocated (#3, Mdn = 2.0), $U = 35$, $z = -3.56$, $p < \frac{0.05}{91}$). PMU was not significantly different (#5, , Mdn = 3.25, #3, Mdn = 4.17), $U = 44$, $z = -3.18$, $\frac{0.05}{91} < p < 0.001$), nor was PAU (#5, Mdn = 2.33, #3, Mdn = 3.42), $U = 67$, $z = -2.31$, $\frac{0.05}{91} < p < 0.05$. All (trends) were in the direction of decrease of OIS/PMU/PAU for the connected distributed teammate (#5) compared to a connected colocated teammate(#3).

None of the social presence constructs or the IOS scale indicate a difference for the two versions of the game. For Hypothesis 5.2, no significant differences are seen for teammates in the distributed teams conditions comparing *connected* (#4) and *individual* paddles (#5), (7x n=16, $p > 0.05$). Furthermore, no effect is seen for teammates regarding Hypothesis 5.1, if we compare the colocated version (#1 and #2), (7x n=16, $p > 0.05$). Regarding Hypothesis 5.3 and its measurement, although not significant, as opposed to our expectations there were even indications that aspects of social presence (PAU/PMU) of the remote opponent might even increase with individual paddles (#4) instead of connected paddles (#5). PMU did not differ significantly (#4, Mdn = 3.33 vs #5, Mdn = 2.67), $U = 61.5$, $z = -2.52$, $\frac{0.05}{91} < p < 0.05$. Nor did PAU differ significantly (#4, Mdn = 2.92 vs #5, Mdn=2.00), $U = 53.5$, $z = -2.82$, $\frac{0.05}{91} < p < 0.01$).

4

4.3.3.3 Coordination Between Players

One measure for coordination between people is their correlation in movement[1] [208]. For our exploratory study we see speed as an appropriate measure for movement. If over the game both players have similar speeds at the same moments in time (e.g. both have high speeds or both have low speeds), we see this as form of coordination. If players are coordinating their play-behavior more, we should be able to see an increase in correlation between player speeds.

Implementation of Coordination Measurement with Players' Speed To investigate this form of coordination we filtered and transformed the position data. Using Matlab 2012a we did this as follows [2]. Our tracker provided 'lines' of raw position data with a time stamp ($t(i)$), id, and x,y positions. The interval with which the tracker provides information is not constant (varying around 12.5 to 28 fps). For every first time stamp ($t(0) = ts_0$) we encountered, we looked for position data within a time slot of 50 ms ($\pm\ ^1/_{fps}$) or less (($t(i) \leq (ts_0 + 50)$)), and saved all available position data for all players. When more than one position is given for a player ID within this time slot we only used its latest value. We continued until position data with a time stamp outside this time slot was found ($t_i \geq (ts_j + 50), \rightarrow ts_{j+1} = t(i)$).

We then interpolated the empty slots for each player with the x and y positions that were available. For values that had many consecutive missing values ($\geq$ 10, $\geq$ 500 ms) we kept the slots empty instead. We then calculated the speeds between slots and used a median filter (5 values, $\geq$ 250 ms) to filter out noise/outliers. We averaged the existing values over a period of 10 slots ($\geq$ 500 ms). We put a threshold on these values to a realistic maximum value of 11.61 km/h (top 0.05%), in order to minimize impact of extreme values for which Pearson's r is sensitive. We then correlated these average speeds between players.

Correlations The correlations of teammates can be seen in Table 4.2. If teammates correlate their movement most, this allows one to attempt to automatically recognize teams using the optimal scores of correlations between player combinations from the correlations matrices. This optimum correlation combination resulted in 19 out of 20 proper combinations, including most individual paddle games as well with only one mismatch in the colocated version #1, where the baseline would be 7 accurate combinations.

Feeling slightly more confident in the applicability of the used correlations, we investigated our three expectations regarding coordination with the explained method. We expected 1) correlation values in *#1 > #2*, 2) correlation values in *#3 > #5*, 3)

[1] Ramseyer and Tschacher also incorporated Pearson's r as a core part in their automatic measurement of synchrony[208]. They used temporal correlations and nifty corrections for random correlations. For our study we will keep to correlating (windowed) average concurrent speeds over entire sessions.

[2] MATLAB Release 2012a, The MathWorks, Inc., Natick, Massachusetts, United States

Table 4.2: Pearson's correlations (r) of teammates in the different configurations. L1 or L2 labels Location 1 or 2. Each session (s#) has two teams shown left and right in the table. * *Not the optimal combination, r optimal non-team: .10 and .20.*

	condition									
	#1 co.$_{ind.}$		#2 co.$_{con.}$		#3 dis.-opp.$_{con.}$		#4 dis.-team$_{ind.}$		#5 dis.-team$_{con.}$	
	r_{L1L1}	r_{L1L1}	r_{L1L1}	r_{L1L1}	r_{L1L1}	r_{L2L2}	r_{L1L2}	r_{L1L2}	r_{L1L2}	r_{L1L2}
s1	.15	.15	.57	.49	.45	.52	0.16	0.07	0.31	0.17
s2	.14	.15	.40	.45	.34	.56	0.11	0.24	0.38	0.33
s3	.13*	.10*	.48	.47	.44	.47	0.18	0.07	0.32	0.16
s4	.11	.13	.6	.43	.49	.30	0.10	0.12	0.30	0.33
avg.	.14		.47		.45		.13		.28	

4

correlation values in *#5 > #4* but due to the exploratory state of the research we also tested for differences in the other direction using two-tailed test. Pearson's r is known to have a non-normal distribution and a Fisher z-transformation can be applied to transform towards a normal distribution [70]. Knowing the known non-normal distribution of Pearson's r we simply performed the more well known non-parametric two-sided Wilcoxon rank-sum test, all with $n_1 = n_2 = 8$.

In the colocated game, the speed of players shows a significantly different Pearson's r correlation between teammates when their paddles are connected (#2 Mdn = .47) compared to individual paddles (#1 Mdn = .14), $W_r = 36$, $z = -3.36$, $p < 0.001$.
This difference is in the expected direction of higher coordination in movement of teammates if teammates are *connected*, when they are playing a colocated game, $\#2 > \#1$.

With connected paddles the Pearson's r correlation of the the used speed values significantly changes between teammates being colocated (#3 Mdn = 0.46) or teammates being distributed (#5 Mdn = .31), $W_r = 42$, $z = -2.73$, $p < 0.01$.
This difference is in the expected direction of an increase in coordination of teammates if they are *colocated*, when they are playing distributed play where they are connected to their teammate, $\#3 > \#5$.

In this distributed playground with distributed teams the Pearson's r correlation of the used speed values significantly changes between teammates when they are connected (#5 Mdn = .31) instead of having an individual paddle (#4 Mdn = .12), $W_r = 41$, $z = -2.84$, $p < 0.01$. This difference is in the expected direction of an increase in coordination in movement of teammates if the teammates are *connected*, when they are playing with a distributed teammate, $\#5 > \#4$.

4.4 Discussion

4.4.1 Coordination Between Players

The method of correlation that we used seems usable to investigate the difference between distribution and enforcing team work. Our results suggest that forcing people to work together, to control/share an element together, increases a form of coordination. It would be interesting to investigate whether these results would generalize to other games. It is important to realize that the FPS and the recognition quality seemed to differ between locations. As the temporal character, linear interpolation and linear correlation are intertwined in this (new) analysis: results should be considered carefully. The colocated version did not suffer from the location dependent problems and still showed similar tendencies, larger correlation between teammates and especially larger when they were enforced.

4.4.2 Social Presence Related Measures

Regarding the analysis of social presence it seems we set out too broad an investigation. It seems that enforcing team work does not fully mitigate effects of distributing players, it does not even lead to an increase in social presence in a colocated version. The suggested distribution of the teammates might not result in measurably higher levels of perceived social presence, when compared to distributing the opponents only, at least with our currently used between subjects approach. There might be some positive shift for some constructs but this would need further investigation in a more dedicated study. In general it would be worthwhile in the future to look with more focused attention at aspects of interactive distributed play and other factors that do influence social presence.

One shortcoming of the study is that we did not yet look at personal differences which could also influence the results. It could be expected that age, gender, or the level of familiarity changed between groups. Further investigation using statistical models that partially account for this could be applied. On the one hand, this could also turn into fishing and cherry picking results of such a questionnaire. On the other hand, our current approach does show the shortcomings of having many hypotheses in an exploratory state of research but could still trigger future investigations into specific aspects.

Probably only some constructs from the questionnaire are of real interest to investigate such aspects, either because some constructs are not sensitive enough to measure perceived changes or there are only limited changes due to distribution for them. For instance, none of the comparisons found a trend of change for Perceived Emotional Interdependence (PEI). Nonetheless, looking at the results it does suggest we might be able to measure a trend towards a decrease in some social presence constructs once teammates get distributed, suggesting it is worthwhile to investigate these effects and possible ways to mitigate this decrease further.

4.4.3 Types of Play

Although this was not in our original plans we also had a first informal look at how players played the game, to this end we plotted the positions of the players on the field for each game. The different teams played the game with different strategies, this can be seen in Figure 4.8. Some players both played towards the middle line, others used the seemingly optimal strategy of moving less and staying close to the goal, some split sides, and yet others split in front and back. The results of this analysis also seem to fit the suggested increase of coordination if we were to look at enforcing teamwork in distributed teams, comparing the similar position patterns in the last images: positions during #4 compared to #5 and, slightly less clearly #1 to #2. We could not distinguish other differences between conditions in strategies. During one game from which we knew one participant had an autistic disorder, in our direct observations we noticed he would walk straight through (the movement path) of his distributed team member. This was seen less during other games, however,

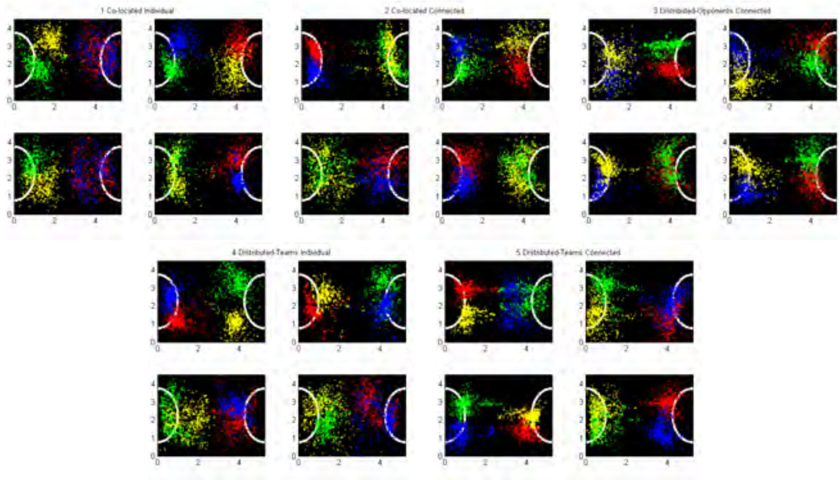


Figure 4.8: Representation of the positions of the players in the different configurations, grouped per configuration in respective order from left to right, top to bottom. For the distributed game #3, #4, and #5 the blue and yellow player are at a different location.

this behavior was not clearly visible when we plotted all the positions afterwards. It would be interesting future work to see if such social habits or lack thereof could be detected during play in such a playground.

4.4.4 Enjoying Future Versions of Distributed Team Play

The game was enjoyed by many players, therefore it seems that distributed team play could bring enjoyable interactions. We think the colocated aspect in combination with distribution and the novelty of such a system were important reasons for this.

The enforced teamwork did change the interactions and steering such behavior in wanted directions seems to be a fruitful approach. The game itself could be improved, as suggested by some players, to trigger other more risky types of game play and providing a richer game play. For instance, adding a ball that speeds up, or restricting the time that a player can be near to the goal. We also found the idea of doing a Turing test with distributed interactive exertion games very interesting. Perhaps, future distributed exertion games could even become a combination of colocated players, distributed players, and computer players.

4.5 Conclusion

We reported on what to our knowledge is the first distributed embodied game with a focus on teams with colocated and distributed play at the same time, the Distributed Interactive Pong Playground (DIPP). We investigated whether we could increase coordination, measured as correlation between speed of players, by more strictly enforcing teamwork in the game. This was done by letting both players control one end of a shared paddle (the main game object), as opposed to both players having separate paddles. Although the results should be taken with care, the comparisons strongly indicate that we could steer coordination between players in this way. A simple metric was sensitive enough to show this. Furthermore, we investigated the effect of distributed team play on the level of coordination. The results indicate that coordination goes down if the team mate is at another location. In this distributed team setting, enforced teamwork through a connected paddle still leads to a higher level of measured coordination. In contrast, our current analysis of self-reported social presence did not show a clear difference for either enforced team work or team distribution. More focused research is needed to make any conclusions regarding the social presence, as some trends and some effects were found for constructs related to social presence. Nonetheless, the combination of distributed and colocated games seems to be an interesting new avenue for distributed embodied play.

5

Steering Player Interactions in the ITP

You know, I think you are wrong.
Bond: I am?
We always have a choice.
– Dr. Swann, Spectre (2015)

This chapter deals with different examples of steering players' interactions in the Interactive Tag Playground (ITP). Steering refers in this sense to the deliberate design of an intervention to encourage particular in-game physical behaviors. The ITP augments the game of tag using the Interactive Playground Platform described in Chapter 3. This chapter starts with our observations of play in school playgrounds, observations in our lab of non-instrumented play, and some of the fitting design choices for building the ITP. We then summarize a study regarding the increase in engagement in first time use of the ITP compared to a traditional game of tag [156].

Having shown that the ITP can lead to engaging play, we then present three modifications of the developed ITP that aim to steer the gameplay actions of the players in wanted directions. The modifications are intended to make good players easier to tag and less skilled players harder to tag; to influence who will be tagged next by the tagger; and to influence the locations visited by the players. We report on a user study showing that the first two of these three modifications have a significant effect on the behavior of players in the ITP, and discuss opportunities for future research that follow on from this study.

5.1 Creating the Interactive Tag Playground

Combining technology and the benefits of play can be used for important issues, as we mentioned in Chapter 2. One, this combination can address the obesity epidemic

This chapter is based on:
R. W. van Delden, A. M. Moreno, R. W. Poppe, D. Reidsma and D. K. J. Heylen "Steering gameplay behavior in the interactive tag playground" in *Proceedings of the European Conference on Ambient Intelligence (AmI 2014)*, pp. 145–157, 2014.

and the description of non-augmented tag, the ITP, and the study on engagement was presented in the theis of Alejandro Moreno [153] and is based on:
A. M. Moreno, R. W. van Delden, D. Reidsma, R. W. Poppe, and D. K. J. Heylen "Augmenting Playing Spaces to Enhance the Game Experience: A Tag Game Case Study" in *Entertainment Computing* 16, pp. 67–79,2016

Figure 5.1: The two playgrounds in the Netherlands used during the observations. The playground on the right coincidentally also included a small interactive playground, the Yalp Sona. Image taken from Google Street View and slightly edited for anonymization purposes.

as games can increase energy expenditure by stimulating exertion, for example, with exergames [245]. Two, this combination can address the need for social interactions, which becomes increasingly important as children seem to be interacting more and more via their interactive screens and less with the people surrounding them, or as Turkle suggests: being *alone together* [254]. The combination can address these social interactions by creating games that require human interactions, and by smart game design to especially stimulate human interaction of those people that are in general not interacting very much with others [89].

5.1.1 From Traditional Play to Augmented Playspaces

To become more informed about traditional play and which game we could augment, we observed several traditional play sessions of children, and report on this here.

5.1.1.1 Observing Traditional Play at Schools

In total we observed about ten hours of un-instrumented traditional play sessions. This was done with four sessions, at two primary schools in different parts of the Netherlands during play breaks, see Figure 5.1. We asked for permission to be present during breaks via school teachers: parents were informed via an information letter. Due to the sensitivity of such research we did not record any material and only used direct observations, followed by taking notes on a voice recorder directly after the break. Roughly 150 children were observed in total, approximately in the range of 4 to 13 years old (the range of primary school classes in the Netherlands), but with a focus on those of six and older.

Children played a range of different games and play activities, including: football, catch, jumping rope, tag, hide-and-seek, climbing playground equipment, throwing a ball around, tug-of-war, and skating (including riding a ripstik: a two-platform skateboard propelled by torsion of the platform, jump sticks, or a one wheel bike). Also some other less familiar games/activities were seen: collecting lady beetles, playing with the Yalp Sona (an interactive playground), fantasy play involving crossing the imaginary woods, and some newly created games were played. These new games included games focusing on stepping against a wall as high as possible, or throwing around a ball until it imaginarily 'explodes'.

Many different social behaviors were seen during these games that can be expected during children's play [157]: taking *leadership* (via rule and game invention), *rough-and-tumble* (often during games of tag/catch/football but also outside these games), *violence* (only sporadically e.g. stepping on lady beetles or pushing another person very roughly), *helping* (only sporadically between peers, for example helping around a girl with a sprained ankle), *performances* (children dancing, playing horse, cheering over-the-top when scoring a goal during football, or supporting players during jumping rope), *mimicking* (actions, rules, dances but also more unconscious non-verbal gestures nodding their heads etc.), *cooperation* (throwing a ball around), *competition* (football or jumping rope), and *other social behavior* (having discussions while hanging around the playground).

Football seemed to be played by most children during the observed breaks. Playing the game of catch was also popular, as was jumping rope and sometimes the game of tag. It was interesting to see that most of the games were played with quite some intensity by most children. However, some children kept more to the sides and did not interact much with the other players. There were also occasions of boys teasing girls in a playful manner, groups teasing a girl or a boy, and even bullying and fighting; a boy hit a girl with his fist, the same girl later on tripped another child. It was interesting that several times the Yalp Sona was just used as a trigger for other games. Hitting the button during hide-and-seek when calling a name, or using the music from the game as a duration in their own non-interactive game.

One teacher present made clear that not all playgrounds at schools include climbing or other equipment that were seen at these two schools, which will influence the type of play. She also mentioned that at a certain bigger school playing soccer was forbidden, mainly because more children tended to play together at the same time at that school.

5.1.1.2 Observing ‘Instructed’ Play at the Lab

Based on the insights gained from observations at real schools, we had a closer look at three kinds of games: jumping rope, throwing a ball around, and playing tag. To this end we organized one play session where we instructed children (aged 8-12) to play several types of games in our lab, this only lasted a few hours, and we did it with two groups of children. Parents of the children were given an information letter and all parents of the participating children provided signed consent. During these sessions we had one researcher acting as referee, instructing players what kind of game they should play every few minutes. The referee also intervened when needed in order to keep the game going. In this study we did take video recordings, with four top-down depth sensors and three RGB camera’s. These were also used to create our *play corpus*. This corpus includes position data and manually annotated roles (tagger/runner) of children during uninstrumented tag sessions—also see Moreno’s work for other details regarding these recordings, annotation, and availability [153].

We had the children play several types of games of tag: normal, additive and freezing. *Normal tag*, is a game where the player that is *it* (the tagger) has to tag another player by touching him/her (the runner). Now that player becomes the *it* instead, and this game is generally continued until a child gives up. We also had a variation of normal tag with two, three, or four taggers from the start. In contrast, *additive tag*, is a game where taggers only keep on adding taggers instead of relieving themselves from their tag role, making the game end if all children have been tagged. *Freeze tag*, is a game where the runners when tagged have to stand still until another runner touches him/her. In total 12.5 minutes were recorded and analyzed, including nine different sessions, and 74 tags (avg. 10.14 sec) [153]. Between sessions a new tagger could be assigned or the game could be changed. Often (most minutes) the various tag games were played with 4 or 5 players, with a maximum of 8 players.

Jumping Rope We omitted the in-depth analysis of jumping rope as several of the invited children were not capable of jumping rope well enough, leading to really noisy data. The game does seem to have some game mechanics that are not really ideal. The people who are not good at it will also play for a shorter amount of time. Due to this shorter play time, one might expect the performance of those players as also less likely to catch up. Once children are out of the game they become spectators who are mainly showing sedentary behavior. Furthermore, as is the case for most games, the number of children that can play simultaneously is limited, in this case related to the size of the rope.

Throwing a Ball While children were throwing the ball we did not really notice clear indications for improving the activity. Some children were clearly worse at throwing and catching than others, and to keep things interesting we awarded points during the game with a doubling bonus at the end. This did seem to have an effect on their efforts. However, we decided to proceed our efforts towards the ambient intelligence / 'easy stepping in and easy stepping out' kind of play solutions [243], which does not go well with providing equipment.

The Game of Tag We started and stopped the sessions, let players in and out, in order to generate a realistic and insightful corpus, see Moreno [153]. Based on our experiences and discussions of the observed sessions, the game of tag was chosen as a prime candidate for augmentation. It allowed a simple easy-in-easy-out kind of play and was liked by most children. The game leads to exertion but also has lots of social interactions. Nonetheless, the game mechanics in tag still provide room for improvement [276]. Next, we will provide a more in detail description of these observations .

5.1.2 How to Augment the Tag Game?

During our observations we had seen several issues and behavior that needed to be addressed or at least kept in mind in the augmentation of the tag game. We will describe these first, without addressing them directly with a technological solution.

5.1.2.1 Player Behavior

The players were highly active during all the game sessions. Many players really exerted themselves when running to tag other players, or to run away from them. Besides running, players also slid across the floor, jumped, ducked, or pushed other players around in an attempt to prevent being tagged. We never saw children walking or losing interest in the game due to exhaustion, but this could be because we allowed them to rest by bringing other children into the game while they waited just outside of the playing area.

We also saw players interact with each other often and in many different ways. The most common one was verbal communication, for instance, to ask who the tagger was or to jest about the game. Nonetheless, players also taunted each other, or tried to get revenge when tagged. Some players also exhibited acts of deception. These players pretended not to be taggers, to make it easy to tag other players, or simply because they wanted to stay runners.

Lastly, players had a lot of fun during the game. They looked happy and engaged throughout most of the sessions, with a couple of exceptions due to some players not being very good at tag. A lot of yells and laughter could be heard during the sessions. Also, some actions unrelated to the game could be witnessed, such as players dancing or pretending to swim on the floor.

5.1.2.2 Tag Game Shortcomings and Breakdowns of Play

Due to tag game's nature as a playground game, there are several events that can disrupt the flow of the game, or outright cause the game to end before players meant to stop playing. We call such an occasion *breakdown of play*. We saw several of these during the recording of the *play corpus*, the most common one being losing track of who the tagger was. When the game started, it was fairly easy for everyone to identify who the tagger was. However, as the game progressed, children started running with their backs to other players, which resulted in them being unable to identify who the tagger was afterwards. This was especially evident in sessions where the number of players was high (6-8 players). This led to players pretending not to be the tagger, walking close to someone, and then tagging them. Sometimes, players cheated saying they had not been tagged. If confusion continued, the game would sometimes just end.

Another problem that led to play breaking down was the difference in abilities between some players. We noticed that certain players were quite slow in comparison to other players, and thus had difficulty tagging them. Initially, they would try it earnestly, but after several unsuccessful attempts, they would slow down and eventually give up. This is understandable as frustration builds up from not being able to tag others. Importantly, this affects not only the tagger, but also the runners that are not being challenged. They would also start to slow down and eventually taunt the tagger to attempt to restore the player's interest in the game. This sometimes helped temporarily, but after some unsuccessful attempts apathy kicked in again. In several cases, the referee had to assign a new tagger or recruit an additional tagger from the pool of players.

5.1.2.3 Fun and Engagement

Based on the insights gained from analyzing player behavior in the *play corpus*, we identified several points to address in our interactive tag game installation implementation. We detail these below, where we occasionally link back to our observations.

The main objective of an entertainment installation is to provide an engaging and fun experience. One way of keeping the players engaged and interested is by enhancing the original game of tag by adding visually attractive game elements that introduce variety to the game. We like to employ methods that allow players the freedom to behave as they would normally. Following this, the use of projections is a good approach, as additional information can be displayed onto the playing area without disrupting play. Ambient speakers or LED screens (on the floor) would also have worked for this.

Another way to maintain player engagement is by adapting game mechanics, a specific example of this is skill-balancing, which would be very useful in tag games as big disparities in skills led to the breakdown of play. If such disparities in skills are left unchecked, players can become annoyed or irritated.

In this regard, the playground should aim to minimize the chances of play breaking down, as it can detract from the overall game experience and reduces physical activity during the game[1]. Besides skill disparities, other common causes for the breakdown of play were players being confused about who the tagger was, or people pretending to not have been tagged. The system should, at the very least, try to prevent these things from happening. This could be achieved by mediating the interactions between players and the game, by providing their current status in the game with visuals.

5.1.2.4 Unobtrusive and Autonomous Functioning

If players cannot play as they want, this would inevitably lead to a) diminished levels of engagement and b) unnatural behavior. Using cameras to sense player behavior seems like a valid solution, as they can be used to measure behavior while giving players the opportunity to play 'without' restrictions. Of course, the cameras should be placed in such a way that they are not in the way of the players.

Moreover, since the game of tag supports the concept of players joining and leaving the game as they wish, our playground should also support this easy-in, easy-out style of play [243]. This means that the playground should be able to locate and track players that walk into the playing area and add them to the game immediately. On the other hand, as soon as they walk out, the system should remove them from play without causing any disruption for the remaining players. Finally, we want the playground to be able to run autonomously in public spaces, therefore we should not rely on wearable devices to gather player data as they need to be handed out and retrieved.

5.1.2.5 Physically Active, Social Behavior

Tag games are especially effective at encouraging players to exert themselves by making running and chasing the key game mechanics. To be able to retain this characteristic, players should be allowed to run freely inside our interactive playground.

Players also exhibit a wide array of social behaviors during tag games, such as talking, joking, taunting, performances, and so on. As such, our installation should also support—or at least not hinder—these types of social behavior. This means players should be capable of communicating verbally and physically while playing.

5.1.3 Design of The Interactive Tag Playground

We developed the ITP based on these insights and building on some of the insights shared in the literature on game design and interactive play [61, 196, 226, 232]. This interactive tag game for our playground also makes use of the IPP introduced in Chapter 3. The ITP has been designed to retain the essence of a game of tag, while novel elements can be easily introduced to improve the game experience. Variations of this game are used in this Chapter and Chapter 6, and some of the differences between implementations are described in the text below.

[1] We do realize that learning to deal with such issues is also an important aspect of childhood play.

Figure 5.2: The ITP situated in the art gallery. Each player has a circle showing their status in the game. The previous tagger (semi-transparent blue circle) has just tagged another player (orange circle).

5.1.3.1 The Game with Clear States

We chose to augment the normal tag game with only one tagger, as this game was least chaotic and simple to understand, in short: this variation of tag worked best during the observed sessions. Each player that walks into the playing area gets a circle projected around him/her. The assigned tagger gets an orange circle and the three runners get a blue circle, see Figure 5.2. In our first version we used bright red but this was harder for some colorblind players to distinguish from blue. Instead of physically touching other players to tag them, the tagger has to get his/her circle to overlap with a runner's circle. We use an appropriate size of the circles, so people have to be close but do not need to touch each other. When the tag happens, the color of both circles switch to indicate that the roles have changed. A kick-drum sound is also played to indicate this event. If a player is tagged, he is not allowed to tag the previous tagger back for two seconds, enforcing a cool-down period. To make this clear to the players we used transparency, so the players still know they are being tracked and know when someone cannot be tagged. In the second version (Chapter 6) we eventually used a slightly shorter cool-down period of 1.5 seconds and a clearer transparency visualization. The cool-down period encourages players to look for other players to tag, and not make it a two player game.

When the game begins, a tagger is chosen randomly from the detected players. If a tagger leaves the playing area, the system also randomly chooses one of the remaining players as the new tagger. With such behavior, the installation is *de facto*

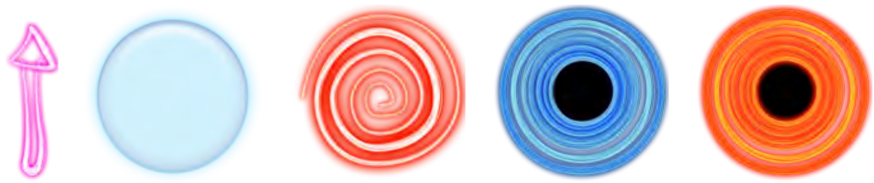


Figure 5.3: Visualization of some game elements used in the ITP: an arrow, a shield, a spiral/mini-me helper, and the circles projected around the runner and tagger.

a referee, capable of enforcing rules to prevent disagreements between players. In the second version we added a bright green border around the field to encourage players to stay within the playing field, which was needed as there were no physical boundaries constraining that field.

Once a player enters or when the game starts, the circles move towards the players in order to show them that this circle will follow them, or is theirs. The circles also leave bright trails behind the players when they move. We do this to make it clearer for the players that their movement was correctly tracked and that their movement has an impact, and to indicate where their circle is located, even if it is partially occluded by a player's body.

5.1.3.2 Look and Feel

The look and feel of the playground is inspired by what we describe as futuristic graphics that are present in some space shooters, we were inspired by some of these examples and decided to use overly bright effects (Bloom) and neon colors, see Figure 5.3. These gave the ITP a contemporary look and fit the projection onto a dark floor well. The ITP thus displays neon-colors such as orange and blue circles beneath the players to indicate each player's role.

5.1.3.3 Interpolating Circle Movement

The movement with which the circles follow players in the game also uses a linear interpolation method. This is done to deal with some lag that occurs; it prevents jumps in movement, deals with jitter and smooths the movement, making the circle follow a player, as if it is on a short leash. The interpolation did have an effect on how the game is played as it makes control somewhat indirect and more challenging to tag someone. The lag happens slightly more in the first version due to the use of the TCP protocol for nodeJS in combination with Windows 7 OS. Based on some informal testing we decided on a compromise in the interpolation between the delay in movement and the required smoothness. The second setup uses a UDP protocol when communicating between computers that noticeably reduced the lag. Nonetheless, both versions use the interpolation method.

5.1.3.4 Pulsating Circles

The circles also pulsate slightly, in an attempt to give a more life-like feeling to the game. They constantly become a little bigger and smaller, all having a slight offset in timing. This happens even if the players are not yet doing anything other than just standing in the playground. For some use cases this will help to attract attention to the playing field if no players are yet playing the game, possibly inviting players to interact with it [61].

5.2 Evaluating Engagement on the ITP

One of the aspects that needed to be tested for the designed ITP, was whether the augmented game was any fun and whether players still showed social interactions, such as small theatric performances. To this end we did two sets of tests, one with groups of students and one with groups of children. Each group of four player both played the traditional and the augmented game of tag. We will briefly summarize the results here, for more in-depth information we refer to [156].

5.2.1 Study and Participants

The first study was done with adults, the second study with children aged 9-12. The adults were recruited at the university and played both games for 3 minutes: we changed orders between groups. After playing the game they filled in a revised version of the GEQR questionnaire [27], with a 7-point Likert scale, which was intended to measure constructs of game-engagement. The players also participated in a short group discussion about the game. In total 29 adult players participated, divided over 7 sessions, one with five instead of four players. The adults played with a version of the ITP in which the game automatically changed the size of the circles depending on how long someone was the tagger, which balanced the game based on performance. This aspect of the game will be evaluated in another way at the end of this chapter.

The children were recruited for a field trip day from two nearby schools, each with two different classes[1]. They played the game of tag for 90 seconds. This was because the entire group was only available for a few hours. This shorter game time allowed us to have more players play the game in these hours while still providing a complete game experience to the players. The children only participated in a discussion, asking them what they liked/disliked, and whether they would like to play again (yes/no/maybe). This latter was a quick method based on the 'Again-Again' table that has been used to evaluate perceived fun reasonably well for this target group [211]. In total 76 children were included in the study, divided over 19 sessions.

5.2.2 Results on Playing Augmented and Traditional Tag

Overall in terms of our questionnaire dimensions the adult players enjoyed the game more than the traditional game (avg. = 5.37, formulated as 'more than normal tag'), were more immersed (avg. = 4.93), and players liked the game elements (avg. 5.31) although the sound that was played when someone was tagged was not clear enough for all players. With respect to gameplay the questionnaire in combination with the discussion seemed to indicated that a lag between movement of players and their circle's movement had a negative effect. Nonetheless, on average players leaned towards enjoying gameplay of the augmented version (avg. = 4.96, without 2 questions regarding delay avg. 5.82). During the games we saw an abundance of social interactions, the players were making jokes, doing small performances, and yelling at each

[1] Similar to all our research (with children) these studies took into account several ethical consideration (being able to stop at any point, asking for participation etc.), and the studies were approved by the University of Twente EEMCS department's Ethical Committee.

other. Players indicated that the game was quite exhausting and this was also clearly visible during the games.

In general, children were very positive towards the interactive tag game. Out of 76 children, 75 indicated that they would have liked to play interactive tag again. Their responses were also immediate, with a lot of them eager to play again, even begging to be allowed to play once more. The children were hesitant when asked whether they would like to play traditional tag again, with only 38 saying yes, 22 maybe, and 16 no. There was only one boy that indicated he liked the traditional tag game more than the interactive one. A lot of children indicated interesting reasons during the interviews about why they thought interactive tag was better than traditional tag, without us mentioning those game aspects. Those aspects included the game being digital, being harder / more challenging, not requiring to touch each other (which could result in tripping, discussion and fights, according to some children), being novel, and making clear who the tagger is at all times.

This accompanied with our observations of both children and the adults showing several forms of social interactions (shouting to each other and doing performances), showed us that we could be satisfied and proceed with this implementation of the game of tag.

5.3 Steering Behavior in the ITP

The ITP seems to be a successfully augmented version of tag. Augmenting an engaging game can also give ample opportunities to use the technology to change game play in wanted directions. With the introduction of technology we can start to steer the physical behavior of players, which in turn can impact the experience. Digital and mixed reality games allow for interventions in the game state, game difficulty, or game behavior. Personalized adaptation of the interventions allows people with different skills to play together, increasing fairness and engagement in a fun and challenging experience [30, 64].

Playing tag can be fun and exhausting, and entails a lot of physical as well as social activity. In our playground we find that player behavior in the game of tag is very well defined according to players' roles [154]. During our first observations of non-instrumented tag, we had also observed people getting bored and disengaged. This happened for example because they were less skilled and therefore had to be tagger for prolonged periods of time, or because they were running from a tagger who was not skilled enough, offering too little challenge. In the ITP we try to implement subtle interventions that can steer player behavior into different patterns while keeping the engagement high and the game experience intact. If selected well, such interventions could help balance the game, re-engage players that are less involved, get players to move more and to interact more socially [155].

For this study we focused on steering specific gameplay actions of players through three modifications of the game. We explored whether it is possible to (1) balance the time that each player is a tagger by changing the size of each player's circle based on the time they have been a tagger so far, (2) get players to move around to specific locations on the playing field by placing power-ups that can be picked up, and (3) directly steer the tagger's choice of whom to chase next by pointing an arrow to one runner. In the long run, with automatic measurements and interpretations of player behavior we could deploy such interactive elements in our ambient play environment

Figure 5.4: Visualization (left) of the arrows and (right) the adaptive circles.

at the right moment, to steer player behavior in desired directions.

5.3.1 Steering Behavior through Gameplay Elements

In order to test the effectiveness of the three modifications introduced to the ITP, we performed a user study with eight groups of four participants playing four different versions of the tag game. Three versions constituted the three modifications (adaptive circle size, power-ups in the playing field, and arrows pointing at one runner); the fourth version was the standard ITP tag game without modifications, used as a baseline for assessing player behavior. We tried to influence gameplay in three ways: adaptive circle sizes in order to change the amount of time someone is a tagger, power-ups to make players move more to certain positions, and the use of arrows to suggest someone to be tagged. We used the automatic measurements of positions from the tracker and the roles logged by the ITP, to investigate whether the player behavior changed in the expected ways. In our study we looked at whether our implementation was successful in achieving the targeted changes. First we explain the three elements in further detail below.

5.3.1.1 Adaptive Circles

The adaptive circles are used to balance out the time players have the tagger role. This is achieved by adjusting the size of the circles of both taggers and runners. By making a tagger's circle bigger, it becomes easier for him to tag others. The size of the circle of all players is adjusted solely based on the time they have been taggers. When a player has been a tagger for more than the average amount of time, $\frac{gameTime}{\#players}$, then (a) when he is a tagger, his circle grows and (b) when he is a runner, his circle shrinks. The rationale behind this is that players that have been taggers for prolonged periods of time are either having difficulties tagging others, or are bad in avoiding being tagged. This adaptation makes it easier for them to tag other players, and harder for other players to tag them. On the other hand, when a player's tag time is below the average, then (a) when he is a tagger, his circle shrinks and (b) when he is a runner, his circle grows. This is the opposite case as before, where we want to make it harder for this player to tag others, and make it easier for others to tag him.

The formula for the circle adaptation is applied to every player in each frame, and is defined as:

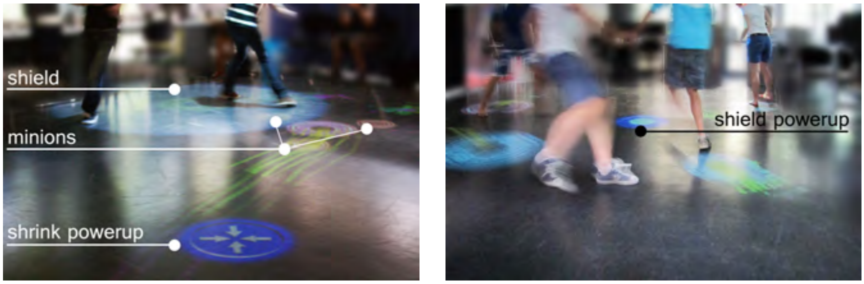


Figure 5.5: Visualizations (left) of the *shrink* power-up and, the *minions* and the *shield* in use and (right) someone trying to collect a *shield* power-up

$$addedSize = prevAddedSize + \left(\frac{timeBeingATagger}{gameTime} - \frac{1}{players}\right) * K \qquad (5.1)$$

where K is a constant that was empirically set to suit a 2 minute game, and the *prevAddedSize* variable is the size of the circle in the previous frame. To prevent the circles from getting too big or too small, predefined values where set to limit the maximum and minimum sizes. When a player switches roles, there is a small time window in which their circles quickly reset to their normal size before starting to shrink or grow. As explained in the design of the ITP the circles also pulsate slightly in all versions, this should make it slightly less noticeable at what point the circles grow or shrink. This is done in a separate formula that basically changes the *prevAddedSize*.

We expected that the adaptive size would lead to a more balanced game in terms of the duration each player is a tagger. The differences between the duration of people being a tagger during one session should thus go down in the adaptive version of the game. Therefore, for the adaptive circle condition we hypothesized:

Hypothesis 1 *The variation, per group, in the duration of each player being a tagger, is lower for the adaptive game than for the standard game.*

5.3.1.2 Power-Ups

With power-ups we try to influence which locations the players visit during the game, steering players towards specific locations in the playing field. In previous work we had seen that runners often move near the border of the playground and the taggers move near the center. In our ITP we distributed power-ups outside these standard positions, power-ups for runners are in the center, and power-ups for the taggers are at the edges of the playground, see Figure 5.8. Power-ups were intended for either the tagger or the runner, the power-ups for the runners cannot be gathered by taggers and vice versa. This way, it should be possible to steer players away from their normal playing strategy with respect to locations visited.

We implemented four types of power-ups. For the tagger there is a *grow* power-up and a *minions* power-up. The grow power-up increases the player's circle size. The minions power-up adds three small balls that rotate around the players' circle that can be used to tag someone with as well. For the runners there is a *shrink* power-up and a *shield* power-up. The shrink power-up reduces the size of the circle. The shield power-up will create a 'force field' around the player, that slows down the speed with which the circles follow the real world location of the players in that force field. Both make it harder to get tagged. Both the runners and the taggers can pick one power-up that directly influences their size, and one power-up that influences an area outside their circles.

All power-ups that are collected last for 25 seconds. Upon collection, the collectable power-up disappears; every 10 seconds a new one appears that can be gathered. When a power-up is collected an accompanying sound is played. For the sake of experimental control, there are 8 positions at which the power-ups appear. Four around the center for the runners and four spread around the sides of the playground for the taggers, see Figure 5.8.

We expected that people would gather the power-ups and be in those (unusual) locations more often than in the normal condition. We therefore hypothesized:

Hypothesis 2a *Locations visited by the runners change structurally in the power-ups game, runners will be near the middle of the playing field more often.*

Hypothesis 2b *Locations visited by the taggers change structurally in the power-ups game, taggers will be near the edges of the playing field more often.*

5.3.1.3 Arrows

In playing tag one of the main choices to be made is who to tag. In the 'arrow' version of the game, we try to influence that choice. To this end we use arrows pointing towards a random player, see Figure 5.4. Every time a player is tagged the arrows will then point to another random player. The only difference when someone with the arrow is tagged instead of someone else, is a slight change in the sound that is played. No further restrictions or changes follow from the assignment of the arrow.

We expected that these arrows would influence the decision of the tagger on whom to tag. This should lead to runners being tagged more often when they have an arrow pointing at them. Therefore, for the arrow condition we hypothesized:

Hypothesis 3 *A person with an arrow pointing at him/her is tagged more often.*

5.4 User Study of Steering Behavior in the ITP

With the ITP we investigated the effects of the previously described elements. We used a within-subject design: for each modified version of the game, we compared the measurements from players playing that version to the measurements from the same players playing the standard game as baseline.

5.4.1 Participants

In total 32 participants participated (27 male, 5 female), divided in eight groups of four participants playing the four versions of the game. Participants were mostly university students aged between 18-30 years. Some of the participants had participated in a previous user study regarding the engagement of the adaptive circle version of the ITP.

5.4.2 Procedure

Participants were asked to read and sign an informed consent form. The consent form also contained the explanation of the game, including a description of the power-ups. It also explained that four different types of versions of the ITP would be played, one with arrows, one with power-ups, and two with just circles. We briefly explained the game and procedure of the user test. Each version was played for two minutes resulting in eight minutes of play in total. The order in which the games were played was semi-randomized. In each game the first player recognized by the tracking system was selected as the tagger. Players were given time to rest between each game session. Once they all agreed they were ready, the next session was started.

During the game two of our researchers were sitting directly outside the playground to start the game, observe the gameplay, check the tracker, and when necessary respond to questions about the playground.

After all the games were finished there was time for a group discussion of about 5 minutes. We asked questions such as *'With a few keywords, how would you describe the experience of the playground?', 'Which different versions did you recognize, in which order, and how do you think these versions work?', 'Which version did you like most?'* The entire session including filling in the consent form and discussion took around 30 minutes.

5.5 Results and Discussion

Before presenting the results for the three hypotheses, we will first present some qualitative observations, and findings from the group discussions. We will then look into the quantitative results of the three targeted effects for each intervention separately. We will also discuss the implications of the results per element, taking into account the observations and findings from the discussions where relevant.

5.5.1 Group Discussion and Observations

Concerning the technical setup, there was a noticeable lag between the movements of the players and their circles following their movement, due to tracking and communication delays. In later versions of the ITP, used for the study in Chapter 6 we reduced this lag by switching to a UDP protocol that had no stacking problems. When we asked the players about the lag, some found it irritating but most thought it made the game more interesting. You had to incorporate a different strategy, predicting the movement of the players, their circles and then trying to cut them off. As one group put it *'Is it a bug or a feature? [..] At the start it is frustrating, later on it became a part of the game'*. As for the tracking accuracy, in most locations players could stand shoulder to shoulder and still be recognized correctly by the system. Nonetheless, during some games players were switched when they were close to each other and made quick turns. On some other occasions, the tagger was reassigned to another player when a tagger was not recognized for some time by the tracker. We observed around 10 of these glitches over all sessions, Moreno et al. regarding this tracker later on found that this would happen about every 45s [156]. This led to discussion in the group and laughter as well as frustration. For a more thorough description and test on the performance of the tracker see [153].

When we asked players which game they liked most, 71% preferred the one with power-ups[1], 21% liked the one with adaptive circles, and 8% the normal one. We also asked players to state some keywords describing the playground. Recurring responses were: '*sweaty, hot, tiring, exhausting, good exercise, interesting, cool, fun*, and *innovative*'. This shows that players were having physical exercise and that they also enjoyed the other versions. Another clear sign of the energy expenditure was the visible sweat, red faces, and the heavy breathing. Overall players were extremely positive about the mix of physical activity and technological enhancement.

5.5.1.1 Observations regarding the adaptive circles

Certain players tried to make their circles grow with their movements. For instance, one tried to make a gesture with his hands, and another tried to stand still. Most players recognized that the circles were growing or shrinking. However, most players thought it was related to the speed of running. Most of the people preferring the adaptive circles were from a group with an injured and a less skilled tagger in their midst, represented as session 8 in Table 5.1.

5.5.1.2 Observations regarding the power-ups

We heard and saw players exploring the effects of the power-ups, they were engaged in this exploration and discussed their findings with others. Therefore, we now think that by occasionally adding new kinds of power-ups over time, we might regain engagement of players that were less involved and increase social interaction. During the games there were at least two players intentionally hiding the power-up from the tagger by standing on top of it, making it almost invisible as their circle covered the power-up.

5.5.1.3 Observations regarding the arrows

In all sessions, players noticed early on that they could tag anyone and not just the player that was being pointed at. This could be recognized by their chasing behavior and by remarks made during the game. We observed that the one initially being chased, seemingly often the one with an arrow pointing at them, was not always the one getting tagged eventually.

5.5.2 The Effect of Adaptive Circles

During the games we logged which player was the tagger, to investigate the effect of the adaptive circles, see Table 5.1. With this we looked at Hypothesis 2.

The standard deviations for the adaptive, $D(8) = 0.959, p = 0.803$, and for the baseline condition, $D(8) = 0.972, p = 0.910$, did not deviate significantly from the normal distribution. A two-tailed paired sample t-test comparing the standard deviations of the normal ($M = 6.79, SE = 1.24$) and adaptive sessions ($M = 15, 86, SE = 2.47$), showed a significant effect ($t(7) = -3.077, p < 0.05, r = 0.76$[2]), in the direction of the expected decrease for the adaptive version. This significant decrease shows we can balance the game: adaptive circle sizes led to less variation in the duration

[1]We refer the interested reader to the following video: `https://youtu.be/W2JibBlGm3U`, which shows participants playing the power-up condition.

[2]Effect size for this t-test is $r = \sqrt{\frac{t^2}{t^2+df}}$, for which a .5 benchmark is reasonable [70]

Table 5.1: Table showing the percentage of being a tagger per player for each session (s#), and the standard deviation in the session. On the left the adaptive condition, on the right the baseline ITP game. Played with four players, the baseline percentage of being a tagger during this game is 25% . We have highlighted the player being taggers the **longest** and the *shortest* percentage of the game.

s	std	players in adaptive ITP			
s1	13.3	29.7	**38.8**	*7.10*	24.3
s2	1.62	**27.0**	24.7	*23.1*	25.2
s3	8.81	*14.8*	21.9	**35.5**	27.8
s4	7.64	**32.1**	19.7	*17.2*	31.0
s5	6.80	22.7	*18.8*	**34.7**	23.8
s6	4.34	**30.7**	24.6	*20.1*	24.7
s7	4.46	26.3	26.5	**28.7**	*18.5*
s8	7.32	*17.4*	20.5	28.9	**33.2**
avg	6.79				

s	std	players in normal ITP			
s1	9.14	*14.6*	21.4	28.0	**36.0**
s2	20.0	25.1	26.0	**48.9**	*0.00*
s3	20.7	16.3	**55.7**	*10.4*	17.6
s4	11.2	**37.3**	*14.0*	31.6	17.1
s5	17.5	33.5	17.3	**44.4**	*4.86*
s6	4.97	28.1	**29.4**	24.1	*18.4*
s7	16.9	**47.9**	*8.06*	25.9	18.1
s8	26.5	6.38	37.5	*0.00*	**56.2**
avg	15.9				

of each player being a tagger. We strongly believe that balancing helps in making the game suitable for differently skilled players.

5.5.3 Power-Ups

We know that, in tag, runners often move near the border of the playground and the taggers move near the center [154]. In Figure 5.6 we can see that the distribution of location of players for the normal interactive tag version indeed follows this pattern. We put power-ups in the ITP to see if we could change the location of players. We distributed the power-ups outside the 'standard' positions, power-ups for runners are in the center, and power-ups for the taggers are at the edges of the playground.

We separately saved the positions of taggers and runners, as the power-ups were placed at different locations for these different roles. With this data we looked at Hypotheses 2a and 2b. For every frame in the recordings of a session, we calculated the distance of runners and taggers to the center of the playground. Table 5.2 shows the average distance of runners and taggers to the center of the playground, and the standard deviation. A paired sample t-test does not show an effect on the average distance per group (N=8) between the unmodified ITP and the power-up game for either runners or taggers.

Several reasons could help to explain the lack of effect. Only one player would gather the power-up and once gathered would directly leave that spot. In Figure 5.7 we plotted the average distance to the power-ups in the period surrounding a power-up being collected. We can see that players approach the power-up's position, and once it is collected they move away from this position again. Furthermore, there were only a maximum of 12 power-ups to be collected during each session and they appeared 10 seconds apart. Finally, the size of the player's circle and of the power-up also diminished the intended effect. The player's circle had to touch the power-up; the player himself did not need to be at the actual center position of the power-up but could remain a few steps away from it (see Figure 5.8).

We did not find a significant effect in the locations visited by players. The players did however like the power-ups and over all sessions 85 of the 96 power-ups were gathered. Power-ups might still be a useful mechanism to steer people, but not in the

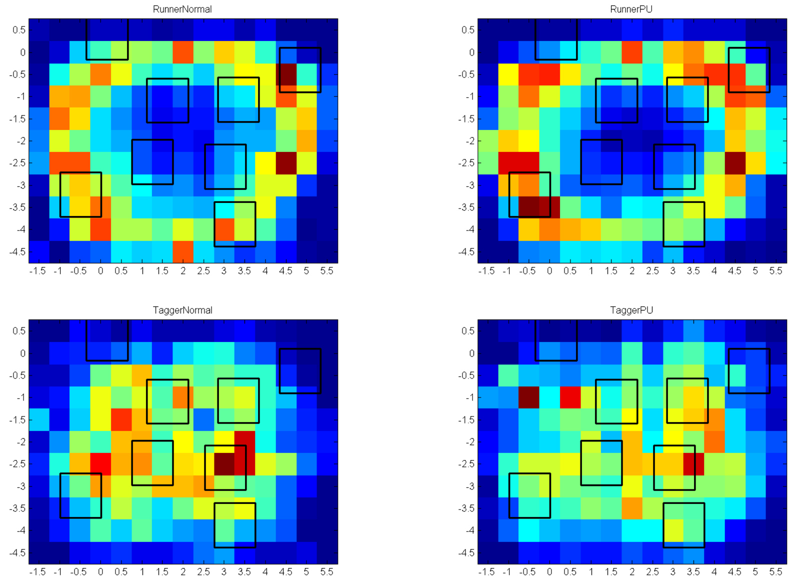


Figure 5.6: Heatmaps of players' positions for the different versions, showing the locations of the power-ups with black rectangles. Runners' positions are shown in the top (T) images. In the left (L) images we show the positions in the baseline unmodified version of the game and in the right images the positions in the power-up version. TL: runners' in unmodified, TR: runners' with power-up, BL: taggers' in unmodified and BR: taggers' with power-ups

Table 5.2: Table showing the average distance to the center of the playing field, and standard deviation, for runners and taggers in the baseline unmodified version and the power-up game.

	baseline		power-up game	
s	runner	tagger	runner	tagger
s1	3.82(1.71)	3.14(1.57)	4.62(1.61)	3.99(2.02)
s2	3.96(1.71)	3.81(1.84)	4.24(1.71)	3.81(2.06)
s3	3.84(2.04)	3.37(1.75)	4.62(1.87)	3.53(1.71)
s4	4.18(1.59)	4.15(1.63)	3.99(1.73)	3.47(2.11)
s5	4.54(1.78)	4.24(1.92)	4.04(1.69)	3.45(2.08)
s6	4.81(1.66)	3.73(1.49)	4.38(1.60)	4.12(2.01)
s7	4.27(1.79)	3.98(1.74)	4.30(1.55)	4.25(1.74)
s8	4.20(1.65)	3.92(1.67)	4.19(1.71)	3.48(1.94)
avg	4.20(1.74)	3.79(1.70)	4.30(1.68)	3.76(1.96)

way we had planned.

5.5.4 The Effect of Arrows

To investigate the effect the arrows had on the behavior of players, we logged which players were tagged in each game and whether they had an arrow pointing at them. With this we looked at Hypothesis 3.

Over the eight sessions, 43.3% of the players tagged were players that had arrows

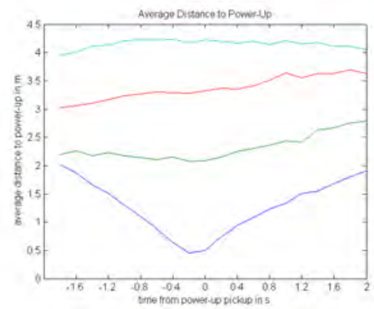


Figure 5.7: The average distance to where a power-up was collected in a 4 second window around the powerup pickup. In blue, the player being closest in this window, in green the player being 2nd closest, in red 3rd closest and in cyan the player that was furthest away.

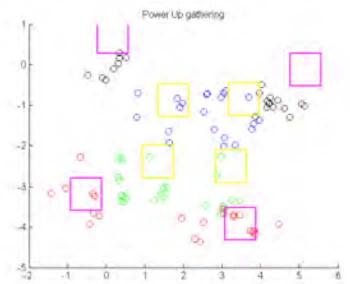


Figure 5.8: The players position's when they gathered the different types of power-ups for tagger (black and red) and the runners(green and blue). The actual placement of the power-ups for the taggers (magenta) and for the runners (yellow) are shown with rectangles.

Table 5.3: Table showing the percentages of players tagging someone who has been assigned an arrow in the arrow game version

Group	1	2	3	4	5	6	7	8	avg
%	46.2	50.0	37.5	50.0	50.0	40.0	50.0	23.1	43.35
# tags	13	18	8	10	12	15	8	13	12.1
# arrow tags	6	9	3	5	6	6	4	3	5.3

pointing towards them, see Table 5.3. The percentages of being tagged with an arrow, D(8)=.257, p=n.s., did not deviate significantly from a normal distribution. A two-tailed one sample t-test comparing to chance-level (0.33) does show a significant effect ($t(7) = 2.97, p < 0.05, r = 0.75$) in the expected direction of people being tagged more often ($M = 0.43, SE = 3.38$) when an arrow is pointed at them. In our experiments pointing an arrow at someone in the ITP increased the chance of getting someone tagged more often.

Therefore, arrows might be used in an attempt to make people more physically active and interact with each other more. For instance, it could be used to engage people that were less active in the game by pointing the arrow to them, or it could encourage people to walk more by assigning an arrow at someone further away. In addition, this offers another potential way of balancing the game, by pointing arrows at the players that have had the lowest amount of tag time.

5.6 Conclusions

By investigating the ITP and the three elements and effects we have shown that ITP was (1) able to steer the behavior of players, (2) able to quantify useful effects based on position data, and (3) provided an attractive enjoyable environment for physical activity. The observation that people find ingenious strategies, such as hiding power-ups, and are able to incorporate shortcomings of a game as a feature, the lag, signifies the importance of always observing play as well.

We designed the Interactive Tag Playground (ITP) making use of observations from traditional play. We showed that (first time) play in this ITP is in general engaging or fun. We also showed that it was possible to steer the behavior of participants during a game of interactive tag in various ways by adding new game mechanics in the Interactive Tag Playground, although caution is needed in generalizing these results given the relatively low number of participants. The adaptive circles showed a balancing effect on the duration of each player being a tagger; the arrow pointing at someone showed an effect on who would be tagged next. The power-ups did not lead to a visible effect on distribution of the locations of the players. Nonetheless, players did gather them and therefore went towards the chosen positions at least for a very short duration. Moreover, most players preferred the session with the power-ups. We believe this gives room for trying out other more long-lasting game mechanics to influence the position of players.

We believe the work from this study shows an important aspect of successfully steering behaviors in playgrounds.

6

A Thing of Beauty: Steering Behavior by Collecting for Embellishment

They call the snow leopard the ghost cat,
never lets itself be seen.
Walter Mitty: Ghost cat....
Beautiful things don't ask for attention.
– Sean O'Connell, The Secret Life of Walter Mitty (2013)[1]

Whereas we steered the behavior of students in the last two chapters, in this chapter we turn towards steering children's in-game play behavior in the ITP. We will also show a 'new' strategy to steer behavior. In Chapter 5 we used functional rewards to steer behavior in the ITP. In Chapter 4, in the Distributed Interactive Pong Playground (DIPP), in order to steer the coordination of players we even changed the main rules of the game: changing from the use of individual paddles to shared paddles. We now investigate incorporating more subtle new game mechanics that use aesthetic power-ups, collection of objects resulting in prettier shapes, to steer game play behavior. In this Chapter we show how one can use such an ***enticing strategy*** to encourage players to perform desired behavior by adding rewards in the form of embellishments, without removing the fundamental game rules that existed before the intervention[2].

In this study, we made a version of the ITP that embellishes the circles projected around the runners upon collecting power-ups near the tagger. We specifically aimed at steering players' proxemics: make runners move close(r) to the tagger. We observed several play sessions, with a total of 600 children playing in an art gallery, to improve this version of the game. Based on the insights gained we conducted

This chapter is based on:
R. W. van Delden, A. M. Moreno, R. W. Poppe, D. Reidsma and D. K. J. Heylen "A Thing of Beauty: Steering Behavior in an Interactive Playground" (conditionally) accepted in Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, pp. TBA, 2017

[1]In this chapter we will actually argue that beautiful things do grab attention and can change behavior.

[2]We would also like to refer the interested reader to a short video that summarizes the work of this chapter https://www.youtube.com/watch?v=NmvGm67-KZQ

Figure 6.1: Young children playing on the interactive tag playground. The young boy with an orange circle projected around him is *it*, the players with partially green circles are temporarily shielded from being tagged.

a within-subjects study in our lab with 48 children. Compared to the play without embellishments, runners came significantly closer to and moved more towards the tagger. This demonstrates the applicability of steering behavior with a more subtle strategy in interactive playgrounds, a strategy that also seems to have positive properties for transferability to other playgrounds and for adaptive/adaptable systems.

6.1 Steering Behavior during Embodied Play

In general, interactive playgrounds are room sized environments that encourage forms of play that foster cognitive, social-emotional, and/or motor skill development[1] [23, 142, 207, 233]. In many cases, these developmental goals are reached by carefully designing interactions that deliberately influence or guide player in-game behavior in specific directions. We have introduced this as *steering* player behavior. Steering can influence physical play behavior in several ways. For instance, Landry and Parés changed the rate at which mandatory collectable objects appeared to increase physical activity [128]. It can also be used to change how players interact with each other. In Chapter 4 we already showed that playgrounds can increase coordination by adding (changed) game objects [256], and in Chapter 5 we showed it can balance the game for players' skill differences, or influence with whom players interact [260]. These kinds of steering behavior can be clearly relevant for the goals that are often used as argumentation for interactive play, especially when integrated as adaptable or adaptive elements of the game. Well-targeted interventions in a game might elicit

[1] In Chapter 2, we indicated this with the following goals: stimulate physically active behavior, s(t)imulate physical (sports) activities and skill development, stimulate social interactions, improve childrens' cognitive development, and provide joyful experiences.

less involved players to re-engage in the game, or balance the game between players based on performance.

These descriptions show that behavior steering is primarily about in-game change of (play) behavior and not about long-term change of lifestyle behaviors (e.g. smoking, (un)healthy diets, medication etc.). In the end, in-game steering of behavior might lead to players' long-term adjustments. It is therefore related to, but different from, behavioral change support systems and other persuasive technology.

6.1.1 Three Ways to Steer Behavior

In the last two chapters we could recognize two strategies of behavior steering in embodied play [260]. In the first one players are ***required*** to take certain actions to control the game. For example, Parés et al. required players to stand in a ring in order to make their interactive fountain emit a stream of water [198]. This could also be seen in the way we steered coordination in the DIPP of Chapter 4, where the coordination was more or less enforced.

In the second strategy the game ***insists*** that players do something by adding game objects or giving game-outcome related rewards. For example, taking a certain action that enables a power-up that makes the player more effective in the game. This could also be seen in the Chapter 5 where we used functional power-ups, such as, making it easier for a player to avoid getting tagged, in an attempt to steer where people would go. Often, although not necessarily, this strategy introduces a positive feedback loop [96, 225]: players that are good at the game are also more capable of collecting items, which increases their chances to perform well in the game, which makes it more likely for them to keep on collecting items.

We believe that these two strategies, ***requiring*** and ***insisting***, can be quite forceful in how they steer player behavior. In the current study, we adopt and explore a third strategy by which behavior can be steered in interactive playgrounds, one where players are not required or insisted to take a certain action, but rather ***enticed*** to do so by the game.

We propose to steer player behavior by ***enticing*** players to take a certain action by designing game mechanics that are akin to achievements used in digital games, rather than ones that afford actions that lead to functional advantages related to the core mechanics of the game. In digital games, a player's achievements can be accompanied with making an avatar look nicer, for instance, adding a hat to an avatar in Team Fortress 2 [83, 152], which, on its own, has no useful impact on the game outcome or the performance of the player. However, Hamari and Eranti point out that it is important to realize that the aesthetic function of an object (e.g. wearing a hat and looking nice) might provide players with an important goal of their own. This emergent goal and meeting the conditions to obtain such an achievement, 'can entice players to try out new features and ways of playing', and can therefore influence player behavior [83](p10). In fact, every achievement reward, or at least most of them, provides no advantages that serve towards the primary goal of the game. Instead, they function rather as a handicap towards success, setting conditions that may be challenging to meet and drive players away from the primary goal [83]. Similarly, in an *enticing* strategy, the added mechanics are optional; the reward offered does not contribute towards achieving the primary game goal and if anything, using them can make the game more challenging. We use an implementation of an enticing strategy where players that collect items are rewarded with beauty, we like to call this steering of behavior with aesthetic rewards ***embellishment-based steering***. However, the study in this Chapter does not allow for any conclusions yet on the aesthetic part, only on the combination the *enticing strategy* of collection for an aesthetic reward.

6.1.2 Embellishment-based Steering: an Enticing Strategy

This *enticing* way of behavior steering is related to the well-known use of nudges. Nudges are a way to change behavior that is not (significantly) related to the users' economic incentives and does not obscure options [247]. A well-known example used by Thaler is the fly in a urinal to reduce spillage in restrooms [247]. Recently thermocromic decals were even introduced that introduce a bit of interactivity. In a game-like context, we see that the two other strategies (excluding the enticing strategy) often rely on providing players with 'in-game economic incentives'. In other words, the *requiring* and *insisting* strategies employ rewards or responses that are related to the main game-outcome, for example, power-ups, shields, additional lives, or reaching the main goal. In relation to game design, nudges rather correspond to the introduction of secondary goals and rewards, just as is done by for instance achievements [83]. An *enticing strategy* applies the idea of nudging to embodied play in interactive games.

The embellishment can be more than just making an avatar more appealing. We can all imagine examples that could be used in multiple settings, such as triggering a pleasing sound, triggering dazzling cinematic content, or adding an appealing written status to players such as king, captain, or legend (irrespective of actual performance).

The *enticing* strategy for steering has some advantages when compared to other forms of behavior steering. One, fitting the libertarian approach of nudges [247]: it is more subtle and less forceful than other strategies for steering play, which, especially working with children, can be preferred in many contexts. Two, we argue that it will be easier to transfer to other similar playgrounds, as the introduced game mechanic does not need to be closely tied to the existing core mechanics of a particular game. The reward does not need to be part of the feedback system of the game [96]. The implementation of our *enticing* strategy for an interactive tag playground (ITP), might also work in an interactive team-pong playground, or on an interactive slide. This can save time and allows for better transfer of research results. Note that, although the players' actions do not need to be part of the feedback system, they can be influenced indirectly, where the enticed actions for instance might introduce risk taking behavior resulting in a negative (i.e. stabilizing) feedback loop. Three, this way of steering allows us to switch the interventions on and off more easily, providing additional ways to steer behavior with adaptable and adaptive systems.

6.1.3 Operationalized Contribution: Changing Proxemics

As a proof of concept of our enticing strategy, we aimed to steer proxemics in a game of tag. We did this by designing a game mechanic that aims to get runners closer to the tagger. Proxemics can be operationalized into distance, orientation, identity (distinguishing players), movement, and location [77, 177]. In line with this, we propose two hypotheses to show that our game mechanic can influence similar aspects of proxemic behavior: 1) the distance between taggers and runners becomes smaller, and 2) movement in the direction of the tagger occurs more often. In the specific context of tag games, this can be seen as a form of risk taking, which might be meaningful on its own as coming closer to a tagger increases the chance of getting tagged and might be appropriate when balancing games or changing engagement levels. This also exemplifies that the added *enticing* game mechanic has no positive effect on the primary game outcome for the player involved. Indeed, in this particular case, the strategy has the opposite effect: it makes the game harder. Given the potential benefits of a behavior steering strategy that employs enticement, we show its applicability in interactive play by adding a possible action strongly related to the aim of changing proxemics (players can collect particles close to the tagger) which is rewarded with the embellishment of game objects (players' circles) to steer meaningful play behavior (proxemics) in an interactive playground.

In this Chapter we will show that an *enticing* strategy can be used for steering behavior in at least one meaningful dimension of interactive play: steering proxemics [81].

6.2 Related Work

6.2.1 Game Design Principles

We build upon game design principles such as Schell's lenses. The players are rewarded with beautiful circles that provide '*endogenous value*' to the mechanic. As Schell mentions in his analyses of Busby versus Sonic, only collection for the sake of collection is likely to be less successful [226]. The created variation of the game also has a certain '*juiciness*', with only a limited number of interactions and easily controllable actions the player gets more power and rewards [226]. The well-known MDA framework as well as Schell, and Salen & Zimmerman explain that player's actions and experience can only be designed for indirectly, players do not always follow anticipated actions or show anticipated responses [96, 225, 226]. It is also important to realize that it is likely that not all game design principles will hold for movement-based games [100]. There are several guidelines, models, terms, and best practices that are insightful when building interactive playgrounds and designing interactions for these games [60, 100, 220, 232]. Isbister and Mueller explain that in movement-based games players played in a different tempo and scale than precise and rapid button presses in normal games. Furthermore, due to the more exaggerated movements visible to the spectators it changes the spectator-gameplay relationship [100]. We therefore also included this aspect of spectatorship into the design of the evaluation study. So although we could anticipate the effects of our intervention, it is all but certain, and still insightful to study the applicability of an *enticing strategy*.

6.2.2 Relation to Work on Enticing Players

There have been several studies on enticing players to interact with public displays, playgrounds, and other interactive systems. However, this is often done in order to get people interacting: seducing players into interaction taking into account stages of play [60], making players curious and eliciting exploratory behavior [249], or overcoming social embarrassment barriers of players [38]. Here, we study *enticing* players to change their behavior (i.e. steering) once they are already interacting. Outside the field of embodied interaction there was a study more in this direction. Anderson et al. analyzed, modeled, and showed that with the use of badges, user's online activity was steered [10]. This shows that the idea of *enticing* is not new but the implementation to change ongoing play, in combination with showing the applicability in a structured comparative study, does add to the growing body of work on physical play.

6.2.3 Interactive Playgrounds

As we showed in Chapter 2, interactive playgrounds can exist in many forms. They can be responsive environments where children have to come up with their own meaning of objects and interactions, enabling open-ended play patterns [23, 228, 242]. They can also implement much more specific games with instructions, rules, and game goals (and outcomes) [128, 260, 285]. Spanning a continuum between the two, somewhere in the middle would be most of the camera/projector exhibits, defined as *social immersive media* by Snibbe and Raffle [232]. These provide interactions that (often) contain a certain narrative, creating exhibits that range from performative dances to a more goal-oriented genre with a clear ending [232].

All of Part I reflects work on installations that implement specific games, where we can let the game function as a referee, and can augment existing games [156]. The variation of a tag game that is part of our *enticing* way of steering, gives an additional element which places this version slightly more towards the open-ended play side, moving it slightly away from the far end of the spectrum with specific games; in the version in this Chapter children can set additional goals, can discuss about it, and have to decide on their relative importance.

6.2.4 Changing Proxemics in Interactive Playgrounds

There are various movement-based games (interactive playgrounds) that contain game mechanics to influence proxemics, trying to get people closer to each other [177]. These examples show that it is a relevant research topic in our field. *Proxemic Pong* includes penalizing players that are too close, in order to change distances between players [77]. *Jelly-Stomp requires* people to get close to each other in order to stomp an interactive floating device [177]. *Bubble Popper* is a game that revolves around popping colored shapes on a vertically oriented interactive projection [253]. In this game, the shapes move in order to get competing players to make physical contact with each other. *Boundary Functions* is an exhibit that contains an educational message in the form of an interactive Voronoi diagram [232]. It uses players positions to project lines on the floor between players, and relates to personal space and proxemics. Proper use (and well targeted change) of proxemics of players, or players and objects, can be an essential part of engaging HCI [77].

6.3 Three Versions of the Interactive Tag Playground

For our study we again made use of the ITP, and moved our setup to Tetem Kunstruimte, see Figure 6.2. Due to the switch in locations the size of the playground slightly changed.

In order to exemplify the three strategies of steering we have three versions of the ITP. Besides the baseline (the normal version of the ITP), in two additional versions taggers periodically emit particles (small balls) that runners could then collect. The particles are emitted with some aesthetically appealing randomization, they differ in size, in the duration before they disappear, and in their relative velocity compared to the tagger, see Figure 6.4 and 6.6. Runners can collect the particles by letting their

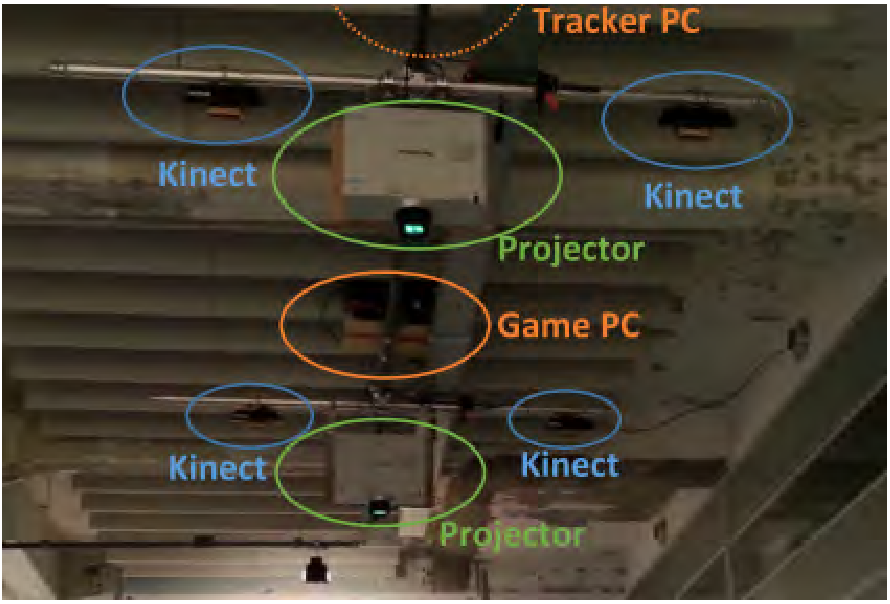


Figure 6.2: The hardware and construction for the Interactive Tag Playground at the art gallery.

circle collide with the particles, a *'plop'* sound is played at that moment. If a runner collects enough particles the circle of that runner changes in visualization, see Figure 6.5. The actions of the runners, in the form of collecting these particles, should have a clear effect on the proxemics.

For the first strategy, we always *require* taggers to come close to runners, they have to let their circle overlap with that of a runner (the *baseline* version, without adding particles). For the second strategy, if players (runners) collect the particles they are rewarded in a game-outcome related way, we use *shields* that temporarily prevent players from getting tagged (the *insisting* way of steering)[1]. To make this clear to the players, a number of green rings are formed around the circle. For the third strategy, players are *enticed* to come close by rewarding collection of particles only with embellishment of their circle, the circle becomes more complex and beautiful, see Figure 6.5. In the results and figures we name this last version *swag*, to distinguish it from other possible implementations of an enticing strategy.

6.4 Exploring and Improving the Intervention

Prior to performing a structured user study, we observed many play sessions to investigate our *swag* intervention, in order to improve the intervention, to create an appropriate study design, and to see if children would like it as well. The playground we used for exploring and improving our intervention had a size of about 4 by 5.5 meters. We were invited to exhibit the ITP at a local art gallery, where it would remain for a period of two months, see Figure 6.3. Making this transition from lab to a more public space, and dealing with a high number of users is a challenging task

[1] This is a different type of shield than the slowing down power-up used in Chapter 5

Figure 6.3: Tagger running towards a runner, the chased runner has an embellished circle, see the other runner in the top of the image.

[198]. We had to make a version of the ITP that could be started with a press of a button, take into account the daily practice of the space, and more importantly: the rules and ethics for doing research in this environment.

6.4.1 Organizing Play Sessions at an Art Gallery

The gallery is a non-profit organization that is open for the public, free of charge, 8 hours a day. We only observed play on the 18 days that the gallery organized workshops. During these workshops no other visitors were present, each time only one or two primary school classes. Over 600 children in total played during these workshops. The age of the children ranged from approximately 4-13 years. The groups' visits to these workshops, of which playing in the ITP was only a small part, took about one to two hours, and varied in size from roughly 20 to 50 children (on average 33). This meant there was limited time to let all the visiting children play in the playground.

Consent and communication with schools and parents was managed beforehand by the art gallery according to their internal protocols. One researcher first explained the basics of the game and showed how the game is played by tagging a facilitator from the art gallery. We explained that in some games balls (particles) appeared, that could be collected, we omitted explanations about how the particles exactly worked. Children were always first asked to play and only participated voluntarily. We also

Figure 6.4: A tagger, the same player that was previously a runner with an embellished shape in Figure 6.3, has just emitted a trail of particles.

instructed the children not to leave the boundaries of the game. If necessary, we reminded them during the game. We started with the three versions, the *baseline*, the *shield*, and the *swag* version: each session we automatically alternated between them. Similar to what is suggested by the Rapid Iterative Testing and Evaluation (RITE) Method [149], at the end of each day in the first few days we made several changes (e.g. circle size, the visualizations, and duration of a game). In the last few days we played the *swag* version more often in order to explore a change in how the particles were emitted.

The context had the following 'restrictions': 1) explanations for the tests had to be brief, clear and consistent, 2) the use of questionnaires was discouraged and impractical, and 3) use of non-anonymous data including video recordings was not allowed. These restrictions actually helped us to work towards the user study, as the restrictions, especially one and three, were also limitations for our user study. In both the workshops and our study there was a limited time to play tag, and parents were reluctant to have their children participate if we took video recordings. Only two teachers during two workshops at the art gallery were given permission by their school and the parents to take pictures and share these with us, these pictures were used in this thesis.

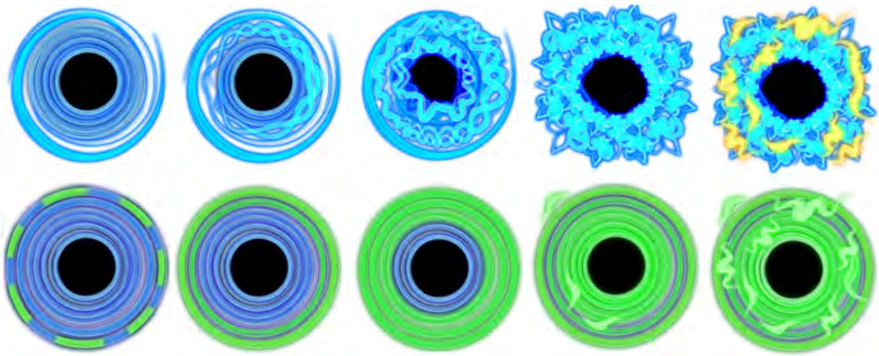


Figure 6.5: Circles depending on the number of particles collected (increasing from left to right). On the top the aesthetics of circles used for the *swag* version and in the bottom the circles for the *shield* version.

6.4.2 Observations and Improvements

Based on our observations during the play sessions at the art gallery we made the ITP better suitable for children and worked towards an effective user study. We removed a pre-recorded explanation to speed up sessions, we limited the game duration to better fit the extent of the visit, we changed the players' circle size to fit the size of the playground and the children's abilities, and we changed the duration of the cool-down period before tagging someone back and improved its visualisation. Most importantly, we changed the particles' size, occurrence rate, and way of spreading, see Figures 6.6.

We noticed a large difference in how children played the games, seemingly related to among other things the children's age, gender, and stamina. We observed no real difference in playing for the few children that played the game for a second time. The youngest children, based on the group with which they visited about four to six years old, liked the experience but did not play the game in the expected way and instead were often distracted or overwhelmed. For example, see how the young girl is staring at her circle instead of running away in Figure 6.1.

We observed that the older children realized early on in the game, often within an estimated twenty seconds, that the particles changed the appearance of their circles. The rules of the shield intervention were not always recognized as quickly. It is not surprising that the shield mechanics were harder to interpret, as recognizing how the shield protected a runner from being tagged not only needed the runner to collect several particles, it also required that an attempt had to be made by the tagger to tag this runner while he/she had the shield. Nonetheless, in both particles conditions we did see children gathering these particles intentionally.

We observed several children deliberately collecting and liking the particles, especially the embellishment to the runner's circle. Utterances of spectators and players confirmed that the graphics were indeed appealing for the children. We heard things like: *'wow look at X's circle'*, *'catch those balls, it makes your circle more beautiful'*, or *'ohh no, I am tagged but I finally had such a beautiful shape'*.

Although we did not count certain responses nor asked children about whether they had fun, there were clear observable indications that the ITP was fun for the

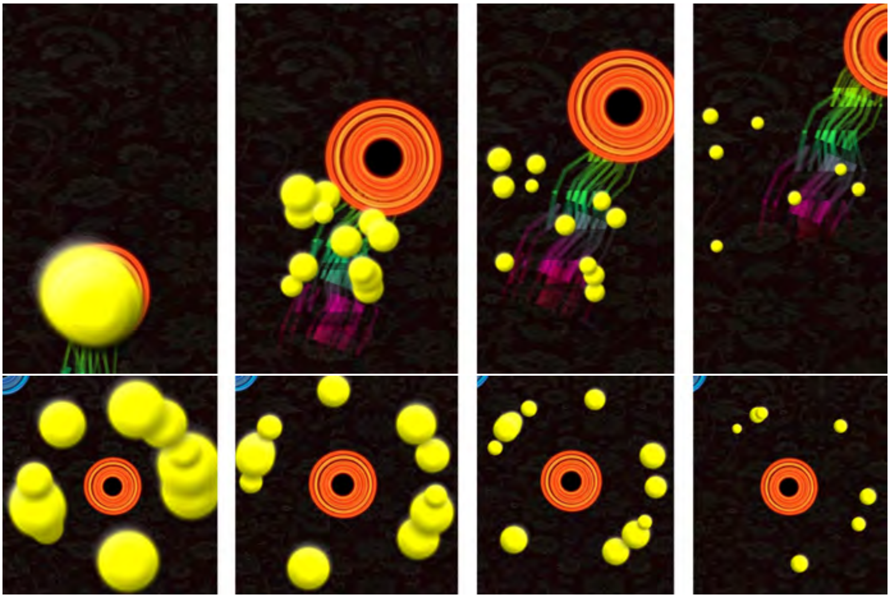


Figure 6.6: Visualization over time of two versions of emitting particles. In the first version (top) we used a wider spread of particles based on the velocity of the tagger, instead in our study (below) we used a more effective spread of particles keeping them in a circle around the tagger.

majority of the players. Most of the children asked us, they actually even begged us, if they could play again, which can be linked to a fun experience [211]. We got very positive and enthusiastic responses from the children, teachers, and parents that were present during the workshop. People from the art gallery told us that several children even came back some days later with their friends or family members in order to play in the ITP again. Using the observations and these positive responses about the children's play we proceeded to set up our user study.

6.5 Study: Steering Proxemics in the ITP

6.5.1 Study Design

Based on our observations we only included children in our study that were at least five years old. The differences between the children also made us choose for a within-subject (altering the order) as the effects should be due to the intervention and not due to imbalanced groups. This meant that there was a more limited time for the play sessions, as we wanted to give all the visiting children the opportunity to play. We decided to simply omit the shield intervention, as such a strategy for behavior steering has already been shown to change behavior [128, 260]. Instead we did a comparison between the normal ITP (*baseline*) and one with a more enticing way of steering (*swag*), to demonstrate that this strategy for steering behavior can be applicable and effective. This means that we have not yet compared the relative effectiveness of the shield and the swag mechanics.

Figure 6.7: Context and location of the user study, 4 children are playing tag at our lab during a field trip. There are some spectators at the sides. We have anonymized, blinded, and color corrected the image.

6.5.2 Participants

We organized field trips for two elementary schools, taking one morning per field trip. These field trips allowed us to analyze how 48 children played interactive tag. We had 18 play sessions, from these we omitted six sessions from analysis. Four sessions had to be omitted as they included one or more children of whom his/her guardian had not given permission for using the data for scientific purposes. Two other sessions had to be omitted for technical reasons, as sunlight had interfered with the recognition system. The remaining 12 sessions (48 players) were analyzed. The first 8 sessions were done with pupils from one school and in the age range of 8-12 years. The last 4 sessions were done with pupils from another school, in the age range of 5-9 years.

6.5.3 Context

We used a permanent version of the interactive playground in one of our labs, this version is slightly bigger than the one at the art gallery: both sides are 5.5 meters, see Figure 6.7. In this context we no longer had many children sitting at the sides as spectators. Instead, during most games only the next group of children, a teacher, or the previous group was present: limiting their influence but still providing a realistic setting without giving a too orderly context for play. During the field trips children engaged in interactions with a variety of interactive products in our lab: several student projects, robots, and interactive installations (including the ITP).

6.5.4 Procedure

The field trips were approved by the faculty's ethical committee. We had information letters and signed consent forms for all children that participated in the study. These were distributed via the teachers several weeks before these field trips.

We gathered four children at a time from the other field trip activities in a room next to our playground. In some cases a group of children walked towards the playground of their own accord. We always asked children if they wanted to play. We explained and demonstrated the *baseline* game for each group. We alternated the order in which they played the two conditions: *baseline* and *swag*. We explained the game, 4 children played, and the game lasted 90 seconds. In order to start at a clearly recognizable moment in time we started the game with a countdown consisting of both visuals and sound *'3,2,1,GO!'*. The time between the two sessions was enough for the children to catch their breath. In order to prevent differences between starting positions being of influence, we instructed them to stand at the four corners of the game. We indicated these positions with a projection on the floor. Before the *swag* condition we explained the workings of the particles. Based on our experience we had already seen that most children would understand the workings of particles eventually. However, we wanted them to have an effect earlier on in the session, therefore we changed this explanation slightly compared to the one given at the art gallery. We explained that collecting balls (particles) was possible and would make their shape nicer, but that by doing so they would increase the chance of becoming the tagger. We told them it was up to them to make use of collecting these balls or not. Log files of the position of the players and their role (tagger or runner) were automatically saved.

6.5.5 Measurements

For the core purpose of the study the automatic measures of players' locations sufficed. Automatic measurements have been used to track a variety of relevant information, including players' positions [154, 165]. The relative position of players is the core element of proxemics: we used both the distance between taggers and runners, and the orientation of moving runners with regard to the tagger (do they actually move towards the runner more often?). We limited discussions after the sessions to keep reasonable throughput of participants in the limited duration of their visit. We omitted video recordings (and analyses) but we did observe the play and wrote down any interesting utterances made during the game.

The ITP provides positions per 'frame', approximately 18 times per second. We used a median filter of 5 frames on the players' positions to reduce noise on x and y positions separately. The distances to the tagger were averaged over the three runners each frame. This average distance per frame was then averaged over all frames of the session. This means that the few tracker issues regarding player switches were unlikely to influence the results. The few frames where one or more players are missing for several frames were automatically omitted from analysis, this made up for 4.7% of the frames.

Regarding the direction of the runners with respect to the taggers, we needed a more comprehensive method. The angle was calculated by taking the difference between 1) the direction of the runner based on the velocity vector, and 2) a vector linking the runner's and the tagger's positions. In this way an angle of 0° means the runner is running straight towards the tagger. For the direction measurements we used the smallest absolute angle, so -10° or 350° is counted as 10°. For all frames we only counted the direction of runners that are actually moving. We removed displacements below 0.01 meter per frame, approximately 0.67 km/h. This made up for 7.8%

of the remaining frames per runner, especially the values at the first few seconds of each game where children had to look who was *it*. To reduce outliers from switches in the tracker (these did not influence the distances between players as these are independent of switches of players' tracks) we also removed those frames where players allegedly moved faster than 25 km/h. This made up for an additional 0.2% of frames per runner. Although results are quite stable showing the same results independent of such parameters, to further reduce possible influence of noise we also used a median filter on the angles. We applied this on these angles over 11 frames (about .6 s). We only used these values of each 11 frames. We then counted the values where runners were walking towards the tagger (operationalized as those angles below 60 degrees) divided by the total number of valid angles of moving runners for each session.

6.5.6 Hypotheses

We set out to influence the distance between players, we expected that runners would gather the particles that were emitted from the tagger during the *swag* sessions. Therefore, the average distance of runners to taggers was expected to be smaller for sessions in the *swag* condition. We based this mainly on Tetteroo et al. that observed that interpreted status in the game can be a powerful motivator for children in an interactive playground [246]. We tested our first hypothesis using a one-tailed paired-samples t-test comparing the *swag* condition to the *baseline*, based on the average distances between taggers and runners in cm (one value per session, n=12).

Hypothesis 1 *The distance between runners and taggers is smaller in the swag condition than in the baseline condition.*

We expected that runners in the particle conditions would be more inclined to walk towards taggers in order to gather the particles. Therefore, moving towards the tagger was also expected to be visible in the angle at which runners moved compared to the position of the tagger (this includes walking towards the taggers' back). We expected runners would run more often (occurrence rate per session) in the direction of the tagger ($<60^o$) in the *swag* condition. We tested this second hypothesis using a one-tailed, paired-samples t-test comparing the *swag* condition to the *baseline* condition, based on the averaged ratio of runners walking towards the tagger (one value per session, n=12).

Hypothesis 2 *Runners move in the direction of the tagger more often during the swag condition than in the baseline condition.*

6.6 Results

Besides the quantitative measures to investigate the hypotheses it is good to have some idea of whether the particles would influence the play experience. During the discussions after both conditions in six groups all players indicated that they preferred the *swag* version; in one group three players preferred the *swag* version and one player the *baseline*. In one group all players liked both equally, and in one all liked the *baseline* more. We mentioned this preference on a group basis, as peers can influence each other in their responses. We also noticed them making many positive remarks about the particles and *swag* circles: *'Look at my circle!'*, *'Yess! Yeah I want those spheres'*, *'Wow he is gold, yes gold!'*, *'Check mine!'*, or *'Yes I have the most beautiful one!'*, again indicating that the embellishment was indeed found more beautiful.

Table 6.1: Average distances between a runner and the tagger in meters. In session one we started with the *baseline* and then alternated the order.

#	**mean** (baseline)	**mean** (swag)	**std** (baseline)	**std** (swag)
1	2.24	2.21	0.54	0.60
2	2.53	2.38	0.55	0.59
3	2.51	2.39	0.65	0.65
4	2.54	2.41	0.55	0.50
5	2.36	2.27	0.60	0.58
6	2.63	2.50	0.60	0.63
7	2.47	2.27	0.52	0.50
8	2.69	2.35	0.52	0.51
9	2.63	2.74	0.57	0.78
10	2.81	2.53	0.81	0.67
11	2.56	2.41	0.63	0.64
12	2.83	2.68	0.69	0.74
avg.	**2.57**	**2.43**	**0.60**	**0.62**

Hypothesis 1 We looked at the data for the individual play sessions, the distances were averaged over the three runners each frame. Table 6.1 shows that on average in 11 of the 12 sessions runners come closer to the tagger. We did a one-tailed, paired-samples t-test (n=12). On average, the distance between the runners and the tagger was significantly smaller in the *swag* condition ($M = 2.43, SE = 0.05$) than in the *baseline* conditions ($M = 2.57, SE = 0.05$), $t(11) = 4.13$, $p < 0.001$, $r = 0.78$ [1]. Runners were about 14 cm closer to the tagger on average during the *swag* condition. We bundled all the distances of all runners to the tagger together into a bar graph. This also shows a similar visualized result, see Figure 6.8. It shows that runners are often closer to tagger for the *swag* condition, seen as higher bars to the left for the *swag* condition. For the *baseline* condition it shows that runners are often farther away in this condition, seen as higher bars to the right. These results lead us to accept Hypothesis 1.

Hypothesis 2 Besides the distances, we looked at the movement direction of runners with regard to the position of the tagger. If we look at the session-based ratio, we see that players moved towards the runner (angle<60°) more often when they were moving in the *swag* condition, see Table 6.2. We did a one-tailed, paired-samples t-test (n=12). On average, the ratio of runners approaching the tagger was significantly higher in the *swag* condition ($M = 0.23, SE = 0.03$) when compared to the *baseline* condition ($M = 0.14, SE = 0.04$), $t(11) = 7.90$, $p < 0.001$, $r = 0.92$. We again bundled together the data of all the runners, now regarding their movement orientation, and placed them in a rose plot. This also shows that in the swag condition runners did indeed move towards the tagger more often, see Figure 6.9. This can be seen by looking at the angles close to moving towards the tagger (<60°), for these angles there is a clear increase in the occurrence rates in the *swag* condition (purple bars) compared to the *baseline* condition (cyan bars). These results lead us to accept

[1] The effect size was calculated with $r = \sqrt{\frac{t^2}{t^2+df}} = .78$, which is above the .5 benchmark [70]

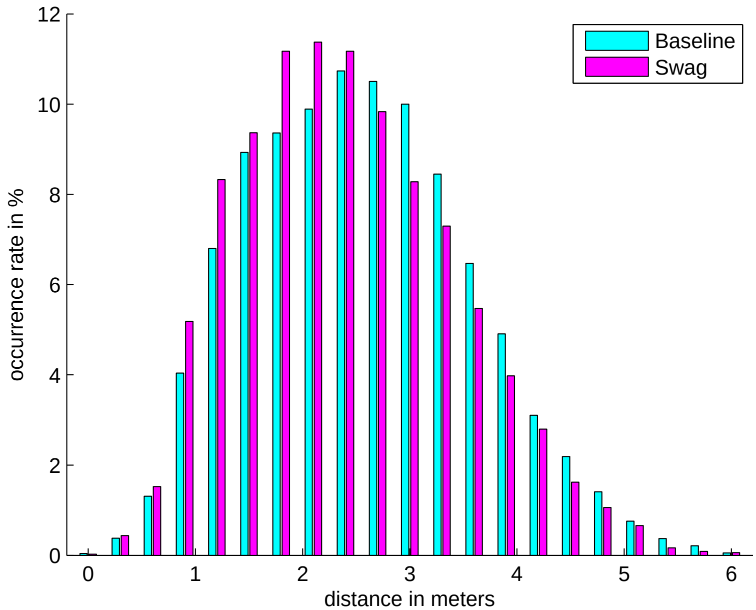


Figure 6.8: Distance between runners and the tagger for the different conditions.

Table 6.2: Ratio of players moving towards the tagger (angle$<60°$) when they are moving, averaged over all values of all the runners for each session, both for the baseline (b) and swag (s) condition.

#	1	2	3	4	5	6	7	8	9	10	11	12
b	0.14	0.081	0.13	0.15	0.11	0.18	0.11	0.12	0.17	0.17	0.13	0.17
s	0.20	0.15	0.23	0.23	0.22	0.26	0.28	0.19	0.19	0.27	0.28	0.26
s-b	0.06	0.07	0.10	0.07	0.11	0.08	0.18	0.07	0.03	0.10	0.15	0.08

Hypothesis 2.

6.6.1 Further Analysis

The results indicate a clear effect of the particles. In this section we perform more in depth analyses using additional relevant measures and tests.

6.6.1.1 Movement

The particle intervention should not diminish the movement significantly; this is an overall goal of such playgrounds, as we discussed in previous Chapters. To this end we calculated the distance per player id per session by summing the distance over each frame for each session. We used a cutoff of 99.7% on the distance per frame to diminish the effects of outliers. In 9 sessions there was a slightly lower amount of movement in the particle condition. The average distance walked per player during

Table 6.3: Average number of frames per tag for each session, both for the baseline (b) and swag (s) conditions.

#	1	2	3	4	5	6	7	8	9	10	11	12
b	84	86	95	68	74	110	78	86	87	91	79	85
s	54	65	54	77	83	76	68	83	105	83	64	97
b-s	31	21	41	-9	-9	33	10	4	-19	8	16	-11

the game was about 109 meters for the *baseline*, and 106 meters for the particles session. However, a two-tailed paired students t-test shows no significant difference between the mean of the *baseline* ($M = 108.90, SE = 11.67$) and that of the particle condition ($M = 106.34, SE = 11.39$), $t(11) = 0.97$, $p > 0.05$, $r = 0.28$.

6.6.1.2 Towards Player Based Distance Differences

For both hypotheses we used results based on the group level, and only visualized a summation of all the individual players to clearly show the two conditions in one image for visual inspection. For our main outcome regarding proxemics, the analysis of distances included in Hypothesis 1, we used group based averages for statistical tests, because results per player might not be independent and switches of tracks between and during games would invalidate within-subject comparisons. So although we found significant effects in the sessions this could either be due to most of the players changing their behavior a little or some players changing their behavior quite a lot.

We did a one-tailed, paired-sample t-test (n=48) where we also saw a significant effect. The x-th closest runners (within-subject approximation taking into account tracker switches) in the *swag* condition ($M = 2.42, SE = 0.22$), is on average, significantly closer to the tagger, than in the *baseline* condition ($M = 2.56, SE = 0.23$), $t(47) = 5.75$, $p < 0.001$, $r = 0.86$. The means were similar to those found when we averaged over the sessions but differed slightly as the number of frames per session were not constant.

The results do indicate that it is probably not one player per session that comes closer a lot but more likely most of the players (in total 37 out of 48) coming a little closer (or coming a lot closer but only some of the time).

6.7 Discussion

The results demonstrate that steering behavior can be done with an *enticing strategy*. The combination of collecting items rewarded with merely changing the color and appearance of a shape can be enough to persuade children to change their in-game play behavior. We demonstrated a significant difference in proxemics, a relevant dimension in play. One might view the absolute distance as only a small effect (14cm) but if we also take into account the direction in which the children ran we can conclude that we managed to steer behavior.

This change of physical play behavior had no positive outcome for the players' primary goal of the tag game itself. Moreover, coming close to the tagger could even have a detrimental effect in regards to the primary goal of the game, as coming closer to the tagger would increase the chance of getting tagged. See Table 6.3 where we show the number of frames a player remained a tagger on average. If we wanted to

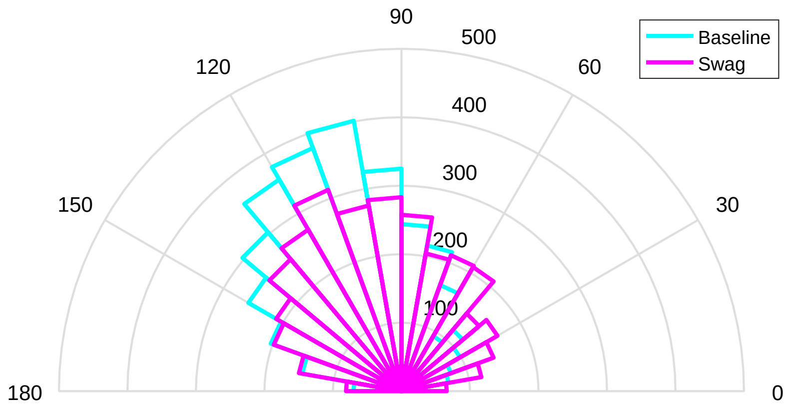


Figure 6.9: Movement direction of runners with regard to the position of the tagger. The angle with respect to the tagger's position ranges from 0 degrees (towards the tagger), to 180 degrees (away from the tagger). The occurrences are in number of frames (corrected for difference in number of frames per condition by normalization), shown in the spread direction of the graph.

focus on such risk taking behavior directly, the particles should have probably been placed only in front of the tagger, as that makes the risk of getting tagged bigger. When developing game mechanics to steer behavior it is important to keep the aim, the mechanic, and the measurement aligned.

We would like to point out three other things in this discussion: 1) there are some limitations to the study which should be considered, mainly that the collection in itself could be acting as the steering intervention irrespective of its (aesthetical) reward, 2) our ITP seems to be quite suitable for a high throughput of players, what Parés et al. [198] indicated with massive flux design, and 3) there are several beneficial aspects of an enticing strategy for steering and opportunities for applying it.

6.7.1 Possible Limitations

One alternative hypothesis that we did not incorporate into our study design is that the collection of the particles in itself could have been the reason for steering behavior. Due to the nature of the game mechanic we implemented, players might see the gathering of particles as a challenge in and of itself. However, children's utterances made during game were mostly directed towards the embellishment of the circle rather than the collection of particles. Therefore, the role of an embellishing reward may warrant further study. It could be interesting to investigate the power of the strategy and see if the non-functional rewards (swag) would even be as powerful as functional rewards (shield). One way to do this, would be by adding a variation where players can collect particles but do no receive a reward for collecting the particles, that is to say, no sounds and no change to the appearance of the circles. To see to what extent this would work, this non-embellished version could then be compared to both a baseline version without collecting particles, and to a version in which collection is rewarded with embellishments.

Another limitation of the study is that the instructions included a description that the circles would become prettier, which might have influenced how the children perceived the circles. We think this influence was limited and that children would have mentioned it if they did not like the aesthetics. Nonetheless, simply instructing the children that their circles would simply become *different* would probably have been more appropriate.

6.7.2 Combining Throughput of Players with Research Goals

In our study we did not adhere to strict lab settings for our exploration and study. After all, children's play is inherently chaotic and certain aspects such as the presence of other children (spectatorship) are likely to be there in real-life situations as well. It is a choice that is often made between internal or external validity of an experiment.

The chosen settings (an art gallery and an organized field trip), did allow us to have many more players than we could have had otherwise. Nonetheless, dealing with a high throughput requires several considerations in the study design and the design of the system. Not all installations are evenly suitable for this purpose. We had over 600 children playing with our installation[1], we made several choices that helped us to realize a capability of a quite high throughput of users. To use Parés et al. taxonomy [198] for issues in massive flux design, we adhered to most of them:

- short preparation and approach phase & non-invasiveness: no devices, easy-in/easy-out, no lengthy instructions

- short learning curve & naturalness: building on a traditional game

- robustness: the system has been used for days, and has been running on a daily basis at our university for over a year, without many issues

- multiuser (vs isolated experience) & participative (vs non-participative): tag is a multi-user game, furthermore present spectators can become enthusiastic and in a way become part of the game.

- excellent flux (throughput): during some workshops we achieved 7 play sessions starting in 15 minutes, thus taking into account the countdown children played 67% of the total time.

In all fairness it has to be noted that under certain circumstances direct sunlight is still an issue for our current computer vision approach. Perhaps making the robustness item less valid for our current tests. Our throughput might seem limited compared to Parés et al. but when we look at throughput per system it reaches about 50% of their enormous throughput. Parés et al. reached 2100+ per hour which comes down to 233+ per fountain [198], where we reach $7*4*60/15 = 112$ per installation. Comparing the complexity of movements and that we choose to have four players, as this is a reasonable number of payers for this limited size of space, this indeed seems

[1] Including the visitors of the expositions and to our lab we estimate we had well over 1500 people that interacted with the Interactive Playground Platform over the years.

to be a reasonably high throughput. This combined with the overly enthusiastic responses of the children and teachers makes it likely that besides using it as a research tool, the playground could also be used in other settings such as holiday parks, theme parks, or shopping malls.

6.7.3 Using Enticing Strategies for Steering Play Behavior

Related work has indicated that embedding game rules that more or less force a change in the behavior of players is an effective approach to change this behavior, at least regarding the proxemics or interactions with a targeted player [128, 177, 260]. In this study, on the other hand, we have changed in-game behavior in the form of proxemics more indirectly with embellishments. This *enticing strategy* in the form of embellishment-based steering seems more appropriate for children, as ***it is less forceful***. The response of children might even suggest that (upon collection of objects) adding embellishments to our tag game resulted in a variation of our game that was preferred over the baseline version. It would be interesting to correctly test whether embellishments do indeed also improve the experience of playing.

The rewards and collection of particles, also ***introduce a secondary goal***. In a game with such a secondary goal the children can decide themselves how important such a goal is. We think it would also be interesting to see how embellishment-based steering, or another enticing strategy, for steering behavior would work in a more open-ended play setting with no main game-outcomes to begin with.

As any enticing strategy for steering does not need to be part of the main goal, it is positive for the ***transferability***. It does become easier to apply the same steering mechanisms in other contexts. In the reported study, the steering mechanism affected the difficulty of the game, and was still intertwined with the tagging mechanics as the circles were lost once the runner was tagged. The motivation for this design choice was to maintain tagging as the primary interaction. We plan to continue exploring this strategy in more games, and in this context also experiment with forms of enticement that exist in parallel with and are fully independent of the core mechanics. This application in another game would not only demonstrate the applicability of an enticing strategy of steering but also demonstrate its proposed added value of transferability.

That an enticing strategy for steering behavior does not need to be part of the main goal or interaction also means it can be easy to switch it on or off. With regard to future systems this seems ***promising for adaptable or adaptive implementations***.

6.8 Conclusion

An *enticing* way to steer can be used to steer behavior during play, presenting an alternative to the more frequently used more functional rewards. In this *enticing* way of steering, actions lead (at most) to 'non-functional' rewards that are not closely linked to the core game goals. As a possible application of this strategy we steered proxemics of children playing a game in an Interactive Tag Playground. We found a significant effect on proxemics in the wanted direction: runners got closer to the tagger on average, and the runners moved towards the tagger more often. This demonstrated that this intervention, as an example of a more *enticing* way of steering, worked in our interactive playground.

The *enticing* way of steering can be a subtle way of steering. It makes it easier to investigate steering with (adaptive) interventions, as the interventions do not have to be strongly linked to main game rules but can be of an aesthetic (non-functional) nature. This should make it easier to transfer these interventions to other playgrounds and allows us to switch them on and off at will. This alternative way of steering can be a beautiful and useful way to steer play behavior in interactive playgrounds.

Outro Steering Behavior in Interactive Play Spaces

In this Part, I introduced our Interactive Playground Platform (IPP). With this platform we created two different use cases: a Distributed Interactive Pong Playground and the Interactive Tag Playground. In both we created a seemingly enjoyable playground and we were able to steer behavior of players. I investigated several aspects of the playgrounds. I presented systematic user tests comparing interventions with a baseline. By applying automatic measurements we were able to show convincingly that we were indeed capable of steering behavior in wanted directions with our interventions. For our last study I even indicated that not every part of an intervention needs to be closely linked to the main game outcome: an intervention can be effective when it is rewarding certain actions with embellishments only.

I also described how we used observations, interviews, and questionnaires in our studies. These showed us that we were able to provide entertaining and promising interactions. I even estimated that our interactive playground platform was used by over 1500 different people, from which the majority also indicated in one way or another that they liked it. During these studies we had children, teachers, researchers, and students playing. I saw relatively large differences in playing styles and the type of people playing. However, all users were able to see, run and listen. When I started doing the research on the other hand, I argued that fundamental human needs will be applicable for all humans [261], I also indicated in Chapter 2 that addressing alternative user groups and looking at alternative goals would be a worthwhile endeavor. In the next part I will address this universality and include a different type of goals. I will investigate applying interactive embodied play for people who do not have many alternative means for entertainment. I will try to create a new leisure activity for people with profound disabilities. We will investigate if we can also steer/promote behavior and experience, in wanted directions in such a context.

Part II

Play for People with Profound Disabilities

7

Play for People with Profound Disabilities

Ça fait quoi d'être assisté
...de vivre sur le dos des autres?
(How does it feel, to be living dependent on others?)
– Philippe, Intouchables (2011)

In this part we look into the potential of truly interactive systems for people with Profound Intellectual and Multiple Disabilities (PIMD).

In this Chapter we will start by placing our activities in the context of the related work, and why we are explicitly looking into improving alertness, movement and mood with an interactive system. This Chapter will continue with a description of an interactive ball that is aimed to achieve this. This quite big ball (50cm) reacts on body movement in an interactive manner. It is a ball capable of emitting lights, playing sounds, and moving from left to right as if it where a gently moving remote controlled car. We will then describe our pilot test, in which five different people with PIMD interacted individually with this interactive ball. In these pilot tests we looked to see whether the interaction could be worthwhile to investigate further, and explored settings of the ball to optimize it for the users.

In Chapter 8 we will describe our approach and results of an exploratory longer-term effect study to measure whether such an interactive system can indeed add something with respect to the dimensions of alertness, movement and mood, for people with PIMD.

Parts of this chapter are based on:
R. W. van Delden, D. Reidsma, W. M. W. J. van Oorsouw, R. W. Poppe, P. van der Vos, A. Lohmeijer, P. J. C. M. Embregts, V. Evers, and D. K. J. Heylen, "'Towards an interactive leisure activity for people with PIMD'" in *Proceedings of the International Conference on Computers Helping People with Special Needs (ICCHP), pp. 276–282, 2014.*

and the introduction of:
R. W. van Delden, S. Wintels, W. M. W. J. van Oorsouw, V. Evers, P. J. C. M. Embregts, D. K. J. Heylen, and D. Reidsma "Do we get your attention?! Looking into alertness, movement and indicators of happiness of people with PIMD upon introduction of a playful interactive product" *in preparation, pp. TBA–TBA*

and it makes use of translations of text that we used in the research protocol and description of the study presented in Chapter 8. That study was approved by the Medical Ethical Committee of the MST (regional hospital in Enschede, the Netherlands), dossier NL 48070.044.14

7.1 Towards New Leisure Activities for People with PIMD

Not all people have the combination of cognitive and physical capabilities to be able to enjoy modern-day sources of leisure, including computer games and interactive installations. Especially for people with Profound Intellectual and Multiple Disabilities (PIMD) there is a limited amount of suitable entertainment [43, 267]. People with PIMD are a heterogeneous group that generally have multiple mutually reinforcing disabilities, are dependent on others for their every-day activities, and have very limited intellectual capabilities (immeasurable or what can be described as an intellectual developmental age of 24 months or less) [138, 181, 182].

There is a fairly limited number of non-passive activities and even a smaller amount of appropriate interactive entertainment for people with PIMD [43, 267]. Many people with PIMD are likely to have too small an amount of non-sedentary activities and have to make do with passive activities such as watching television and lying on a waterbed [288].

Creating interactive entertainment for people with PIMD may help to create more physcially active alternative activities but the design process to get there is hard for several reasons. People with PIMD are in general unable to clearly communicate their preferences or feelings, this complicates finding appropriate interventions. The evaluation phase is also complicated due to the inability to verbally interact with the participants. Instead people with PIMD mainly communicate through body movements [268]. Affective measurements, such as indicators of happiness or agitation, are therefore often based on behavior interpreted from video recordings and on interviews with staff members [43, 65]. One also has to take into account a wide range of peculiarities, disabilities, and contextual limitations. Even the everyday supporting staff members often need to discuss among each other in order to establish interpretations of the actions and preferences of their clients. Furthermore, the process to obtain ethical approval for evaluating new interventions in a more medical setting is an extensive procedure, and as Brodin and Renblad explain some complicated ethical considerations arise for people with cognitive disabilities [40].

This user group is especially vulnerable with regard to living a meaningful life [43, 138]. At the same time it is recognized that entertainment might contribute to self-efficacy, self-esteem, autonomy, and creative explorations even for people with special needs [5, 43, 261]. Recent developments in technology show an array of ways to facilitate the creation of interactive systems to contribute to such needs [155]. Technologies such as depth cameras that can detect body posture and gross body motion (e.g. Kinect), can be especially useful in tapping into the limited non-verbal movement skills of people with PIMD.

More *truly interactive systems* can be created based on the interpretation of non-verbal movements. With this we mean it goes beyond merely turning a product on or off, that is to go beyond pushing a button in order to get a (repeating) constant response, instead it should include a developing dialogue of actions and responses [43, 130]. Such interactive systems provide an expressive experience that is capable of captivating people in the target group [43]. We think such systems can help in heightening their alertness, triggering them to move more, and can result in positive effects on their mood.

7.2 Existing (Interactive) Leisure Activities

One of the few leisure activities that can be offered to people with PIMD is *snoezelen*, which takes place in a multi-sensory environment. A multi-sensory environment contains, for instance, bubble tubes, aroma dispersers, projector wheels, and tactile boards [72]. The trademarked name Snoezelen itself is an amalgamated name of the Dutch *'snuffelen'* (sniffing out) and *'doezelen'* (dozing) [90]. In discussions with staff members of a Dutch care organization, it became apparent that there are concerns that the dozing parts in these environments are often more present than the exploratory aspects. Nonetheless, such a room can be intended to stimulate alertness of the people with specific needs [230, 267]. Activities in such a room can also be non-directive; without targeting specific therapeutic aims, perhaps leading to potential for self-development and self-realization [90]. It can also be aimed specifically at reducing self-injurious behavior, although based on research evidence other interventions seem to be more appropriate to that end [90].

Although many claims of positive effects are made for these environments, much of the research performed is either inconclusive or contains methodological weaknesses, especially with regard to people with PIMD [90, 267]. Individual differences could play a role herein: some people with PIMD might become more alert in these instrumented environments, and others are more alert in their natural environments [267]. Furthermore, it seems as if the interaction from and with the staff has more effect in getting attention than the static overwhelming stimuli [267]. Munde et al. also suggest that waves of alertness occur for this target group and that making use of these moments of alertness could help their learning abilities and overall development [181].

Several hundreds of (commercial) products are available for people with special needs. Only a limited number are suitable for people with PIMD, offering only limited interactivity (cf. [43])[1]. Many of the products labeled as interactive only consisted of micro-switches and therfore did not go beyond pushing a button and the interactive part stops after the initialization [43]. Some of the existing truly interactive leisure activities for people with PIMD focus on the use of music. The commercial Snoezelen® Soundbeam, a system that makes musical tones based on the movement of a user, is one of the most common musical systems for people with complex needs [115]. Capellen and Andersson created a music-making system that used interactive physical objects with sensors in the form of pillow-like objects, and in a later generation used more elaborate algorithms and more familiar content for mastering musicking [47, 48]. Their system also included an accompanying video wall projection that showed animations fitting the music. Meckin and Bryan-Kinns mentioned several other systems that used music and created a set of actuated, acoustic instruments for people with special needs to hear and feel the sound. The instruments could be played based on simple interactions through an iPad [115].

Between 1988 and 1995 Kitt Engineering, a small company turning creative concepts into products with a focus on electronics, developed the Motion Interpreted Media Interface Control (MIMIC). The MIMIC suite provided an interactive experi-

[1] We also did a search in catalogs that were selected based on Google searches with a combination of keywords including *interactive, toys and snoezelen*, *PIMD* or *special needs* and several catalogs suggested by therapists [72]: achievement-products.com, barryemons.nl, dragonflytoys.com, enablingdevices.com, fisher-price.com, flaghouse.com, mikeayresdesign.co.uk/, snoezeleninfo.com, spacekraft.co.uk and wilkinsinternational.com.au

ence with sounds, visuals and MIDI effects based on a video stream. After seeing some children with autism behaving very expressively in such an installation, they were involved in a three month pilot using their system for people with special needs at the health care organization Eemeroord (currently Sherpa). The touch of an object and movements from arms and other body parts could be linked to playing sounds. For some people with special needs it seemed to stimulate movements that were not performed before.[1]

Outside the realm of music and sound making devices there are also other suitable digital products for this target group. Although we aim for a truly interactive system, instead of using one binary on-off switch, simply incorporating multiple switches (now giving the user the ability to turn on and off various features) can also provide additional entertainment opportunities. For instance, for young children with severe physical disabilities a modified ride-on toy-car including adapted steering mechanisms and incorporating additional switches, could increase mobility, and provide an additional activity in which postural control might be trained and cause-effect learning can be targeted in a motivating and fun way [94]. Another interesting system that focuses on stimulating several modalities instead of responding to the user, is the Therapeutic Motion Simulation (TMS) developed by vita-care[2]. It originates from hippotherapy but tries to provide a safer, easier, less costly way to provide a horse riding like experience, including movement, vibration, visuals, and sounds. During one of our visits to the Dutch health-care organization Dichterbij that participated in this project, we observed several sessions that were clearly enjoyed by the target group.

Finally, a series of interactive prototypes were developed during the SID Project (Sensuousness Interaction & Participation [in Danish delagtighed]) [130]. The prototypes created include: *Active Curtain*- a flexible physical canvas that can be pushed for visual and auditory responses, *Malleable Pillow*- a malleable pressable pillowish form where presses are coupled to emitted lights, *Hug Bag*- a hugable bag that responds with sounds and lights to gross motor movements in the form hugging and leaning, *Lively Form*- a cuddleable toy/robot that moves and produces lights based on the way it is touched, and *Water Bed*- an interactive waterbed that reacts to the movements of a child lying on it, based on these movements it provides an interactive *'wavescape'* consisting of sounds accompanied with infrasonic vibration [130]. This latter interaction provides a continuous non-obtrusive experience that can be tailored to the arousal of the children *[H. S. Larsen, personal communication, March 31, 2014]*. In evaluations, the children seemed to take initiative for interaction and to enjoy these kinds of interactions [43, 88, 129, 130]. We refer to [130] for a more thorough discussion on interactivity (the lack thereof in current practice), the interactive systems from the previous paragraph, how the target group interacts with them, and designing truly interactive (tangible) systems for people with PIMD.[3]

7.3 Our Approach and Ideas

Based on the related work and discussions we had with managers and staff members of Dichterbij, we conclude that people with PIMD are offered a limited number of active leisure activities. The products that do exist for leisure have a limited interactivity

[1]The original Dutch coverage of the system for Eemeroord by a newspaper can be found on `http://www.kitt.nl/Previous_Work_MIMIC.pdf`

[2]www.vita-care.eu

[3]Movies and more information can also be found on `http://sid.desiign.org/`

and are limited in how they trigger active behavior. Some people do become alert in Snoezel environments, but it seems to be highly dependent on the actual person and their preferences. We think that tailored interactivity might help in creating more suitable experiences for more users of this target group.

In contrast to the inspirational designs by Larsen et al. we will focus on interactions *'outside the close encounters'* of the users in an attempt of *'stretching the attention into space'* [130, p30].

In our attempt to improve the current situation with interactive systems we addressed several aspects of people with PIMD in our design process. Keeping in mind that we want to stretch attention into the room and knowing that some users do not like to be touched, we excluded the use of wearables. In order to be on the safe side (from an electronic, mechanic and hygiene point of view) we also omitted direct contact as a means of input and feedback.

With our research and activities our ultimate goal was to add to the quality of life for the target group. In our studies we set three suitable primary aims that we have in mind for this target group that should be a first step towards achieving this overarching goal. We selected these three aims from a practical point of view as they a) add value for the user group (are of practical use and urgent), b) are realistically attainable with an interactive system, and c) can be measured. Below we will explain these three aims in more detail.

7.3.1 Alertness

Alertness revolves around someone being involved, and interacting with his/her environment. Alertness is of importance for a proper support and education of people with PIMD. People can only consciously process stimuli when they are alert and focused on their environment [183]. The level of alertness defines whether a client can optimally learn, develop and participate during activities. The focus of attention can be directed at persons as well as objects. Both the environment and physiological factors/internal stimuli (including tiredness and hunger) play a role in the levels of alertness [180, 183]. Interactions with their environment mainly consists of personal interaction, both with family and the supporting staff. Low levels of alertness are often associated with moments in which people are alone, without any form of activity. The combination of sensory stimuli, movement, and triggering a change in orientation of the body with respect to the environment can heighten alertness [183]. Moreover, even micro-switches can lead to an increase of alertness [126].

7.3.2 Affective Behavior

When one creates a new activity and evaluates this for a specific user group, it is of great importance to include the customer satisfaction as a measure. For people with PIMD it is impossible to discuss the product using speech. Instead, for this target group communication is based on body language and other (non-)verbal expressions that refer to the present amount of satisfaction [268]. Observing affective behaviour is therefore often used during evaluation (e.g. measuring the level of happiness and agitation). Dillon and Carr clearly show that indications of happiness and agitation are sensitive to change and keeping track of them is a suitable way to evaluate activities for people with PIMD [65]. Sensitivity to change in this case means that the indicators change when they are participating in an activity or when they are offered an object. These changes can also be indicative of how much appreciation they have for something. It is important to measure both the positive and the negative indicators, as a decrease of agitation can be a valuable result as well [65].

7.3.3 Movement

Only a small part of free time of people with PIMD consists of non-passive activities [288]. This leads to an important issue, as in general people with PIMD often suffer from overweight (or are obese), suffer from diabetes, and have a passive lifestyle; leading Waninge to conclude that this user group 'displays insufficient physical fitness' [273]. Therefore, it seems worthwhile to explore new possibilities for interactive systems to also motivate users from this target group to move more.

7.3.4 Finding a Suitable Interaction

Many people with PIMD, are showing large amounts of self-regulatory behavior, such as the stereotypical rocking, staring at fingers while moving them and making non-verbalized noises [72]. In general it is seen as an important goal to reduce these, for example, with multi-sensory rooms [90, 130]. On the other hand, variations of these actions can be a starting point to initiate interaction, as they are likely to occur anyway, while the interaction itself might help to change the behavior in wanted directions. This approach is related to a design tactic used by Larsen: he was also inspired by the actual actions of the user group to inform the design of their interactive systems [130]. Besides fitting the input to the user we also need to adapt the output to the user. For instance, frequently occurring visual impairments in this user group make it hard to distinguish colors or detailed shapes but quite a few people with PIMD are capable of seeing contours and objects with high contrast. Moving colored physical objects seem to be more suitable than turning to detailed projected images and screens.

7.3.5 Concept of an Interactive Ball

We applied this in our concept for an interactive ball. Besides trying to incorporate the movements they make anyway, the idea is also inspired by observing potential users. We saw someone from the target group seated in her wheelchair, from where she pushed away a big ball with her hands or even manged to 'kick' it away. This is something that many users will not be able to do themselves without help. The resulting concept for the interactive ball is a ball that will respond to the upper body movement (e.g., the stereotypical rocking behavior). This adds new opportunities as many potential users are not capable of making the ball move on their own. The ball will be lying in front of the user. When the user is not focused on the ball, it will gently try to regain focus by playing some sounds, a wiggling movement, and LEDs changing color. When it is in focus it tries to persuade the user to move. This is done by letting the ball move according to the upper body movement of the user, and playing sounds to indicate responsiveness. In order to respond to focus it will respond to the related estimate of the head orientation of the user. The ball is powered from the inside, comparable to moving a remote controlled toy car[1].

[1] The basics of the concept are also explained in a movie that can be found on `http://hmi.ewi.utwente.nl/interactive-ball-save15years-2014.mp4`

7.4 Technical Implementation for an Interactive Ball

The ball moves by changing the center of gravity with servo motors connected to weighted arms, see Figure 7.1[1]. A 50 cm in diameter, pre-fabricated water-resistant expanded polystyrene ball forms the outside. Inside there is a circular laser-cut plywood frame holding a revolving frame containing the electronic components. In this way it is able to move on its own in two dimensions. This also allows for gentle movements, unlike the more direct and quick movements of the commercially available interactive ball Sphero. In its current implementation, we restrict the ball to a one-dimensional left/right movement. The final version of the ball uses a small 12V storage battery, which can be charged with an opening in the ball, see Figure 7.1. We also use this battery as the weight on the arm that makes the ball move.

Using a Wifly module that can be accessed as a wifi-hotspot simple string based commands can be sent to the ball. We programmed a simple GUI in C++ with QT that allows for moving the ball with the keyboard cursors. The GUI also contained some fields that allow for setting the speed and duration of rotation. Key inputs can be used to play 17 different sounds. Most of these sounds were made using free virtual (synthesizer) instruments, 6 were recordings from an online audio database (mainly animal sounds and bells). The sounds are played in front of the user over standard PC speakers. We painted the ball in highly contrasting blue and yellow colors. Based on interactions with objects in their living environment, one staff member suggested that some clients might respond more to bright red colors. Therefore, we also painted a version in red with black. After some sessions we also added a rattle to let the ball make more noise, so that it could be followed better. This is especially important for people with more limited visual capabilities.

7.4.1 An Autonomous Version of the Interactive Ball

Our first concept was based on an automated detection of the user with the Microsoft Kinect. At the same time we used a webcam and a simple background subtraction method to track the position of the ball. We created an interaction in which the ball's position (left/right on a predefined path) was dependent on the position of the head. However, during the first tests we realized that one fully automated interactive system was not flexible enough to deal with the heterogeneity of the user group. For instance, we planned to use the head positions as the main method of interaction but the first PIMD-user did not move her head left/right often enough. Besides lacking the capability to adapt to the users' abilities, the first concept was also not tailored enough to the preferences of the user. Therefore, the first day of testing we had to switch to a Wizard-of-Oz approach. It seemed to be a good first step to see whether the interactive ball, in whatever way, could be beneficial for people with PIMD. Nonetheless, here we will shortly describe that such an autonomous version might be quite easily attainable for normally healthy participants.

In a first attempt to respond to upper body movement we tracked the head position, using the head joint of the upper body tracking the Windows Kinect SDK 1.8. The recognition of focus towards the ball is done with the Microsoft Face Tracking Software Development Kit for Kinect for Windows[2]. We only moved the ball when the face was properly detected, which only happened when the face was turned to

[1]Technically developed and created by KITT Engineering.
[2]`http://msdn.microsoft.com/en-us/library/jj130970.aspx`

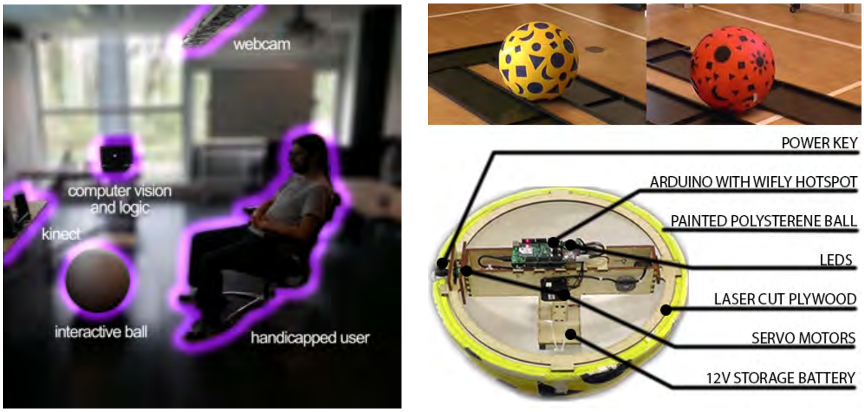


Figure 7.1: On the left, the (planned) system lay-out for the autonomous ball, shown here with a healthy participant. On the right the interactive ball as it was painted in two colors and the parts it was made of. The power key was added later, the ball only works as long as this key is plugged in.

the camera within a certain angle. The position of the ball was recognized with a straightforward background subtraction tracking algorithm based on a webcam feed. Based on the difference between the head position and the ball's position the ball was stopped, or moved either to the left or right. In order to transmit the instruction for movement to the ball, the ball contains a local wifi hotspot and TCP/IP server. In Figure 7.1 the intended system setup is shown, tested with a healthy student. The intensity of the interaction, the intervals of grabbing attention with sounds and the type of sounds could be manually adapted to the user (during run time), in order to improve the effect of the interaction and possibly allow for a larger set of users.

7.4.1.1 Testing the Interactive Ball with Healthy Student Participants

We first tested this autonomous version with healthy participants, 30 of the participating 40 bachelor, master, and PhD students successfully interacted with it for two minutes each. During these tests we did not give instructions, as we would not be able to give these to the target group either. In 10 sessions, especially the first ones there was either a bug that prevented normal interaction, or the students could not figure out how to interact with the ball. After the first, the seventh, and fortieth student we made small technical improvements in the implementation of sending commands including the duration of movement and the speed with which the ball moved. The final version seemed to allow for testing it with the actual user group in a pilot test. However as we have mentioned we soon realized our first interaction paradigm was too restricted.

7.4.2 Towards an Interaction Protocol

For the design of the interactions we spoke with several supporting staff members and a therapist (with a management position) about our intentions and the project, and did a literature study. We also watched uninstrumented play sessions, visited daily living environments, and were informed about a variety of activities for this user group.

This is general practice in our research community and we believe this is essential in coming to a suitable interaction for this user group [130]. As we mentioned and as will be shown in the results of this pilot as well, no over-generalization should take place. Things seen for one user cannot always be transferred to another especially for this type of user. Therefore, we tailored the interaction patterns of the ball in an iterative and individualized way. At every session we continued to work closely together with supporting staff members, in order to analyze and interpret the user's behavior and experience, and to help improve the interactive system.

The exact interaction protocol depends on the user, but we will describe the general way of interaction here. Because of the individualization we used, we applied a Wizard-of-Oz (wooz) approach where a facilitator remote controlled the ball. The facilitator made the ball respond to upper body movement and/or focus of attention. For instance, when the user moved his upper body to the left, the ball would also start to roll to the left. It would also make sounds when an attempt for interactions was made, if a user made vocalizations, or if the ball was kept in focus for some time. Besides the responses based on participants input, for some users it was necessary that the ball moved from side to side when it had not been interacted with for some time. This was done in order to gain the attention of the user. Sounds were also played in that case, to further grab the attention of the user. For the longer-term study, reported in Chapter 8, we developed a more extensive interaction protocol also based on the interactions of the participants seen during this pilot.

7.5 Pilot Tests

Scattered over five afternoons once a week, we did a pilot study with five different participants (from now on referred to as clients). We performed these tests 1) to further explore appropriate actions to respond to, 2) to see if the interactive system would be worthwhile investigating in a longer-term study, and 3) to optimize the settings of the ball and the test setup for the longer-term study.

We did this test at the health care organization Dichterbij. Most participants were in their 40s/50s; none of them could communicate verbally. One participant was able to walk independently; others were wheelchair-bound. Three participants were male and two were female. The first client had a squint(was cross-eyed), the fifth client also seemed to have some visual problems and squinted (narrowing his eyes), it was confirmed by their supporting staff member that the latter participant had trouble seeing. The other three participants could see reasonably well. The participants played with the ball during a varying number of sessions. Respectively in order of participation 3, 3, 4, 2, and 2 sessions. This variation was due to our intention to test with different people and due to their availability on the possible days of testing.

The pilot study described in this paper was 'officially' exempted from a medical ethical review, by the Medical Ethical Committee of the MST (regional hospital in Enschede, the Netherlands) [ID number METC/14004.rie;K-Nr.: K13-51], and was approved by our university's EEMCS department's ethical committee [EEMCS: EWI14/B: Vne/2104/tnc]. Several weeks before the first test we asked the legal guardians for permission and they had to sign a consent form. We sent these, together with a letter explaining the goals and procedure of the user tests, to the guardians of all intended participants. We also needed and asked for permission for taking video recordings for our analysis.

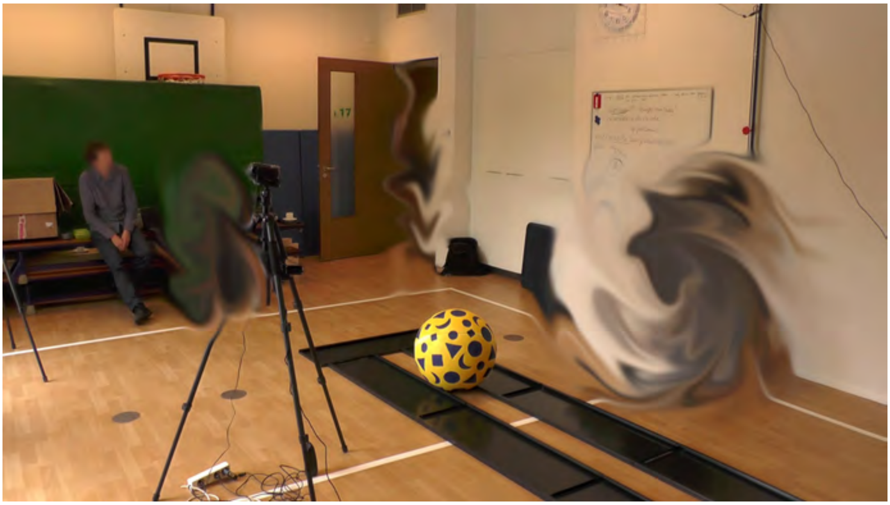


Figure 7.2: The setting for the reported pilot tests, after the second sessions we mirrored the setup to let the participant face the door instead.

7.5.1 Location and Setup

We had the availability of a large space of about 5 by 6 meters at the care center. We set up a gutter in which the ball could only move left and right. This was approximately 3 meters in length. Figure 7.2 shows this test setup, after the third test day we mirrored and placed the users with their face towards the door, this could make some clients less anxious. We also blinded the windows up to eye height after the first user test, in order to minimize distractions. During all sessions a member of the supporting staff who was familiar with the participant was present. The staff member took place on a bench near the end of the ball's path. The participant was seated in his/her normal wheelchair about half a meter from the interactive ball, thus close but out of reach of the ball. For safety reasons, and to diminish the technological challenges, we prevented the users from grabbing the ball. We used three cameras placed on tripods at the left, right, and middle; recording the user, the ball, but also (a part of) the supporting staff member to be able to identify a focus towards the staff member. Therefore, we also asked for the consent of the staff members present during the tests. The middle camera was zoomed-in, in order to show facial expressions of the participants. The Wizard-of-Oz operator was seated at the other end of the ball's path. One or two other researchers were seated next to the staff member and made observations and each day we performed at least one semi-structured interview with a staff member.

7.5.2 The Session

A session took roughly between 20 and 30 minutes depending on the enthusiasm of the participant and signs of tiredness. Although we never witnessed any person being over-stimulated, anxious or seriously irritated, we instructed the staff member to stop the test (and sooth the user if possible) if such an should take place.

Each session we watched the participant and what actions s/he performed on which the system could interact. We also tested the response on feedback and tested if/which sounds were preferred, varied the speed of the ball, and on the advice of a therapist and a staff member we added plastic bowling pins in some sessions. These pins were placed at the end of the ball's path where they could get knocked over to increase the impact for some users.

7.5.3 Observed Interactions of the Five Participants

We will describe the behavior of the five participants separately, as they showed very different behaviors with the ball. As stated before this immediately falsified our first (automated) concept for interaction: a strict interaction pattern of positioning the ball based on the position of the head and playing a sound when the user was not looking at the ball for some time.

The first user would for instance regularly fiddle with her hands or rub the arm of the wheelchair, but keep her upper body quite still. It is good to notice that the tracking of both head and head orientation by the Kinect worked ok for her [1]. However, she did not seem to take initiative to interact with the ball, or direct her focus towards it, making the prescribed interaction as good as useless. She did notice the sounds and enjoyed when the ball was bouncing at the end of the path. Therefore, a staff member suggested to add the bowling pins at the end of the path that could be tipped over. In her final session she did seem to respond to this, although not in a very intense way.

The second participant mainly looked at the ball but made even fewer movements. He did notice the ball and looked at it sometimes. He seemed to explore the room just as much as he was looking at the ball. Our initial interaction pattern of attracting focus with sounds and movement did not work for this user. In a second session we played a different type of sounds when he looked at the ball. When he was not looking at the ball for a longer period of time we would roll the ball up and down the path and play a different sound. He was clearly more interested in the ball in the two sessions with this interaction.

The third user was very interested in the ball and we responded on his upper body movements, wiggling the ball when he moved forward, and moving it sideways if he would lean to a side. The user often played with a rattle toy, we played a similar bell sound when he looked at the ball. We again moved the ball when the user was not looking for a longer period of time, but this almost never happened. Instead we played sounds when he was looking at the ball and was repeatedly moving forward and backward, adapting this trigger to the rhythm of his movement. His main input was that he would turn his head away and then slowly turn towards the ball and lean extremely forward. We made the ball move further in the same direction when this happened. This participant also laughed often when he heard the sounds, saw the ball move, and he moved vigorously during the interaction.

The fourth participant clearly noticed the ball and tried to touch it when she entered, but in both sessions she participated in she eventually found no real interest in it. She was yawning several times, rubbing her eyes, she seemed to 'frown upon' the system, and in the end let her head rest on her arm. We decided to shorten her sessions a little. We tried playing all sounds moving the ball when in focus or

[1] We did notice that for several other people from this target group the Kinect's detection, also including upper body tracking, did not work well. This probably had to do with atypical angles and sometimes atypical facial features of the participants seated in a wheelchair.

explicitly when out of focus, playing the bell sound when looking at the ball, playing a horse neighing sound when she was kicking her leg on the chair, changed the color of the ball to red and black and back to yellow and blue, but none of it/the interactions seemed to successfully interest her for longer periods of time. She did regularly glance at the ball but it did not keep her interested. During the sessions, her staff member also noticed that this participant looked uninterested and explained to us that the participant normally rested at that time.

The fifth user had bad vision and was not wearing his prescribed glasses during interactions as he used to throw these off. He reacted especially to sounds; after hearing some of them he would look up and get up straight in his chair. He also smiled quite often. We tried an interaction pattern in which we played sounds when he looked up a little, and played longer lasting sounds when looking up into a certain direction. We also played a specific sound when he made sounds himself.

7.5.3.1 Alertness and responses

As we mentioned in the last section as well, overall we can see the difference in showing alertness, mood, their general actions and the sensory stimuli preferred. Some users looked up and away as they enjoyed the interaction, others glanced at the ball now and then but did not seem to be interested in the ball.

We noticed that for some users sounds were more important than the moving object. The fifth user, especially only enjoyed the sounds and laughed regularly after hearing the sounds. The second and third users seemed to notice and like both the sounds and the movement.

For the second user at a certain point we tried out if he would follow the ball moving up and down the path, which he clearly did, although he had physical trouble turning his neck to one side. This can also be seen as a sign of heightened focus on the world/alertness due to the ball.

It was remarkable to see the difference in responses to the type of sounds. These responses even changed within a session, it seemed that this might be related to both tiredness as well as familiarity, regarding the latter for example, playing some 'new' sounds at times did give responses.

The third participant seemed to be very enthusiastic about the ball. He even seemed to recognize the interaction from the previous session. According to the staff members present during these sessions, the number of laughs and the amount of movement was higher than normally observed for this client.

All participants seemed to have a drop in their ability to focus on the world around them after around 15-20 minutes of playing with the ball. We took this into account in our study design for our longer-term tests.

7.5.3.2 Vocalizations

As mentioned earlier we also used vocalizations as a means of input. For two clients this sometimes led to something resembling a 'conversation', playing a sound and triggering more intensive sounds if these were answered with other vocalizations. However, care has to be taken when using vocalizations as an input. As it might otherwise result in an unwanted feedback loop of distress vocalizations with disliked responses of the ball.

7.5.4 Interviews

On each day we had a semi-structured interview with at least one staff member about a participant of that day. This was both to gather more insight into the activity and to improve the protocol for our longer term follow-up study.

7.5.4.1 Context and Participant Information

We did not perform a complete structured analysis of transcribed interviews, instead we used our notes to summarize the most informative answers. During the interviews at times the staff member pointed out important context information that could have influenced the outcome of the tests. The fourth participant that was sleepy, normally had a nap during the time of the day that the interactions took place. For the longer-term study we asked the supporting staff members to indicate a suitable time for their participating person with PIMD. She was also used to walk/wander around with a special chair but she had to keep still for the interaction. So for the longer-term study we preferred to select participants that were wheelchair-bound.

Some observations (both positive and negative) we made could also be verified during the interview. We did sometimes notice the bias towards pleasing us, giving us the socially desirable answers, especially in the interviews about the two users that according to us did not really seem to like the interaction. For the longer-term study we also relied mainly on observations based on video recordings but did include discussions.

During an interview it was noted that responding to sounds is tricky. As the soft vocalizations seem to indicate pleasurable experiences while the hard vocalizations, the screaming, indicate displeasure (which you actually do not want to reward, and do not want to respond to). For the longer-term study we decided to use an interaction protocol that included some personalized action-response pairs.

7.5.4.2 Opportunities for Additional Benefits of the Ball

We were positively surprised that regarding these play session two supporting staff members mentioned the importance of autonomy and control. Something that we had in mind during our design but did not specifically target as a measurable outcome in our studies. One therapist for instance stated *'Normally everything is offered by the staff members so there is little control for them'... 'perhaps they do not realize this consciously, but the interaction does lead to some form of independence'*. The other therapists stated *'It is nice that he can control something on his own, without us imposing it on him'*. She continued that it would be nice if he could actually initiate something like this interaction on his own at other times as well.

Another staff member pointed out that it is good that this is another type of activity for the users, *'I like that finally, something is done for this user group'*. A third staff member instead liked the possibilities of the system to find out what could be done with this client and what he liked.

A supporting staff member who was interviewed about the fourth client emphasized that there should be some form of communication/contact between the ball and the users. For this contact it would not matter if a staff member would actually steer the device.

In several interviews it was mentioned that the ball stimulated behavior in a way that was normally not seen. This ranged from an increase of (the duration of) focused behavior, to more physically active behavior.

7.5.4.3 Three Types of Individualization

The interviews with the supporting staff members led us to three types of individualization that might be pursued for these users.

The first type of individualization is about having an appropriate interactive experience tailored to the user. A supporting staff member for instance stated, *'He especially reacts to those long sounds'*. Another staff member noticed that a bell sound worked well for client 3, probably as it resembled the sound of the client's favorite rattle toy. A third staff member noticed that playing the same sound perhaps did not work well for client 5, as in the beginning he liked hearing the animal sounds, but at the end he did not seem to enjoy it anymore.

The second type of possible individualization that sprang forward from the interviews, was a discussion about the side people should sit, in a wider context this is about individualization of the evaluation setup. It followed from client 2 having difficulty looking in a certain direction: it could be nice for him to have the staff member at his 'easy side'.

A third type of individualization that came across in the interviews was linked to the measurements, the manual annotations of video and used interpretations. It is necessary to use an individualized coding scheme. For instance, sucking a thumb is positive for one client, but might be negative for another; or sometimes and for some people smiling might be a negative sign, instead of being a positive one. During the interview it was also stated that the staff members also use such an individualized signal-list that is constantly updated, containing an overview of positive/neutral/and negative cues for each person.

7.6 Choices Made for the Longer-term Study

The pilot gave us valuable lessons that were taken into account for improvements to the ball, setting up the long-term study and in designing interaction patterns.

During the pilots we had already enhanced the feedback of the ball with additional sounds. We noticed that participants responded to sounds and especially to some sounds more than others. Increasing the number of sounds and having different types, should allow us to better tailor the feedback to the preferences of the user.

We also added some bright lights that can shine through the outer shell. We were careful to circumvent flickering to prevent eliciting epileptic seizures. We added these lights in an attempt to be better able to grab the (visual) attention of the users. As we did not really test this added functionality in the longer-term study, we simply mention here that it did not really seem to have helped much for the interactions.

We also added the externally accessible on/off switch and charger to the ball. Changing the batteries and charging the replacements every two or three session was quite a hassle, as it had to be done quickly between sessions. Being able to turn off the ball quickly by unplugging the connector also added a little to the safety.

We improved the physical properties of the ball among other things by lowering and increasing the counterweight, by switching to two servo motors instead of three, and limiting the rotation from full rotation to 180 degree for one direction (perpendicular to the main direction of movement).

With respect to the study design, based on the pilot we chose for a duration of 15 minutes of interaction, including a pre-interaction and post-interaction rest period for comparisons within session. Although it would have been preferable we were unable to let the participants face the door. We did place the participants with their support staff on their preferred side, so it would be less hard for them to communicate possible dislike of the session (and for the staff member to interpret this). We also placed the ball (in a gutter) on a table, so it would be easier to see, especially useful for people with very limited capabilities of turning their head. We created an improved interview guide, and as is quite common practice for this target group decided to also use personalized interaction and annotation schemes (with regard to alertness and indications of affective behavior). We also included a method for automatic measurements of movement, and used manual annotation. The details of the long term study and analysis are explained next in Chapter 8.

7.7 Discussion

We saw at least one participant enjoying the interaction with the ball during his sessions. This gave us some confidence that we will be able to influence some participants in the longer-term test. During the pilot tests we also made changes to the type of sounds played during the interactions, which seemed to have positive effect for some users. The pilot also resulted in some changes to the ball and study as we mentioned in the previous section.

Possible critiques of the user testing is that we switched back to a Wizard-of-Oz setting and that we tailored the interaction. As there were some technical challenges for interpreting behavior of this user group, a fully automatic system was no longer attainable in the time. We found that we should keep close to future measurable actions but that our approach was a convenient way to first test whether such a system would actually add something for the participants if it were to be developed further. This approach allowed us to respond to many different behaviors. It seems that for this target group many things will also have to be tailored. Besides the interaction also the measurements have to be personalized to the actions of the user. The responses should also be tailored to a certain level, in order to maximize the possible impact of the interactive device. With all these changes one might question if we were actually testing one ‘interactive ball’ on ‘a target group’. Instead it might seem that we just had several case studies of people with PIMD playing with interactive systems.

In an attempt to show that such an interactive ball would be worthwhile for some users, individualization of the system might not be the way to go. Perhaps the system should simply target a different sub-group that would be into the ball and show a group effect for these people. Currently we have too little knowledge to predict who will be into the ball, and who will not. Instead in our longer-term user study we will just use a case based description, and analyze which participants of the study had a benefit regarding to the three goals regarding *alertness*, *affective behavior*, and *movement*. Such findings could still be inspirational to other researchers from the field with respect to what (not) to do, with respect to be the study design, and the interactive system.

The interaction we chose will only be suitable for a quite limited selection of users. It requires some visual capabilities to fully benefit from the system. Moreover, it is mainly aimed at people that are mainly seated in their wheelchair. This only represents a small subset of the target group. Furthermore, to fully benefit from the interaction some form of cause and effect recognition seems to be needed.

7.8 Conclusion

In this chapter we introduced our interactive ball, an interactive system providing a new type of leisure activity for people with Profound Intellectual and Multiple Disabilities (PIMD). We explained that we aimed to improve alertness, affective behavior, and amount of movement, during the interaction with this interactive ball. To this end, the ball moves, makes sounds, and emits lights based on the users' gross motor movements, focus of attention, and vocalizations. In the long-term we aim for an automated system. Currently, due to technological challenges, we have started with a Wizard-of-Oz approach, in order to test the suitability of such a leisure activity.

As is known for this target group, even the sub-group of participants we selected for a pilot study were not very homogeneous. Therefore, we decided to tailor the interaction for the user group mainly with respect to the type of sounds and actions to respond to. Doing the pilot tests led us to make several changes (intended improvements) of the interactive ball and aspects of the study design. This *tailoring of the intervention* was not the only type of individualization we would use. In discussions with staff it also became apparent that both the *physical evaluation setup of the study*, and the *measurements* should be individualized.

During pilot tests investigating the interaction with the ball with five clients (two or three sessions per person), at least one participant really seemed to enjoy the interaction. The ball seemed to make him more alert, focusing often on the ball. The ball also seemed to make him move with his upper body. The ball even seemed to make him laugh. For such a troubled target group, this was a promising result towards further studying the effect of the interactive ball in a longer-term study.

8

Longterm Evaluation of the Interactive Ball

Do you think we did a good thing Stan?
I mean no one even seemed to notice.
Well sometimes the things we do,
don't matter right now.
Sometimes they matter later.
We have to care more about later sometimes you know.
– Stan and Kyle, South Park s06e09 (2002)

In this chapter we investigate the effect of the interactive ball in an exploratory but structured longer-term user study. We had three goals regarding the impact of the ball on the behavior of people with profound intellectual and multiple disabilities (PIMD), see Chapter 7. One, was to increase the alertness. Two, was to improve shown affect, either due to an increase of shown positive expressions or a decline of shown negative expressions. Three, was to increase the amount of (suitable) movement. Nine people with PIMD participated in this study. They participated in 8 to 10 sessions each, where they played with the interactive ball for 15 minutes. For our study we only analyzed their last 5 sessions with the ball. To investigate possible effects on the targeted outcomes, we compared their behavior during the intervention with that shown during a 7.5 minute period before and a 7.5 minute period after the intervention. For this we used both manual observations (for alertness and affect) and automatic measurements (for movement). Results were mixed but showed positive effects for some participants. Results should be interpreted with care due to the exploratory character of the study. Nonetheless, it seems that interactive technology might offer a suitable leisure activity for some people with PIMD, where individual differences play an important role.

This chapter largely is based on:
R. W. van Delden, S. Wintels, W. M. W. J. van Oorsouw, V. Evers, P. J. C. M. Embregts, D. K. J. Heylen, and D. Reidsma "Do we get your attention?! Looking into alertness, movement and indicators of happiness of people with PIMD upon introduction of a playful interactive product" *in preparation, pp. TBA–TBA*

Some additional information regarding measurements is taken from:
S. Wintels, R. W. van Delden, D. Reidsma, V. Evers, D. K. J. Heylen, W. M. W. J. van Oorsouw, and P. J. C. M. Embregts "Watching TV or playing with an interactive ball? Exploring a new leisure activity for people with PIMD" *in preparation, pp. TBA–TBA*

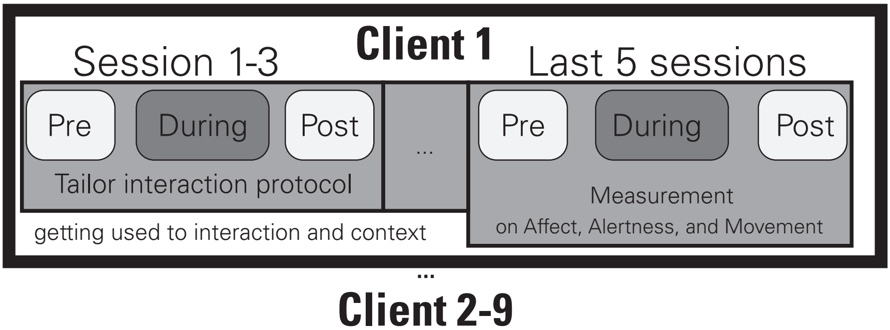


Figure 8.1: Graphical representation of the A-B-A study design of this experiment. Due to large differences per person, comparisons are done on a participant level. Keeping in mind the daily (health) differences (in behavior) results are also reported on a session level per participant. Tailoring of the interaction protocol is done to optimize the chance for success, as this target group shows varying personal preferences for system responses. Fitting the target group's low speed of habituation, several sessions are used for this tailoring, and only the 5 last sessions are used for the outcome measurements.

8.1 Method

We used a case study approach with nine participants studying effects on a per participant level. In this study we compared the behavior shown during interaction with the interactive ball, to the behavior shown during a baseline period with no particular stimuli. In another study we compared the ball to watching TV. A paper on this study is still in preparation, the results are in line with the content of this Chapter but that study was mainly planned and performed by our research partners, and therefore not included in this thesis.

8

8.1.1 Study Design

Doing research on interventions for people with Profound Intellectual and Developmental Disabilities can lead to profound methodological challenges due to the small number of people with homogeneous conditions, fluctuating health differences, contextual differences, and the longer treatment time that is required [248]. Especially if new interventions are researched on a possible health related effect, additional care should be taken in the research design, and in interpretation of the results. This will often require additional ethical considerations. Brodin and Renblad also explain that some complicated ethical considerations arise for doing research with people with cognitive disabilities [40]. Many studies investigating PIMD include a limited number of participants, and tend to perform use case studies to compare an intervention to some baseline intervention [90, 138, 248].

Building on the findings of Chapter 7 and this related work, we used an A-B-A design with multiple measurements of the same individual in two conditions, and did this for 9 participants, see Figure 8.1. Every session consisted of (A) a 7.5 min period of habituation/rest before the intervention, then (B) a 15 min intervention (an interactive ball), followed by (A) a 7.5 min period of rest after the intervention. Every participant with PIMD followed eight to ten interactive ball sessions, only one

Table 8.1: The inclusion and exclusion criteria used for selection of the participants.

Inclusion criteria	Exclusion criteria
Had a profound intellectual disability	Had a too severe lack of balance to be able to interact with the ball
Had severe physical disabilities	Had a too severe hearing impairment to be able to hear sounds produced by the interactive ball
Depended on intensive support regarding all aspects of daily life	Had a too severe visual impairment to be able to recognize the ball to some extent.
Visited day support at care organization Dichterbij	Had a visual focus of attention that was not recognizable to third parties (to manually annotate alertness)
Was between 18 and 65 years old	Had a severe form of epilepsy which would easily be triggered by the interactive ball
	Was at great risk for overstimulation
	Was expected to experience significant physical discomfort when participating in this study
	Was at high risk of serious resistance
	Was known to have dementia

per day.

The first three sessions functioned as habituation sessions to get used to the interactive ball and the room where the sessions took place. Furthermore, they were used to adapt specific parameters of the interactive ball to the participant's individual preferences, see intervention section. Analyses were based on the results from the last five sessions of each participant. For this study we obtained approval by the Medical Ethical Committee of the MST (regional hospital in Enschede, the Netherlands) *Study P14-08, dossier NL48070.044.14*.

8.1.2 Participants

Based on the findings of Chapter 7 it seems that consideration of the type of participants is essential. Furthermore, as we will show in the analysis of our study, it was important to consider the characteristics of the participant in the analysis. In this section we therefore also include a more detailed description of each participant. Besides numbering of the participants, we introduce fictitious names to improve readability, for instance P3. Irene.

8.1.2.1 Inclusion- and Exclusion Criteria

We selected participants based on several inclusion- and exclusion criteria. Participants had to meet all of the above criteria for inclusion and none of those for exclusion, see Table 8.1.

8.1.2.2 Demographics

Originally, ten people with PIMD participated. One participant was withdrawn during data collection due to severe lung problems. Three males and six females had ages ranging from 24 to 62 years (M = 50, SD = 11). Six participants had profound levels of Intellectual Disability (ID), which was based on outcomes of the Vineland Adaptive Behaviour Scales [237]. According to DSM-V criteria [9] the remaining

Table 8.2: Demographic characteristics of participants. The descriptions are used with permission of Dichterbij. The information provided is based on the participants' psychologist, service coordinators, and individual support plans. All participants also have profound ID.

P	M/F	Age	Medical diagnose(s) and disorders	#	Description
1 Bernard	M	62	Cerebral palsy, psychomotor retardation, reduced vision, epilepsy	10	Social, happy, irritated at ill-favored actions
2 Lora	F	48	Cerebral palsy, Angelman syndrome, psychomotor retardation, epilepsy, able to crawl and assisted do steps	10	Social, cheerful, happy, curious
3 Irene	F	52	Cerebral palsy, psychomotor retardation, microcephaly, reduced vision, epilepsy, no cause-effect cognition	10	Calm, content, sleepy
4 April	F	47	Psychomotor retardation, microcephaly, able to toddle, cause-effect cognition	10	Social, spontaneous, opinionated, cheerful, energetic, agitatable, impatient
5 Gretchen	F	48	Cerebral palsy, psychomotor retardation, reduced vision, epilepsy	9[b]	Peaceful, outdoorsy, happy, timid, sleepy
6 Yuri	M	24	Reduced vision, epilepsy, spasm, short-breathed phlegm over-production	10	Happy, alert on sounds ritual recognition,
7 Harold	M	57	Epilepsy, seemingly understands simple spoken language	8[a,b]	Fond of personal contact, cheerful, opinionated
8 Gabriela	F	59	Spasm, encephalitis	9[b]	Anxious, restless, agitated, cheerful and content at times
9 Pauline	F	56	Epilepsy, understands recurrent activity preparing sentences	10	Cheerful, content, tired, fond of individual attention

a) Session dropped as participant had an epileptic seizure at start of a session.

b) Session dropped as the ball stopped functioning appropriately

8

three participants had profound levels of ID as well, but severity of ID was based on clinical judgments of participants' psychologists and service coordinators ($n = 3$). All but one participant had 24/7 residential support at Dichterbij, P6. Yuri only received day support. Characteristics of individual participants are described in keywords in Table 1, and in a more extensive description in the following section.

8.1.2.3 Participant Descriptions

P1. Bernard is a 62-year-old male with profound ID that due to a peritoneal infection (i.e. infection in the thin tissue that lines the abdomen) in the first year of his life suffered brain damage, resulting in cerebral palsy, profound ID, psychomotor retardation, reduced vision, and epilepsy. His epilepsy is under control with medication, he occasionally gets an absence. P1. Bernard sits in a custom-made wheelchair. He expresses himself by the use of body language and vocalisations. He can be described as a happy and cheerful man, who likes to laugh. He is also a social man and likes to be in contact with the people around him. P1. Bernard thrives on experiencing things, and falls asleep easily when he gets bored. Although he likes to be stimulated, he can become tense and irritated in reaction to stimuli he does not like.

P2. Lora is a 48-year-old female with Angelman syndrome (a genetic disorder with various (side) effects) and profound ID. She suffers from spasm, psychomotor retardation, and epilepsy (absences). P2. Lora is able to stand and walk short distances with assistance. She can also crawl, but needs stimulation to do so. Usually she is seated in a wheelchair with the possibility to propel it (with her feet on the ground). She laughs a lot and frequently bends her hands and arm under her chin. She also likes to put things in her mouth, usually her fingers. To prevent infection she wears mittens on her hands when she has no objects in her hands. P2. Lora is very curious and keeps an eye on what is happening around her. She enjoys to be around people and especially around men she is extremely happy. She seems to understand situational communication and communicates through facial expressions, vocalisations, and non-verbal body language. P2. Lora finds it difficult to wait her turn and can become restless and anxious when she gets no attention.

P3. Irene is a 52-year-old female with profound ID and cerebral palsy. She also suffers from psychomotor retardation, microcephaly (small head circumference), reduced vision, and epilepsy. She has her personal custom-made wheelchair. Her preferred position seems to be lying on her back. She is described as a calm and content female. She does not seem to establish connections between events and only reacts to what she experiences at that moment. The support staff is uncertain about whether she recognizes persons and situations, as she shows no clear reactions. It is a challenge to activate her, as she often dozes off during activities. P3. Irene scratches herself often and sometimes wears mittens to avoid scratching. The cause of the tendency for her scratching behavior is not (yet) known.

P4. April is a 47-year-old female with profound ID, psychomotor retardation, and microcephaly. She likes freedom to move and moves around in a (wheel)chair by propelling it with her feet. Support staff describe her as an open, spontaneous, and active woman. She enjoys attention and contact. She seeks companionship by moving towards people, leaning against them and/or looking at them. She seems to recognize recurring situations and objects. She can clearly identify what she does and does not like, with the use of body language and vocalizations (laughing, screaming). She likes to be busy with something, for example with her toys that are fixed to her wheelchair, and needs variation in her activities. She does not like crowds, uncertainty, and waiting. P4. April can be very cheerful but also angry or agitated.

P5. Gretchen is a 48-year-old female. She has cerebral palsy, psychomotor retardation, reduced vision, and profound ID. She also suffers from a severe form of epilepsy, which means that she has multiple seizures combined with muscle spasms during the day. P5. Gretchen sits in a custom-made wheelchair. She is described as a generally peaceful and happy woman who usually sits quietly with her thumb in her mouth. She also likes to suck other materials, for example her scarf. She enjoys physical contact, sensory stimulation, and being outdoors. She does not like crowds and unexpected touches, sounds, and movements. It is a challenge for her to stay awake and alert during the day; she easily falls asleep and remains sleeping. P5. Gretchen expresses (dis)likes by body tension and facial expressions.

P6. Yuri is a 24-year-old male. Due to severe brain damage he has profound ID, spasm, and reduced vision. He also suffers from epilepsy, and congestion/shortness of breath due to over-production of phlegm in his lungs. He receives day care at the care organization but lives at home with his family. He is in a custom-made wheelchair. Due to increased body tension and deterioration in his physical condition, it is important to vary with different postures, mainly in the forms of lying on the side and lying on a water bed or hammock. He is a happy young man, whose life is determined to a great extent by his physical condition. He does recognize daily recurring rituals at the day support center. He also recognizes voices of known and trusted people around him. He is very alert to sounds and voices, and looks to see where they come from. P6. Yuri communicates through facial expressions and sounds. However, his signals can have double meanings, which makes it difficult to assess his signals correctly.

P7. Harold is a 57-year-old male. Due to encephalitis (inflammation of the brain) as a 1-year-old he suffers from profound ID and a severe form of epilepsy[1]. He is seated in a custom-made wheelchair. He is described as a cheerful middle-aged man, that enjoys personal contact. He expresses himself through facial expressions, and by pointing and shouting. He is able to make his own choices and would like to be heard herein. P7. Harold does seem to understand simple spoken language, his abilities do vary during the week depending on his physical condition.

P8. Gabriela is a 59-year-old female. Due to encephalitis in childhood, she suffers from profound ID and spasm. Since the encephalitis she became very anxious and restless but at times also cheerful and happy. P8. Gabriela is seated (also at nights) in a custom-made wheelchair. Due to her spasms, she makes uncontrolled movements with her arms, legs and head. She expresses herself through body language (muscle tension), facial expressions and vocalisations. She can be very content and relaxed, and is able to make sounds indicating that she is content. However, P8. Gabriela frequently shows restlessness, muscle tension, and agitated behavior. She needs to be seated at a place where she can oversee her surroundings and stay in contact with her support staff. P8. Gabriela likes to be approached in a humoristic way with a cheerful tone.

P9. Pauline is a 56-year-old female. She has profound ID and a severe form of epilepsy. She is a cheerful and content woman, but her appearance is strongly influenced by her epilepsy. During the day she can have multiple seizures, absences as well as tonic-clonic seizures. She has a wheelchair, but also sits in a regular chair. When support staff is not near she wears a safety helmet. She enjoys individual attention and activities like bathing or painting nails with support staff. She communicates through body language, for example, her face lights up when she is happy. She understands simple spoken recurrent sentences as preparation to an activity. Due to her epilepsy, she can be very tired and sleepy during the day. When P9. Pauline is having a good (clear) day she can make eye-contact and likes to keep an eye on her surroundings.

8.1.3 Intervention

In this exploratory effect study participants followed a series of interactive-ball sessions. As explained in Chapter 7 the interactive ball central in this study concerned the interactive body-controlled, physically present object of about 50cm in diameter, that was specifically designed for these sessions: see also Figure 8.2 for the version of the ball used in this study. The ball reacted to behavior of participants by moving to the right and to the left, playing a beep, playing different sounds, and/or showing LEDs in different colors. We played the sounds (e.g., virtual instruments, animal sounds and bells) on standard PC speakers in front of the participant. The ball was painted in yellow with blue figures to create a higher contrast. For P5. Gretchen, we

[1]Although he had severe epilepsy we (based on and in discussion with the support staff) did not expect that it would easily be triggered due to the ball.

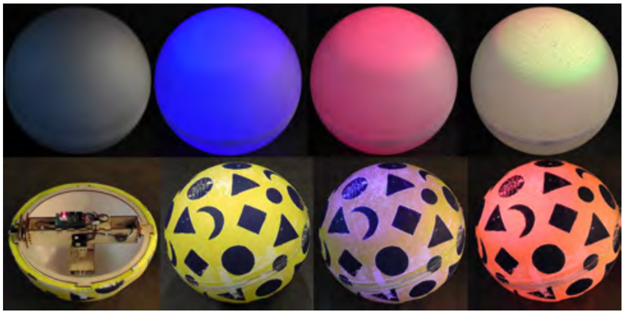


Figure 8.2: The movable remote controlled interactive ball of 50cm. Shown emitting different colors, both with the painted (blue yellow / high contrast) and more transparent white outer shell.

used a white ball cover, as she seemed to react positively to a more transparent cover which showed the colored LEDs better.

Responses of the interactive ball depended on the behavior of the participant and were previously recorded in a protocol. This protocol mapped the possible actions of the participant to a fitting response of the ball in order to standardize the interaction pattern across the sessions, see Table 8.3.

We based the type of actions of participants to respond to on those actions we saw during pilot sessions with five other participants. Based on the first three sessions we extended this protocol for a few participants' actions we had not encountered before[1].

In the first three interactive-ball sessions the interactive ball was also adapted to the individual preferences of each participant in consultation with the support staff. We did this in order to maximize the impact of the ball in this study for this varying target group. This tailoring to the preferences and capabilities of the user is important for activities for people with profound intellectual disabilities, and has been suggested for visits to multi-sensory rooms [72] and music therapy [248]. The pilot sessions in Chapter 7 also confirmed the advice to adapt to both preferences and capabilities of the participants. Besides responding to the different actions of users, the actions thus also generated different effects in the ball. We could change sounds, movement speed, the ball cover, and the use of LEDs. For example, some sounds were excluded for P1. Bernard because he reacted anxiously to those sounds.

We originally set out for a fully automatic system that would allow the participant to interact with it independently. During the pilot sessions we realized it was too technically challenging to respond automatically to a variety of inputs accurately. For instance, applying Microsoft Kinects' skeleton tracking (Kinect for Windows SDK 1.8) and facial tracker was not satisfactory. For this target group the face and pose recognition was too noisy and inaccurate, this might be explained by the tendency of many clients to turn away from the Kinect sensor, obscure their face with clothes, a scarf or their hands, and have their limbs rotated in an unusual way. Instead of focusing on overcoming such (technological) challenges for this user group we viewed it to be more important to first investigate the suitability, and possible benefits of our

[1] P4. April, touching a toy chain : move ball to that end and turn on blue LED.
P5. Gretchen, head straight up : short sound and turn on red LED
P5. Gretchen, wiggle feet : wiggle ball, play short sound and turn on yellow LED. This interaction is interpreted differently from 'wobble leg' as it was one of her few movement possibilities.

8

Figure 8.3: The setup of one of the two rooms used in the study. Three cameras and a Kinect are facing the participant. The ball is placed on a table with a small barrier/gutter to prevent movement in an unwanted direction.

envisioned product. Therefore, during this study one of the researchers observed the actions of the participant and remote controlled the interactive ball based on the predefined interaction protocol. To this end we made a small program to facilitate this. The ball could be controlled by pressing the arrows (movement), numbers (LEDs), and letter keys (sounds) on a laptop that communicated with the ball via Wi-Fi. To keep a close link with future extensions towards autonomous devices, we did stick to gross motor movements and vocalization input that might be detectable in the near future.

8.1.4 Data Collection Instruments

Video recordings were made of all ball sessions from three angles with Panasonic HC-V520 cameras, see Figure 8.3. These recordings were assessed using two observation systems, one for alertness, and one for affective behavior. The video recordings from the middle camera were also used to measure the amount of movement (semi-)automatically with a simple computer vision implementation.

8.1.4.1 Alertness - Alertness Observation List (AOL)

To assess alertness, we adapted the observation list of Vlaskamp et al. (2003) [267]. The resulting observation system consisted of five alertness levels: (1) Not alert (e.g., sleep, stare), (2) Alert, self-directed (e.g., touch own clothing, stereotypical behavior), (3) Alert, directed at environment or other non-person stimuli (e.g., look around/explore room), (4) Alert, directed at people (e.g., make eye-contact), and specifically for the present study, (5) Alert, directed at the ball. To annotate the different levels of alertness we used momentary time sampling (MTS) with intervals of 10 seconds (alertness levels only on each 10 second step)[1]. Annotation with this

[1]This annotation of video material was performed by our research partners that were more experienced with this user group.

Table 8.3: Interaction protocol of the interactive ball including the keys to be pressed, based on actions seen during the pilot sessions of Chapter 7, and adapted for participants the first three sessions of this study. These included exclusion of sounds, interpretation/addition of actions, and a slight change in the movement speed of the ball.

Action client	Response ball system	Action client	Response ball system	Action client	Response ball system
reach towards ball	non-short sound : RTYU away from hand while hand is kept out	leans back	closest end (keep bumping at end)	stretches feet, (up some time)	non-short sound RTYU green leds and change color 5
move both hands	non-short sound RTYU to the end of both hands* turn on blue led lights 1	leans forward (longer and slower)	non-short sound QWE, last direction (switch direction at end) turn on yellow leds 3	kick feet	short sound per kick QWE half way to end of that foot's, next time to end, wiggle if both
grab wheel of chair	to the end that is grabbed	move forward/ backward	short sound QWE	wobble leg	Wiggle ball purple leds and change color 6
touch wheelchair	a sound QWERTYU	shoulders up/ sits up	non-short sound RTYU, wiggle, turn on cyan leds 4	ball in focus	towards biggest space left, return at end play a sound QWERTYU
move R/L hand up	Wiggle ball, turn on blue led 1	leans head on arm	(every 7s) short sound QWE, towards that end	ball in focus long >2 min	add; purple leds and change color 6
move R/L hand toward right or left	short sound QWE, that direction (keep bumping at end)	leans head and body to R/L side	short sound QWE further towards that direction (keep bumping at end)	NO interaction/ out of focus for >20s (repeat +-7s)	1st:towards focus or wiggle in middle if no detectable focus 2nd /60s; move + play ball's tune 3rd /90s: move+ tune + green leds and change color 5 4rd /120s: move+ tune + leds + a sound QWERTYU
move R/L hand down	short sound QWE, turn on leds in red color 2	vocalisations (if >3 min no interaction)	interactive, QWERTYU* add: towards focus or middle if no detectable focus + beep from ball		
		laughs	Play a sound QWERTYU this triggers a feedback loop		

GENERAL INSTRUCTIONS—
4x no 'reaction' change sound to next in cat and if multiple cat also go to next cat in this set
Wiggle with is a small left and right, the ball moves but should not really roll

*if not same dir. roll back and forth half way
**interactive sound: same vocalisation same sound

8

observation system resulted in one alertness score for every interval. After a period of rehearsal, two raters independently scored 20% of all sessions. The overall inter-rater agreement between the two raters was measured using Cohen's kappa; an agreement of $\kappa = 0.795$ was reached. This was considered good enough for our further analysis in comparison to Krippendorff's threshold of 0.8 [121, 122]. [1]

8.1.4.2 Affective behavior - A tailored observations scheme

In order to assess negative and positive affect of participants we used the approach of Wintels et al. (2014) for annotating affective behavior [278]. The system discerned two scales: (1) negative affect and (2) positive affect. Negative affect had three categories, namely: (a) aggressive/physically agitated behavior (e.g. pushing, biting, negative facial expression), (b) physical non-aggressive behavior (includes stereotypical behavior), and (c) verbal agitated behavior (e.g., screaming). Positive affect consisted of (a) facial expressions as indicators of happiness (e.g., smiling) and (b) vocalizations as indicators of happiness (e.g. laughing vocalizations). To take the idiosyncratic behaviors of the user group [90] into account for each participant we also included individual indicators for affective behavior based on input from the support staff, as suggested by Dillon & Carr (2007) [65]. Wintels et al. (2014) found a 'substantial' ($\kappa = 0.70$) and 'almost perfect' agreement ($\kappa = 0.90$) for respectively positive and negative affect [278]. In the present study, two raters first practiced with the observation system affective behavior. After a rehearsal period, both raters independently scored 20% of all sessions to determine inter-rater agreement. In order to compute Cohens kappa, all indicators for negative affect and for positive affect as well were merged. The inter-rater agreement was considered good enough for our further analysis for both positive affect ($\kappa = 0.91$) and for negative affect ($\kappa = 0.79$), in comparison to Krippendorff's threshold of 0.8 [121, 122].

8.1.4.3 Movement - Simplified Motion Energy Analysis (SMEA)

To measure the amount of movement we implemented a computer vision method similar to the motion energy analysis (MEA) by Ramseyer and Tsacher (2011) [208]. A more comprehensive implementation called motion history was successfully used for tracking movement of people with severe and multiple disabilities [103]. We adapted these two methods to a simpler method that measures overall movement, which we will call Simplified Motion Energy Analysis (SMEA). We used a computer program framework based on OpenCV 2.1 to implement a way to do the SMEA. The SMEA measured the amount of movement which was based on the difference in pixels between video frames, see Figure 8.4 for a visual description of the SMEA[2]. This framework allowed us to perform the following steps:

1. grab frames from the video of the middle camera facing the participant
2. convert them to grayscale
3. crop the images to a fixed region per session to record the movement of the user in the image and not other people sitting to the side of the room

[1] A more detailed analysis of inter-rater agreement will be made available in another publication by Wintels et al. that is in preparation, details of this paper are mentioned on the first page of this Chapter.

[2] Our software and this 'pipeline' of operations we used can be downloaded for free from `https://github.com/Robnocop/parlevisionBin`.

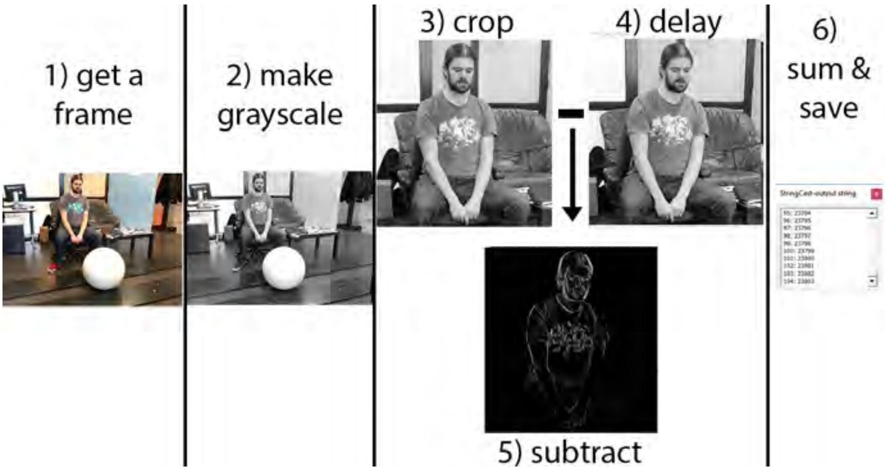


Figure 8.4: Graphical representation of our SMEA procedure, using a recording of testing the ball with a friend as an example. This SMEA procedure is done for each frame of the video. It results in the sum of the grayscale differences between frames (0-255) for each pixel of the cropped image (in the range of 0 to 255 x number of pixels).

4. copy and delay a reference frame with 2 frames, which equals a 2/25 second time span
5. subtract this from the current frame, sum the absolute difference in pixel values from these 'subsequent frames' [1]
6. save this to a text file

8

This leads to many measurement values ($25 * 60 * (7.5 + 15 + 7.5) = 45.000$) representing movement per session. We filtered out some noise by removing zero values (some dropped frames occurred) and applying a 3-sized median filter. We averaged the remaining values over 20-second slots, and then normalized in order to make the values somewhat comparable between sessions. For this, we subtracted the average movement of that entire session from these values. This simple normalization method, allowed comparing between conditions (within sessions), and allowed us to deal with noise levels (that differ mainly between sessions). Values below zero for a condition, are those where the participant moved less than average. Nonetheless, one should take care in comparing between sessions, as the differences in positioning the participant, cropped area, or amount of sunlight that day, can have a noticeable influence between sessions on how the values change with the same amount of movement.

We inspected the (noise) peaks of movement data in combination with the actual behavior. We manually annotated whether occurring peaks in measured 'movements' were due to actual movement of the participant. Some parts of the sessions needed to be taken out, the moments in which the change could be partially attributed to something other than movement of the participant, for example, support staff needed

[1] Instead of using the actual absolute difference in values, counting the pixels that changed beyond an appropriate value with a background subtraction method gave similar results.

to wipe a participant's chin, or due to camera's automatic change of color filter. The remaining values were assigned to the proper condition and session.

8.1.4.4 Interview Guide

To improve our insight into the applicability of the ball regarding the outcome measures, we created an interview guide to perform a semi-formal semi-structured interview with the staff members after the sessions. This was only a secondary source of information, and therefore not analyzed and reported in-depth. These semi-structured interviews included 35 questions, that covered the following topics regarding their interpretations of : 1) the response of the client (sounds and lights), and the changes in alertness, affective behavior, and movement, 2) the appreciation, what parts were like/disliked by the clients, 3) suggestions for improvement, 4) added value of the ball, and 5) the suitability for clients, for whom it would be usable.

8.1.5 Procedure

Ten people with PIMD were selected by a team of researchers, service coordinators, and daily support staff. All support staff members were provided with research information letters and were requested to give their written consent, as they were present during the sessions and (partly visible during) the video recordings as well. We approached legal representatives with help of support staff and service coordinators to give written consent on behalf of the participants with PIMD. Information letters and written consent forms were sent or hand-delivered. After receiving consent forms, we interviewed support staff about behavioral indicators of positive and negative affect of each individual participant. We also interviewed support staff members twice about the interactions with the ball, for each participant we did this at the end of the first week of sessions, and after finishing all sessions.

All sessions took place in a small conference room (n = 5) or empty living room (n =4) at the participant's day-support center, see Figure 8.3. A total of six participants had to postpone their last session from Friday to Monday (n = 2) or to Wednesday in the third week (n = 4), due to technical problems with charging the ball (n = 2) and a group outing (n = 4). The number of sessions with the interactive ball also varied across participants. Due to technical problems (e.g., ball was defect) (n = 3) or an epileptic seizure (n = 1), the number of sessions with the interactive ball varied between eight (n = 1), nine (n = 2), and ten (n = 6) sessions. All sessions were video recorded from three angles and combined to one video file for manual annotation with the tools below. The video recordings from only the middle camera were used to measure the amount of movement. In total we had 86 sessions (6x 10 sessions, 2x 9, 1x 8), a total of 2580 minutes of video recordings, 1350 minutes used for quantitative analyses.

After tailoring the protocol to a participant in the first three sessions, no more changes were made and it remained fixed for the remaining (five to) seven sessions, including all the sessions that were used for analyses.

Raw data were archived within a protected environment which was in accordance with the guidelines of both Tilburg University and the University of Twente. Data were merged by creating one movie file for each session, syncing them based on the audio, and adding an enlarged feed of the participants' face from the middle camera. Sessions were divided across two raters and subsequently annotated. Ratings from both observation systems were analyzed using Microsoft Office Excel and IBM SPSS Statistics 22. To perform the SMEA we started with manually setting the area to be analyzed, and filtering out noise, this required inspection of the (noise) movement peaks in combination with the actual behavior. In this process we used Matlab R2012a to filter out the to be omitted moments and to visualize the results.

8.1.6 Data Analyzes

The data was analyzed and presented on an individual basis, fitting the heterogeneous character of the group. Furthermore, we report descriptive statistics only. For the overall estimates of the participants with regard to the intervention, the impressions are based on visual inspection, comparison of the values, and discussions with both staff members and amongst researchers. Partially this was informed by the semi-structured interviews, for analyses hereof we chose a semi-formal approach: to summarize these qualitative insights we recorded the interviews, listened again to the questions of interest, and used our interview notes.

8.2 Results

For all participants, Table 8.4 presents the numeric average of alertness, Table 8.5 presents the numeric average of the affective behavior, and Table 8.6 presents the numeric average of movement. In Figures 8.7 and 8.8, we also visualize these same affective behavior results. In Figures 8.5 and 8.6 we visualize the results regarding alertness. Regarding the movement Figures 8.9 and 8.10 show the SMEA results in more detail, also including the movement over time during each session.

A condensed estimate of the overall results per participant is depicted in Table 8.7. In this results section we mainly report the mean values over all sessions per participant, for instance (**M** = 9%) is reported as (9%) unless indicated differently. Before describing these quantitative results regarding alertness, affective behavior, and movement of the participants, we summarize the most important remarks and feedback we have gotten from the involved support staff members in order to better contextualize the meaning of the results with regard to individual differences, and possible shortcomings of the device and study.

8.2.1 Feedback Staff Members

The following feedback is based on the semi-structured interviews, remarks that were made by the staff members, and observational notes of the researchers made after the sessions. This mainly concerns the difference in appropriateness of the ball per participant, the appropriateness of the chosen modality and how the ball relates to social interaction, and the day-to-day contextual differences for participants that might be of influence.

Several staff members remarked that the impact of the interactive ball is ambiguous: for some of the clients the intervention might well be beneficial, however, it would add only little for others. The type of intervention and how well it fits the interests of the participant might have influenced the habituation process and general liking of the interaction. For instance, the staff member present at the sessions of P7. Harold, suggested that for him a tangible device that he could hold and touch,

Table 8.4: Alertness total as annotated for 5 ball session, showing percentage of interval scores before (B, 7.5 min), during intervention (D, 15 min) and after intervention (A, 7.5min). In this table 's-d' is used for self-directed, 'env.' is used for environment, we highlighted noteworthy results in light gray mark (positive) and dark gray (negative).

		Not Alert			Alert, s-d			Alert, ball			Alert, env.			Alert, person		
P	S	B	D	A	B	D	A	B	D	A	B	D	A	B	D	A
1	I	2	23	31	49	56	38		8		40	11	18	9	2	13
	II	0	2	0	29	29	31		16		62	48	67	9	6	2
	III	0	0	0	38	54	58		10		49	31	38	13	4	4
	IV	27	69	100	33	9	0		7		38	14	0	2	1	0
	V	44	77	4	47	17	22		4		7	2	56	2	0	18
	I-V	15	34	27	39	33	30		9		39	21	36	7	3	8
2	I	0	0	0	36	10	58		44		36	9	9	29	37	33
	II	0	0	0	4	10	24		50		9	0	2	87	40	73
	III	0	0	0	36	7	33		24		9	1	20	56	68	47
	IV	0	0	0	2	6	62		28		18	4	7	80	62	31
	V	0	0	0	42	6	38		44		4	0	2	53	50	60
	I-V	0	0	0	24	8	43		38		15	3	8	61	51	49
3	I	0	0	0	67	74	60		6		29	20	38	4	0	2
	II	13	2	53	62	61	38		10		24	27	9	0	0	0
	III	2	3	31	82	64	62		28		16	3	7	0	1	0
	IV	31	84	76	69	16	13		0		0	0	11	0	0	0
	V	7	18	69	60	54	13		6		33	22	18	0	0	0
	I-V	11	22	46	68	54	37		10		20	14	16	1	0	0
4	I	0	0	0	27	7	18		51		38	36	62	36	7	20
	II	0	0	0	64	18	69		47		16	21	27	20	14	4
	III	0	0	0	53	22	62		48		20	23	7	27	7	31
	IV	0	0	0	38	27	44		41		40	18	53	22	14	2
	V	0	0	0	36	30	64		42		40	14	27	24	13	9
	I-V	0	0	0	44	21	52		46		31	22	35	26	11	13
5	I	27	97	91	64	1	0		0		9	2	9	0	0	0
	II	47	72	100	42	22	0		0		11	6	0	0	0	0
	III	40	83	84	60	17	16		0		0	0	0	0	0	0
	IV	60	82	96	29	13	4		0		11	4	0	0	0	0
	V	33	19	100	42	58	0		10		24	13	0	0	0	0
	I-V	41	71	94	48	22	4		2		11	5	2	0	0	0
6	I	31	19	71	58	24	27		42		11	14	2	0	0	0
	II	49	1	27	27	43	49		39		24	17	24	0	0	0
	III	42	29	69	51	26	13		17		7	29	18	0	0	0
	IV	0	20	80	60	67	20		2		40	11	0	0	0	0
	V	31	22	67	47	31	24		30		22	17	9	0	0	0
	I-V	31	18	63	48	38	27		26		21	18	11	0	0	0
7	I	0	88	87	100	12	13		0		0	0	0	0	0	0
	II	11	6	2	71	63	76		27		18	4	22	0	0	0
	III	11	48	60	84	52	40		0		4	0	0	0	0	0
	IV	76	47	47	20	53	53		0		4	0	0	0	0	0
	V	56	26	24	27	64	73		10		16	0	2	2	0	0
	I-V	31	43	44	60	49	51		7		8	1	5	0	0	0
8	I	71	29	11	29	53	44		4		0	13	44	0	0	0
	II	62	9	9	31	59	82		9		7	23	9	0	0	0
	III	18	9	16	60	54	56		7		16	22	18	7	8	11
	IV	2	0	0	62	80	82		6		16	14	18	20	0	0
	V	91	27	0	9	60	64		3		0	10	36	0	0	0
	I-V	49	15	7	38	61	66		6		8	17	25	5	2	2
9	I	0	0	0	49	41	67		31		47	27	31	4	1	2
	II	40	13	93	49	66	7		14		9	7	0	2	0	0
	III	84	82	98	11	10	2		0		4	8	0	0	0	0
	IV	100	90	100	0	9	0		0		0	1	0	0	0	0
	V	0	0	0	47	49	49		18		53	33	51	0	0	0
	I-V	45	37	58	31	35	25		13		23	15	16	1	0	0

might be of more interest than the ball. Focusing on other modalities and means of interaction was also suggested by support staff for some other participants.

On the one hand, staff members suggested that a lack of social interaction and lack of social physical contact could also play a role in the limited effect of the ball. For instance, P7. Harold was able to be alert and move when he was triggered with social interaction by his supporting staff member after the sessions. The ball simply did not suit his needs. He did (and thus was able to) notice the ball at times and followed it with his eyes, but showed no interest in it.

On the other hand, regarding the aspect of social interaction, it was interesting to see that P2. Lora and P4. April showed alertness to people throughout the sessions. During playing with the ball this behavior was interpreted by one staff member as if the participants wanted to share their enjoyment and laughter.

For some participants there were day-to-day differences in the behavior of the participants, that also led to difference between the conditions from day to day. This could be dependent on the day they had had so far. When asking the staff members about this, several times we heard about other activities and events they had that day, these included: took a shower just before the session, had a visit to a Jacuzzi, only just woke up, slept too little, had a seizure that day, had interactions with their favorite staff member, or had a prolonged walk to the location itself. It was likely that for some participants such contextual factors had an influence on the results for that session or even on a number of sessions. For instance, P9. Pauline had several epileptic seizures in one week, unrelated to the interaction with the ball according to the supporting staff. The tiring effect of these seizures seemed to influence her overall alertness levels and ability to interact in a negative manner.

8.2.2 Alertness

For P2. Lora, P4. April, and to some extent P6. Yuri, during the intervention there were higher levels of alertness when compared to the baseline of before and after the intervention. For P1. Bernard the results differed a lot per day but overall there was a slightly negative tendency. For the other participants no clear differences were seen regarding alertness, see Table 8.4.

We will first look in more detail at the participants with positive effects regarding alertness and to what extent this was seen. During the intervention P2. Lora showed a reduced amount of self-directed alertness (8%) and was instead often focused on the ball (38%). Most types of alertness were similar before and after the session, however, after the intervention she tended to be more self-directed (43%) compared to measurements before the intervention (24%). P4. April also showed less self-directed behavior during the intervention (21%) than before (44%) or after (52%). During the intervention instead she often focused on the ball (46%). She showed alertness towards people mainly before the session (26%) and less during (11%) and after (13%). P6. Yuri showed attention towards the ball regularly (26%) during the intervention. The change in alertness did not diminish the alertness towards the environment, the combination (ball + environment) was thus also higher during the intervention (44%) than before (21%) or after (11%). He also slept more after the intervention (63%) and before (31%) than during the intervention (18%).

We will now look in more detail at the participant with negative effects regarding alertness. P1. Bernard did show alertness to the ball but only for a limited amount of time and in a limited number of occasions (9%). During the intervention, he

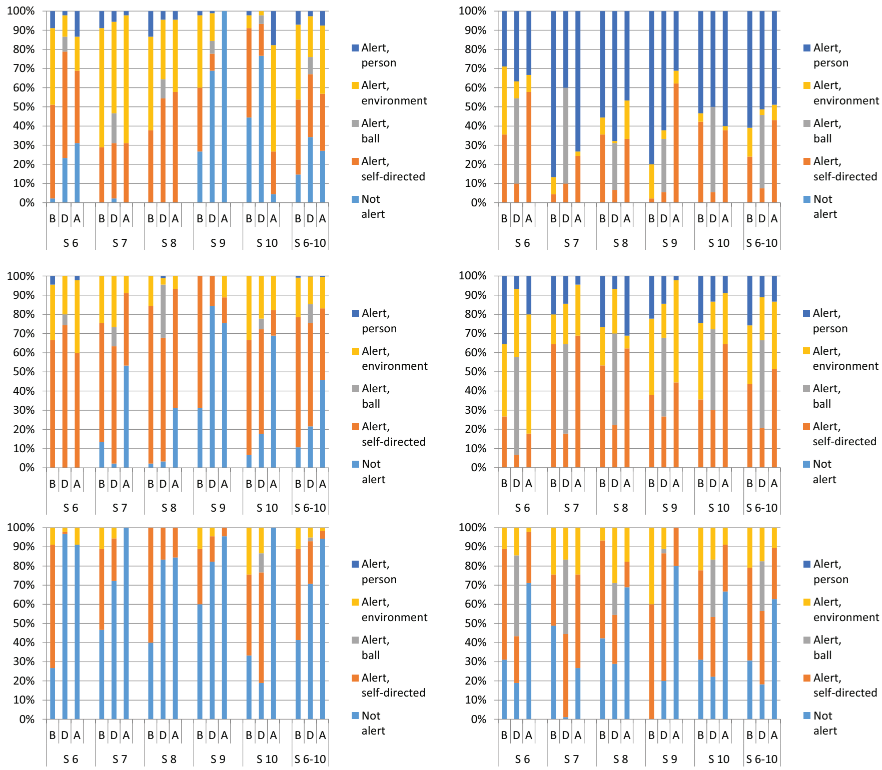


Figure 8.5: Graphical representation of alertness behavior as annotated per session for P1. Bernard, P2. Lora, P3. Irene, P4. April, P5.Harold, and P6. Yuri (from left to right, top to bottom). Where the occurrence rates are indicated for the last five sessions (S#), for the conditions before (B), during (D), and after (A) the interaction with the ball.

showed a decrease of alertness towards the environment and towards people (21%; 3%) when compared to measurements before (39%; 7%) and after the intervention (36%; 8%). Oppositely, P1. slept more during the intervention (34%) as compared to measurements before and after the intervention (14%; 27%), and was less alert to the environment.

8.2.3 Affective Behaviour

For P2. Lora, P4. April, and P6. Yuri there were also improvements during the intervention for the levels of affective behavior. Similarly, for P1. Bernard there were also diminishing levels for affective behavior. For P8. Gabriela the levels also indicated diminishment. For P3. Irene there were increased level of her idiosyncratic stereotypical behavior, which can be regarded as an increase of negative affective behavior. From the remaining participants for both P5. Gretchen and P7. Harold no affective behavior was observed. For P9. Pauline there were no clear differences seen in the amount of affective behavior, see Table 4.

We will first look in more detail at the participants with positive effects regarding affective behavior and to what extent this was seen. For P2. Lora the percentages of

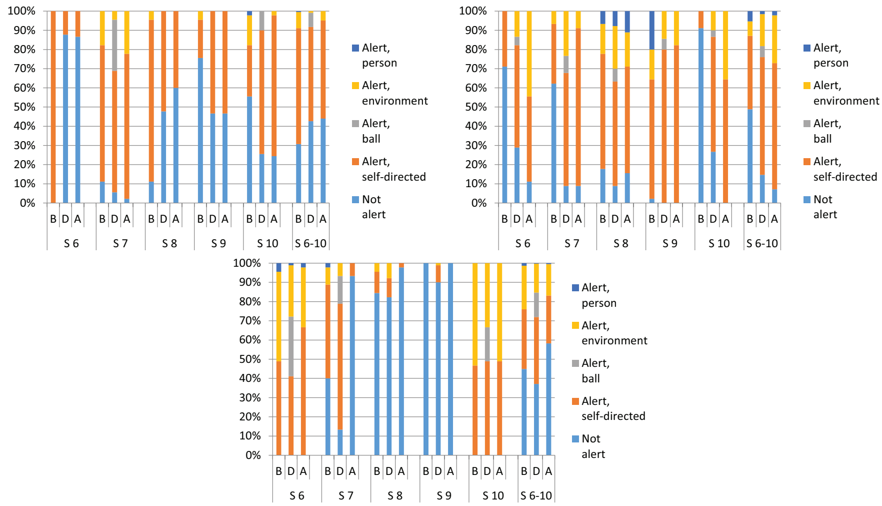


Figure 8.6: Graphical representation of alertness behavior as annotated per session for P7. Harold, P8. Gabriela, and P9. Pauline (from left to right, top to bottom). Where the occurrence rates are indicated for the last five sessions (S#) and average over them, for the conditions before (B), during (D), and after (A) the interaction with the ball.

positive affect were highest during the intervention for both positive facial expressions (78%) and positive vocalizations (60%). Before the intervention she showed more positive affect (22%; 7%) than after the intervention (6%; 4%). No signs of negative affect were observed. For P4. April self-regulatory behavior was seen less during interaction (4%) and more often before (16%) and in a comparable amount after the intervention (7%). During the intervention she showed the most positive affect, both in the form of positive vocalizations (56%) and positive facial expression (69%). Before the intervention started she already showed many signs of positive affect, (36%; 50%), after the intervention the number of occurrences diminished (4%; 11%). P6. Yuri showed more positive facial expressions during the intervention (29%) than before (0%) or after (M = 2%, range 0-11%). He had some positive vocalizations during the interaction (5%) and none before or after the intervention.

We again also look in more detail at the participant with negative effects regarding affective behavior and to what extent this was seen. For P1. Bernard the average percentage of positive facial expressions was lowest during the intervention (M = 5%; range 0-20%), compared to measurements before (M = 10%, range = 2-32%) and after (M = 15%, range = 2-46%) the intervention. For P3. Irene there was an increase in the amount of idiosyncratic behaviors during the intervention, this behavior can be seen as stereotypical behavior, and as such it can be seen as an increase in the negative type of affect. Note that some of the staff members and researchers involved remarked that this fits the set-out analysis but that these types of behavior are not per se actual indicators of negative affect for her. The amount at which she displayed tongue/mouth movement (44%), vocalizations (36%), and to some extent rubbing hands (12%), all increased during the intervention, compared to before (28%,24%,7%) and after (0%,0%,2%). On the other hand, albeit in a very small amount, she only showed some positive facial expressions during the intervention

Table 8.5: Affective behavior in % as annotated, with ISB as short for idiosyncratic behavior.
For P3. Irene ISB 1 = tongue/mouth movement, ISB 2 = vocalizations, ISB 3 = rubbing hands.
For P4. April ISB 1 = upper body movement (rocking), ISB 2 = sad vocalization (different from agitation).
For P9. Pauline ISB = sighing while rotating head, ISB 2 = folding her hands (indicated as positive)

		Positive facial exp.			Positive voc.			Negative voc.			Negative facial exp.			ISB1			ISB2			ISB3		
P	S	B	D	A	B	D	A	B	D	A	B	D	A	B	D	A	B	D	A	B	D	A
1	I	4	1	9	0	1	2	0	0	0	0	0	0									
	II	2	2	16	0	1	4	0	0	0	0	3	0									
	III	33	20	2	4	7	2	0	2	0	0	2	0									
	IV	7	0	0	0	0	0	0	0	0	0	2	0									
	V	4	0	47	0	0	11	0	0	0	0	0	0									
	I-V	10	5	15	1	2	4	0	0	0	0	2	0									
2	I	0	69	4	0	49	2															
	II	62	57	0	16	42	0															
	III	24	92	7	13	72	0															
	IV	13	81	11	4	54	9															
	V	9	93	7	2	80	7															
	I-V	22	78	6	7	60	4															
3	I	0	0	0										36	71	2	40	67	0	18	22	0
	II	0	1	0										33	30	0	27	29	0	4	12	0
	III	0	6	0										44	79	0	31	51	0	2	18	0
	IV	0	0	0										4	0	0	2	0	0	0	2	11
	V	0	9	0										24	39	0	18	33	0	11	3	0
	I-V	0	3	0										28	44	0	24	36	0	7	12	2
4	I	53	68	9	16	49	7							13	7	9	0	0	11			
	II	27	76	2	16	68	0							11	13	13	0	0	0			
	III	71	72	29	53	63	16							22	0	2	0	0	0			
	IV	49	67	2	44	50	0							24	1	0	0	0	0			
	V	51	63	13	49	48	0							11	0	9	0	0	0			
	I-V	50	69	11	36	56	4							16	4	7	0	0	2			
6	I	0	39	0	0	12	0				0	0	0									
	II	0	36	11	0	2	0				0	7	0									
	III	0	26	0	0	6	0				0	0	0									
	IV	0	4	0	0	0	0				4	8	0									
	V	0	42	0	0	4	0				0	0	0									
	I-V	0	29	2	0	5	0				1	3	0									
8	I							11	28	20	18	51	29									
	II							9	44	53	11	51	67									
	III							0	0	0	0	0	0									
	IV							16	73	71	16	79	80									
	V							0	30	42	0	59	67									
	I-V							7	35	37	9	48	48									
9	I	13	17	2										11	17	7	51	56	98			
	II	0	3	0										0	8	0	93	72	100			
	III	0	0	0										0	3	0	0	0	0			
	IV	0	0	0										0	0	0	0	0	0			
	V	0	0	0										0	0	0	0	61	0			
	I-V	3	4	0										2	6	1	29	38	40			

(3%). For P8. Gabriela the number of expressions of negative affect, both in negative vocalizations (35%) and negative facial expressions (48%) was higher during than before (7%; 9%), and was comparable to after (37%;48%)[1].

8.2.4 Movement

For P2. Lora there was a clear increase in the measured amount of movement during the interaction with the ball. For P4. April there was a decrease in the measured amount of movement. For the other participants the movement was similar or diverging too much between sessions to see any trends, see Table 5, and Figure 5 and 6.

[1]This mainly seemed to be a time dependent factor more than a response on the ball, according to care givers she also showed a similar time-dependent increase of agitation in other situations. To some extent her movement and alertness results also showed time dependent trends.

Table 8.6: Amount of movement measured with our simplified Motion Energy Analyses in pixel differences, normalized by subtracting the session average.

P	#	S 1	S 2	S 3	S 4	S 5	1-5
P 1	Before	1267	673	370	543	-871	396
	Intervention	-329	-205	241	-74	-712	-216
	After	-651	-268	-862	-405	2279	19
P 2	Before	-760	434	-479	311	-1163	-331
	Intervention	724	465	759	426	1392	753
	After	-672	-1340	-850	-1179	-2256	-1260
P 3	Before	-48	357	-157	413	218	157
	Intervention	550	257	612	-92	242	314
	After	-1044	-869	-1067	-253	-696	-786
P 4	Before	-137	1577	3838	4721	2337	2467
	Intervention	288	-1937	-262	-1417	-785	-823
	After	-470	2412	-3241	-1649	-1673	-924
P 5	Before	329	77	60	41	5	102
	Intervention	179	78	113	2	92	93
	After	-595	-235	-268	-35	-195	-266
P 6	Before	-286	-52	44	95	9	-38
	Intervention	190	123	58	48	46	93
	After	-70	-167	-169	-160	-96	-132
P 7	Before	313	303	-44	75	-25	124
	Intervention	-77	50	48	33	61	23
	After	-160	-398	-45	-142	-106	-170
P 8	Before	-789	-765	-55	-278	-809	-539
	Intervention	438	142	13	77	190	172
	After	131	531	31	173	439	261
P 9	Before	78	-263	-203	96	43	-50
	Intervention	142	274	148	31	13	122
	After	-364	-298	-98	-145	-71	-195

Only for P2. Lora there was a clear increase regarding movement during the intervention (753) when compared to measurements before (-331) or after (-1260) the intervention. The amount of movement was also more limited after the intervention compared to both during and before the intervention. For clarity, the negative amount of movement means that the participant has moved less than average in that session. [1]

Only P4. April moved noticeably less during the interaction. She moved very intensively before, during, and after the intervention but she did move less during the intervention (-822), than before (2467), or after (-924). The type of movement often differed between conditions. During the intervention she was often moving towards the ball (leaning forward), or moving towards the people. Before the intervention, related to both movement and affective measures, she showed more stereotypical body-rocking (16%) than during (4%), or after (7%), and had slightly more moments in which she played with her toy hanging from her wheelchair (43%) than during

[1] Counter intuitively the three values do not have to sum to zero, as the number of values used per condition will differ due to the removal of noise.

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(33%), and after (33%).

The other participants showed no, limited, or non-consistent changes in movements. For P1. Bernard there was a small trend towards more movement before the intervention (396), than during (-216), or after (18). Visual inspection of the movement over time does not show there is a clear difference between the conditions, see Figure 8.9. P3. Irene moved less after the intervention (-786) than before or during the intervention. On average the difference in movement between before the intervention (157) and during (314) was only very small. For P5. Gretchen her movement was only slightly less after the intervention (-266) when compared to before (102) and during (93)[1]. Most of the time she did not move at all, in some occasions she only turned her head. For P6. The movement was only slightly more during the intervention (93) than before (-38) and after (-132). For P7. Harold the movement was only slightly lower after the session (-170) than before (124) and during (23)[2]. For P8. Gabriela her movement was comparable during (172) and after (261), she was moving less before (-540) as she was then also sleeping more often. For P9. Pauline her movement was only slightly higher during the intervention (124) than before (-51) and after (-197).

[1]For her the range of values for the SMEA were fairly small compared to other clients from the first five sessions. This is due to her restricted movement but also the result of a stricter cropping of the footage. In one of the sessions there was someone also on the other side behind her, we cropped each session accordingly.

[2]During the second session it seemed that there was a larger difference between after (-398) compared to before and during (303;50), which was mainly due to a recognizable change in the automatic color filter of the camera, this was not seen in other sessions.

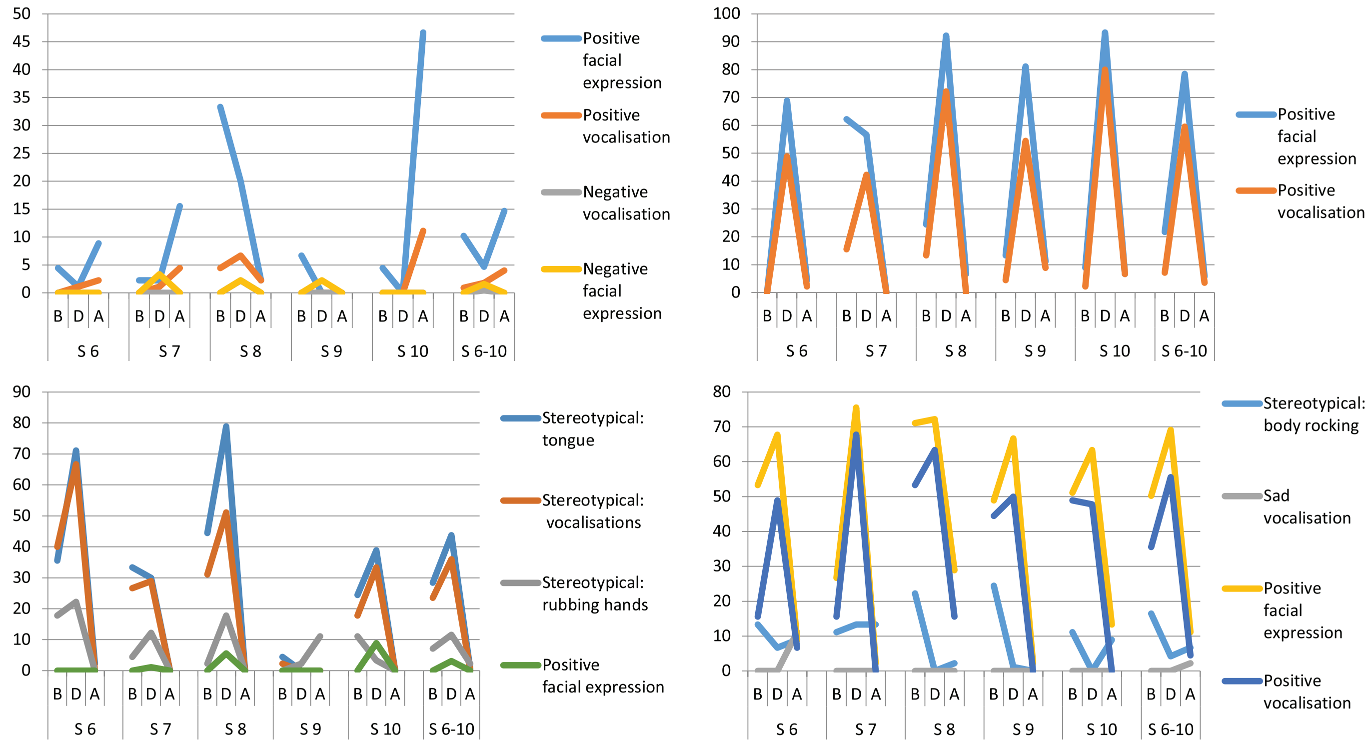

Figure 8.7: Graphical representation of affective behavior as annotated per session for P1. Bernard, P2.Lora, P3. Irene, and P4. April (from left to right, top to bottom). Where the occurrence rates are indicated for the last five sessions (S#) for the conditions before (B), during (D), and after (A) the interaction with the ball.

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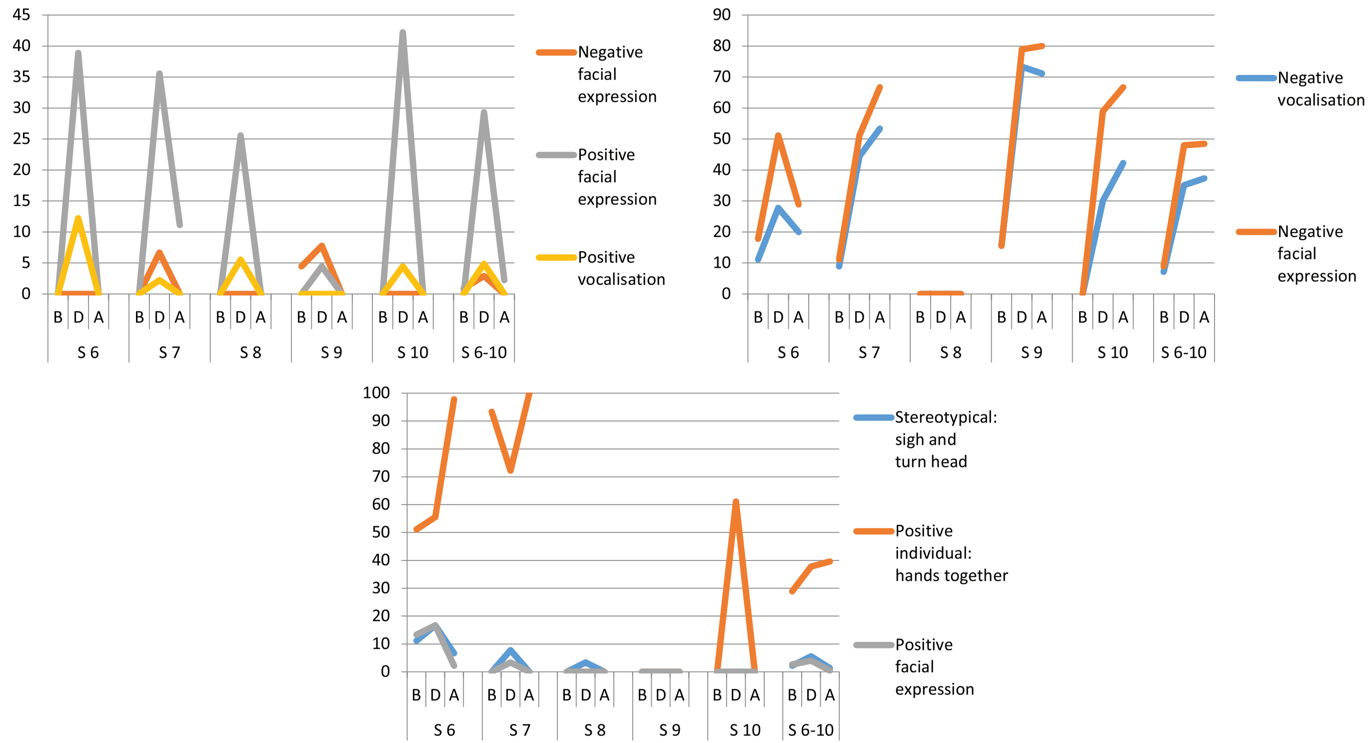

Figure 8.8: Graphical representation of affective behavior as annotated per session for P6. Yuri, P8. Gabriela, and P9. Pauline (from left to right, top to bottom). Where the occurrence rates are indicated for the last five sessions (S#) and average over the sessions, for the conditions before (B), during (D), and after (A) the interaction with the ball.

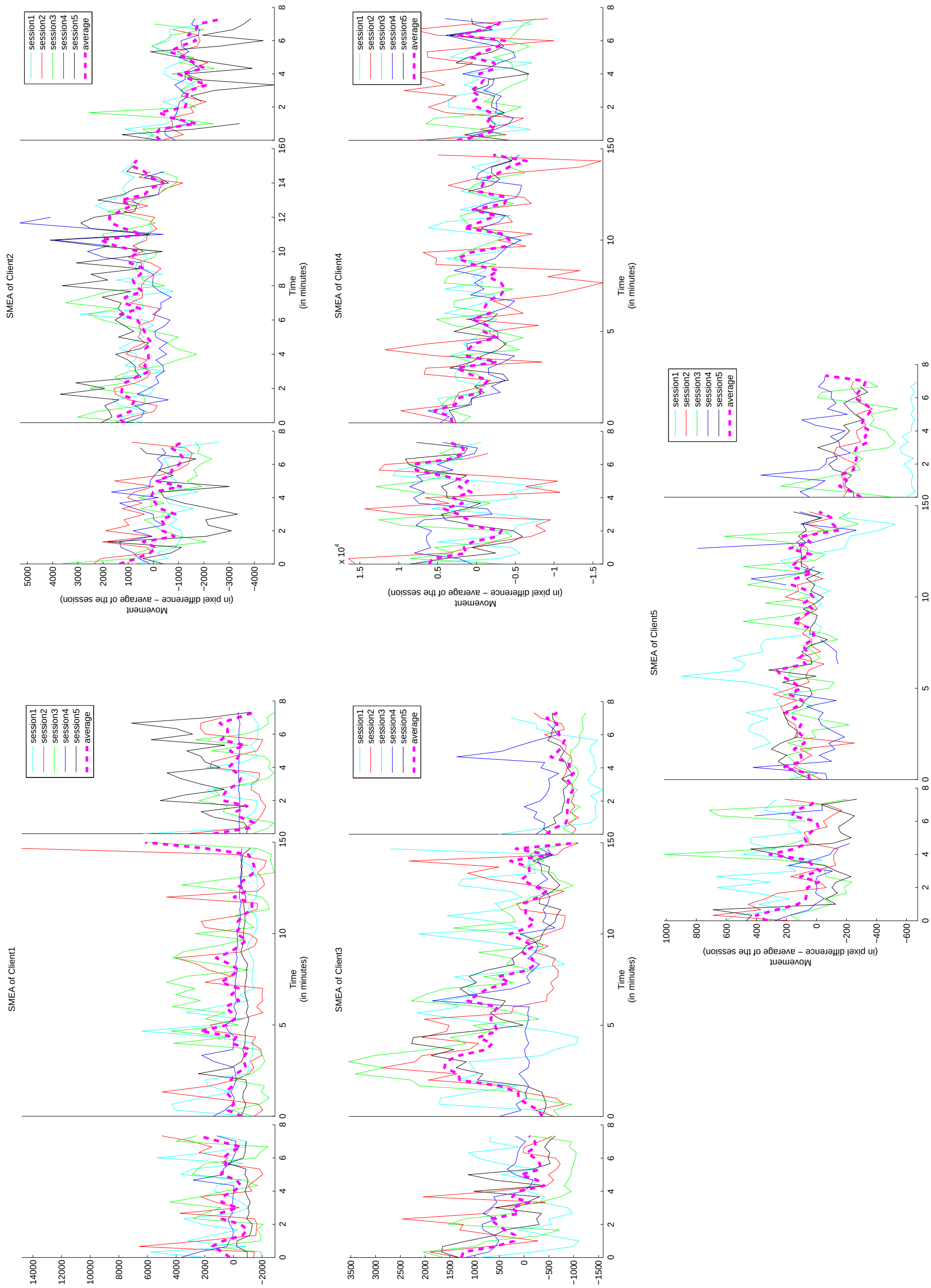

Figure 8.9: More in detail results regarding the amount of movement per sessions over time for the first five participants.

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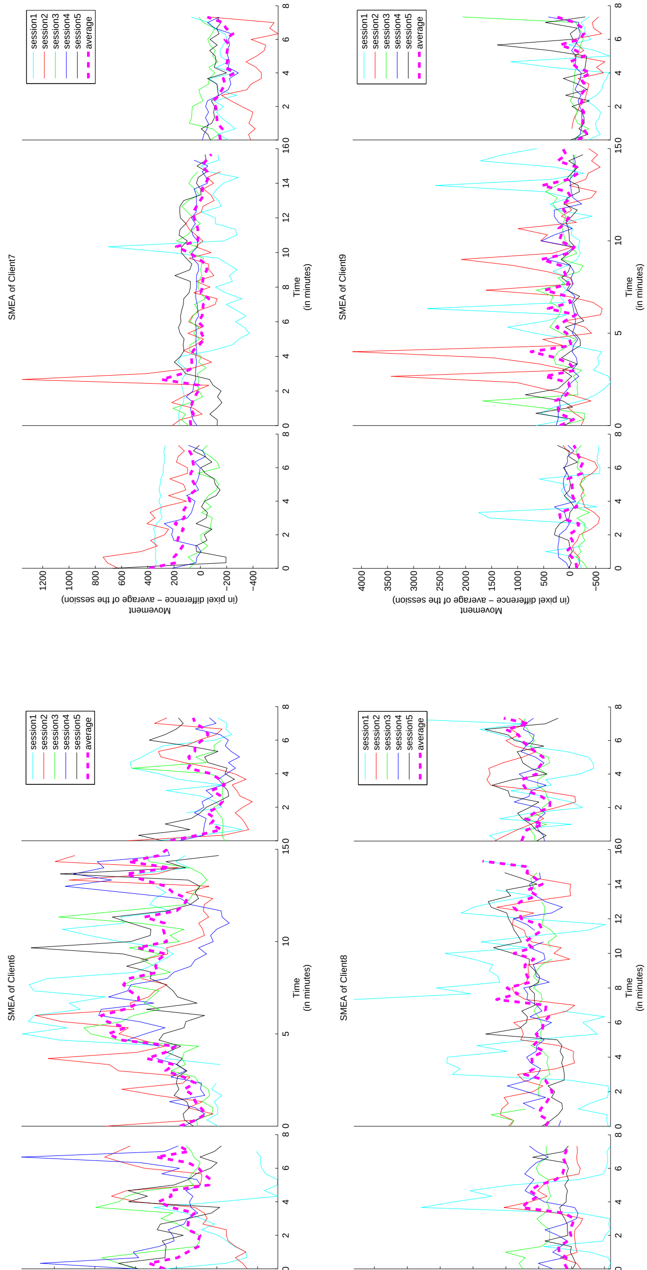

Figure 8.10: More in detail results regarding the amount of movement per sessions over time for the last four participants.

8.3 Discussion

In the present study we investigated the effect of an interactive device for people with PIMD on alertness, affective behaviour, and amount of movement. The present study was exploratory. The results need to be interpreted with caution and several lessons can be taken regarding the experimental design and future intervention.

No clear overall effect was seen for the entire group of participants, as could have been anticipated based on the individual differences also seen in Chapter 7. For four participants some negative effects were seen, but for three of these participants other individual factors seemed to play an important role in the negative effects on a dimension. For P4. April the diminishment of movement during the ball sessions was actually seen as positive by the staff and by us, as in general she shows an overactivity or restlessness. For P8. Gabriela there seemed to be time-dependent behavior, rather than the ball affecting her behavior. For P3. Irene, the increased amount of self-regulatory behavior (vocalizations) might have been an indicator of positive affect, according to some staff members, although this was not indicated clearly when compiling the annotation scheme. Only for P1. Bernard did the ball indeed seem to be a somewhat unsuitable leisure activity. However, for three participants positive effects were seen on one or more of the three outcome measures and each dimension was successfully targeted with the ball at least once.

Below we will discuss several points for improvement of the ball and reflect on our experiences of doing research with this target group and on the goals set out.

8.3.1 SMEA for Measurement of Movement

For measuring movement we used a simplified motion energy analysis (SMEA) as a measurement for the amount of movement. Unfortunately, and unlike the implementation of the software, the analyses of the data was less straightforward and time efficient to use than we had expected. As we explained in the method section we needed to manually cut out the sections of video footage in which the camera was visibly moved, changed focus, or changed color. Before doing the experiments we did not realize the stabilized cameras would auto-focus multiple times during a recording. It seems this occurred slightly more often during the intervention than before or after. For one, the ball indirectly moved the camera sometimes, as both were put on the same table; luckily this did not occur often. However, it is of course related to the amount of movement of the participant, as movement of the participant triggers movement of the ball and in turn can be a trigger for movement of the participant. We expect that due to cutting these moments of peaks in movement, this might have actually underestimated the movement during the intervention slightly.

Moreover, we intended to put the participants in the same spot for every session, but slight variations in the distance to the camera occurred each session. The movement of some participants (especially P2. Lora and P4. April) happened with such intensity that the wheelchair was also rotated. This increases the effect of movement on the measurement. Also, the movements that made the wheelchair wobble (not always very intensive) resulted in larger movement peaks as this influenced a larger area of pixels for several frames. Furthermore, the placement of the camera between the first five and last four participants differed due to the different room we used.

Variations in clothing will have also influenced the results as more contrast in clothing will inherently lead to higher (S)MEA values. Combined with the need to zoom in a little, a setting that could not be saved, this makes it harder to compare sessions with each other.

We think the simple method used for normalization makes comparing between sessions somewhat more valid but should be still interpreted with care. Nonetheless, most of the results of the MEA do represent our own impressions we had before knowing these results. For instance, we thought P6. Yuri had session dependent outcomes, and we did anticipate the positive effects on movement for P2. Lora.

Not all movement made during the sessions actually states something about the movement made due to the intervention. Especially with automatic measurements it will be hard to distinguish between these types of movements, even more so for this user group. For example, during the sessions with P6. Yuri it was clear that his coughing also had a large impact on the resulting SMEA values.

Based on these kind of issues we would like to advise for future work to use, setup, and interpret SMEA (and quantitative measurements such as these) with as much care as observations, as some of the issues might be affected by the intervention.

8.3.2 Tangible Interaction

The type of intervention and how well it fits the interests of the participant could influence the habituation process, as the staff suggested for some participants. For instance, the supporting staff member present at the session of (sleepy) P7. Harold, suggested that for him a tangible device that he could hold and touch, might be of more interest than the ball. Something that was also suggested by other support staff for some other participants. Unfortunately, we had excluded these type of devices for safety reasons and in order to increase their alertness *'outside the close encounters'* of the users in an attempt of *'stretching the attention into space'* [130, p30]. This seemingly detrimental effect of using a distant ball instead of something tangible is also strengthened by the large number of people with PIMD that suffer from visual impairments [273]. It would be interesting to incorporate interactive tangibles or haptic devices and test them in a similar semi long-term fashion in future research about interactive devices.

8.3.3 Social Connectedness

Another type (or aspect) of intervention that seemed to be missing for participants was one focusing on social connectedness. Many participants did like social contact and supporting staff members also deliberately made social contact outside the sessions. For instance, P7. Harold was able to be alert and move when he was triggered with social interaction by his supporting staff member after the sessions, probably also due to the tangible and haptic aspects of these interactions. The ball simply did not suit his needs. He did (and thus was able to) notice the ball at times and followed it with his eyes, but showed no interest in it. Otherwise he would have waved or laughed at it, as he did when he was triggered socially after the sessions. For P8. Gabriela we observed an increase in alertness, diminishing amount of negative affect, and increase in amount of positive affective behavior, when the supporting staff member socially and physically interacted with her after the session. Although, as this could not be annotated, this should be interpreted with care. P1. Bernard also seemed somewhat more alert when a supporting staff member was interacting with him after the sessions. For P2. Lora social contact was also clearly beneficial for her affective behavior. P4. April also responded to social interactions positively.

The examples of positive effects of social interactions show a current limitation of the ball, it does not trigger *playing together*. Possibly new devices could generate new opportunities for social interactions between participants and supporting staff members, or even among participants. Triggering this social interaction aspect can be an important part of such leisure activities [90, 261, 267]. Conversely, with a participant and a staff member playing together with the ball during the first few sessions, the participants might have been more able to interact with the ball in subsequent sessions. Playing together with (interactive) material might stimulate (learning how) to interact with it [130, 183].

It also forms a clear reminder that a device like the interactive ball should be an addition to current interactions for those moments where there is little room for personal interaction. We think that a further developed interactive ball (or any interactive device) should not be intended to replace the valuable social interactions with support staff. Instead it should aim to encourage or mediate these interactions, or provide a leisure activity that can be done without too much help of the staff, where the clients would otherwise get bored and not have an opportunity for social interaction.

8.3.4 Repetition and Anticipation

The number of repetitions seems to be an important factor for doing research with this group. We do suggest to use repeated testing instead of 'first time use' tests, often seen in traditional Human Computer Interaction, for one these tests can be heavily over-influenced by daily differences for this user group. For instance, P3. Irene and P9. Pauline slept during some sessions but were more alert during other sessions. First time use testing does not take into account the additional time for this target group to get used to the environment and intervention either.

With some participants we had the feeling that they started to recognize the situation and the ball a little over the sessions. Especially for P4. April we had this feeling, to be interpreted with some care, that her behavior before the sessions can be seen as a form of anticipation of the intervention. This feeling is strengthened by the somewhat nagging sounds she made after we took the ball away. To lesser degrees something similar for P2. Lora and P6. Yuri seemed to have occurred.

8.3.5 Autonomy and Efficacy

Someone from the support staff suggested that an intervention such as the interactive ball could be beneficial for the autonomy of the participant. Unfortunately, for none of the participants of this study could we clearly show that they knew they were actively involved in influencing the behavior of the ball using their body out of their own volition. Although there were some indications for P4. April, for instance: she made some 'fake' laughs which triggered one of her favorite sounds, which triggered her laughing again, which sometimes looped for a while. She also moved towards the ball going left or right with her body until something happened, as if she was searching. However, this was not always clearly directed towards the ball, instead it was if she was exploring where she would trigger the behavior. We should state here that this is all heavily speculative, although it was also (partially) acknowledged by the support staff. It would be interesting to go beyond speculation and see if such a feeling of autonomy indeed adds to the experience of the participants, to somehow test whether this feeling of autonomy can be triggered by an interactive device, and to what extent this would be possible. Noticeably during the SID project, see Chapter 7, the feeling of affecting the world, although related to efficacy more than autonomy, was one of the main aims for their designs [130].

8.3.6 Individual Benefits and Goals

When we asked the staff members in the semi-formal semi-structured interviews, several members indicated that for some clients the intervention might be beneficial but it would add little for others. Indeed, the results presented are in line with this remark, as they differed a lot between the participants. When looking at participants, and the different level of vitality they show, it is clear that the level of benefit, also depends on what kind of increase can reasonably be expected for what type of client for certain outcomes. Furthermore, one could also be targeting different goals for different clients, for instance restless participants might occasionally move too much, and triggering movement for these participants might be an unsuitable goal. When movement is stimulated but this is accompanied with negative affect, then, from a more holistic view, this could also become an unsuitable activity. This leads us to believe that the decision to offer such an intervention should be made on a person to person basis, and should fit the goals that have been set out by the support staff for this person. Further research is needed to see how similar approaches could better address this individuality in investigating (other) types of truly interactive systems. It is an important challenge to accurately incorporate a proper study design to address these aspects of testing such a heterogeneous user group with individual preferences, individual measurements (e.g. regarding annotation), and perhaps even individual targeted outcomes. Especially, when doing more systematically testing of such a device with a larger population (e.g. in a randomized controlled trial (RCT)), it seems that this individualization would deserve additional consideration.

8.3.7 External Factors and Personal Circumstances

For some participants the support staff indicated there were activities or events outside the sessions that could influence how a session of a day went. Although we used a day-based comparison it is likely that such contextual factors had an influence on the results for some participants. When a participant was very tired it seemed there was simply not enough energy to interact with the ball, and thus this could also influence the before, during, and after analyses. This in turn can influence lack of certain tendencies, as the sessions could differ too much from day to day. For future research, we advise researchers to take these differences into account when deciding on the number of sessions to be done. We also think it will be important to take contextual differences into account and measure them in a useful comparable way. This includes taking into account differences between staff members, as they tend to alternate their shifts. To this end, besides measuring contextual differences, to (partially) deal with day to day differences for this user group, we suggest to use repeated and longer-term testing, yet still with an emphasis on within session differences during analysis.

8.4 Conclusion

We performed a semi-long-term study with nine people with PIMD. Based on video recordings from three different angles, we measured differences in alertness, shown affect (decline of negative expressions or increase of positive expressions), and movement (using an automatic measurement based on the front camera footage). The intervention we used was an interactive ball that responded to the behaviour of the users.

Table 8.7: Rough estimation we have of the effect from the intervention on the participants for the three measured dimensions

Participant	1	2	3	4	5	6	7	8	9
Alertness	-[*]	++	0	++	0	+	0	0	0
Affective behavior	-[*]	++	-	++	0	++	0	-[***]	0
Movement	0	++	0	-[****]	0	0	0	0	0

** Seems to be only a quite small tendency, compared to the changes for participant two and four.*
*** In the results we mention that perhaps the shown idiosyncratic behavior, and its increase, should not be interpreted as negative behavior.*
**** In the discussion we have mentioned that this, knowing more background of this particular participant, could also be time dependent effect rather than an intervention dependent effect.*
***** In this particular case it could be argued that due to her restlessness, it might actually be beneficial if she would move slightly less*

We saw differences for several participants that might be partially explained by external factors. The results are also not uniformly positive. For only some participants the ball had positive effects, for one participant on all targeted dimensions, for two others only with respect to alertness and affect, see Table 8.7.

This interactive ball is probably not beneficial for all people with PIMD, but it might add a new source of entertainment for some of our participants that could improve their alertness, affective behavior, or movement, in a user group that currently can only be offered a limited number of suitable activities.

Outro Play for People with Profound Disabilities

In this part I introduced a new type of interactive leisure activity for people with PIMD. I explained the design of the interactive ball and showed what we changed after our pilot studies. I reported on our longer term study in which we found mixed results. It seems that the interactive ball did indeed add value for some participants but it is definitely not a one-suits-all solution. Similar to what Hogg et al. suggested for Snoezelen, I think it would be important for future research to investigate which personality traits and sensitivities of the participant make interactive devices promising for them, and to subsequently investigate the potentials for tailoring the activity for such a person [90]. Especially for this user group it is unrealistic to assume new interactive devices (or any activity for that matter) will be the new holy grail for the entire population.

In practice it is often the case that the focus of the study is either on the development of new interactive systems, or their evaluation: resulting in a thorough design phase where there is little time left for doing systematic research regarding set out goals, or a focus on a realistic systematic research for evaluation but leaving only time to do this with a underdeveloped (set of) interactive system(s).

Looking back at the design and research process which took over two years, our research regarding the evaluation was more than reasonable with respect to other studies for this user group that looked into Snoezelen (these tend to be less formal) [90]; I believe we used an appropriate research design (baseline and alternative activity [277]), used realistic measures with numerical forms and graphics where needed, and made appropriate (conservative) interpretations. However, the *design process* should probably have been approached differently [130]. For instance, the distance and lack of coupling between action and response could have been detrimental for the interaction [72, 130, 183]. It seemed that I have *'put all our eggs in one basket'*. I probably bet too much on the interactive ball to work. A more thorough prototype design phase before going into our detailed evaluation research would have been better. If I compare this to Part I, I see that there I seemed to have benefited from using existing (interactive) games [156], increasing the chances for success.

For future research it seems that evaluating multiple devices with an approach similar to our pilot studies should have been done before the kind of effect study we did. The SID project mentioned was focused very much on this aspect, and their work also resulted to several interesting concepts. They, on the other hand, focused less on systematic evaluation of such concepts [130]. Both aspects are needed, a suitable effective device for participants, and a study showing its potential in a realistic manner. It seems that fitting the contemporary practice in this kind of health organizations, with the hunger for evidence based research, one also needs to do well planned evaluation research in order to show the efficiency of an intervention. In my opinion this kind of combined research, instead of thorough design with only anecdotal evaluations, is needed for a widespread interest in developing, financing, and implementation of such devices. Although we could not provide generalize-able results we did do our best to work towards pre-defined goals and incorporate an appropriate study with useful measures. This also forced us to focus on practical goals. We hope this work will inspire others to take up where we left off.

In the next section we will explore several games for interactive play in another context, where we do not focus yet on the phase of thorough evaluation. It is a context with a much larger group of possible users. The next chapter is an exploration into interactive play as a motivating environment for gait rehabilitation. The use case described in the next part is based on work by several bachelor students that we tutored.

Part III

Play for Gait Rehabilitation

9

Gait Rehabilitation Games on an Interactive LED Floor

I was there to push people beyond what's expected of them.
I believe that's an absolute necessity.
– Terence Fletcher, Whiplash (2014)

This part, containing only this single Chapter, describes the design of a suite of movement-based games for gait rehabilitation with personalization based on gait characteristics. We used an eight by one meter pressure sensitive interactive LED floor. With the interactive games we attempted to steer different dimensions of people's gait, increase motivation, provide an enjoyable experience, and create an additional platform for gait rehabilitation by physical therapists. In contrast to the previous part, this part will include more games but does not include a properly designed effect study.

We will describe four of the games developed. With the created set of games we performed several days of pilot tests/exploratory user tests. In total 56 patients and 30 therapists were involved. The set of games was positively received by therapists, who stated they could train a variety of targeted domains with it. Furthermore, many rehabilitants indicated they liked it more than normal training exercises. The possibilities for personalization and the variety of games allowed users with a wide variety of skills and limitations to train their gait, although not all rehabilitants could be offered an appropriate level of challenge. Nonetheless, we do believe that one reason for the positive responses is that the games can be adapted to the rehabilitants' gait characteristics with several settings in the games, and that a second reason seems to be that therapists can choose between games to target different aspects of rehabilitation suitable for the type of rehabilitant.

Parts of this chapter are based on:
R. .W. van Delden, J. Janssen, S. ter Stal, W. Deenik, W. Meijer, D. Reidsma, and D. K. J. Heylen, "Personalization of Gait Rehabilitation Games on a Pressure Sensitive Interactive LED Floor." in *Proceedings of Personalization in Persuasive Technology, Volume 1582 von CEUR Workshop Proceedings, pp. 60–73, CEUR-WS.org, 2016.*

9.1 Gait Rehabilitation and Motivating Personalized games

In the last decades more and more interactive body-controlled games have been used in rehabilitation by physical therapists. One of the key reasons for this use seems to be that many forms of rehabilitation require repetition which can become boring quite quickly. The strength of many interactive games is that they make known repetitive movements engaging. Furthermore, games can easily be personalized to provide more efficient and enjoyable training fitting the skills and limitations of users, and different kinds of games can be used to train different aspects in rehabilitation. In this chapter we will introduce several games that can be targeted and tailored to the characteristics of specific users. The games are intended to support behavior change regarding peculiarities in their gait in the context of their rehabilitation.

Many rehabilitants, including those that have suffered from a stroke, will have a tendency to show asymmetrical walking patterns, both unbalanced and arrhythmic. This behavior leads to lengthy recovery and it increases the chances of getting additional injuries. In traditional therapy therapists also use a set of exercises to address such atypical walking patterns. The exercises are guided by the therapist and are done repetitively (a *tunneling* approach) but this can become boring and in turn lead to diminished motivation. With our games we try to motivate the rehabilitants and make them move towards the wanted direction, for example, steering towards a balanced time they stand on each leg and a more balanced step length. The approach of therapy sessions with our games consists of explanation by therapists, explicit steering of behavior during the exercise, and reflection on performance to change people's behavior.

Many persuasive technology (PT) and behavior change support systems (BCSS), take the form of websites, apps, and home-based automated systems. Health care is one of the main application areas but (especially in BCSS) there is often a focus on changing or supporting behaviors regarding *lifestyle* such as smoking, (un)healthy diets, medication intake, and increasing physical activity [118]. In this Chapter we argue that using ambient intelligent systems, such as our games for rehabilitation that will be played on an interactive floor, might also play an important role to address health related issues other than lifestyle. For instance, the *picture frame for proper posture* by Obermair et al. indicates how reflection on physical posture can influence motorical patterns with persuasive technology [187].

This Chapter explores interactive gait rehabilitation games using types of persuasive technology. This research is focused on inspiring therapists, patients, and other people, and to explore the requirements for successful development of such games [1]. As such, we do not yet intend to perform generalizeable user tests showing the effectiveness of the platform as a medical device. Instead, we first want to get the experience of the games right, and make the games appropriate from the perspective of the therapist. That is, the therapists should feel that the game is motivating and that they can carry out their usual therapy exercises within the game. We will therefore share the users', therapists', and our experiences of a set of personalized games for gait rehabilitation played on a pressure sensitive interactive LED floor.

As a platform for this project we used an eight by one meter setup of the commer-

[1] We refer to [203] for guidelines based on observation of gait rehabilitation of stroke patients with a focus on motivation. That paper was published after we did this research and was thus not explicitly incorporated in our designs.

cially available high-end pressure sensitive interactive LED floor from LedGo[1]. We developed games that can be used for different types of users in gait rehabilitation. These users include both the slow and quick, the old and young, and the weak and strong. This wide variation in types of users is one of the reasons why personalization has an important role for the games, and why different types of games have been created.

It is essential to tailor this platform to the preferences and daily practice of the therapists. Therefore, we started from existing rehabilitation exercises. We mapped these exercises to existing entertaining game principles. This starting point might in the future help achieve better long-term in-situ use by therapists.

9.2 Existing Technologies & Research to Improve Gait Rehabilitation

There has been an increasing amount of research on technology in rehabiltation. A large part of this work focuses on monitoring, the detection and analysis part of rehabilitation [287]. For instance, some systems detect pressure patterns of a walk cycle with a pressure sensitive mat [76, 209, 238], or use technology, such as motion capture system and pressure sensors, to measure the effect of standard tests [224]. However, the other important aspect of rehabilitation is correcting, and training the correct movements. With the introduction of affordable kinematic systems, such as the Kinect and Wii, we have seen a rise of interactive gaming technology specifically for this part of rehabilitation therapy. Personalization in this context concerns fitting form and difficulty of the excercises to the skills and limitation to the user [63, 190]. Many existing games for rehabilitation focus on more stationary rehabilitation (e.g. improving balance) and for training only the upper body in smaller spaces. Examples of this are posture games with the Kinect [190] or Wii [105], or games with tangibles where the users are not required to stand or walk [63].

Nonetheless, there is also a variety of commercial installations for *gait* rehabilitation that have been put on the market in recent years. The C-Mill is a treadmill for training gait using a projector and automatic detection of feet placement to provide interactive therapy, including several games[2]. The Computer Assisted Rehabilitation ENvironment (CAREN) is an immersive CAVE like environment in which a user walks on a rotatable treadmill. Original started as a device for gait analysis, it makes use of pressures sensitive plates and detailed motion analysis to provide a variety of activities. For instance, walking over a wiggling suspension bridge, steering a boat or walking through a city[3]. Simple interactive camera-projection systems such as the Magic Carpet have also been used to help in motor skills training sessions[4].

One of the disadvantages of treadmill devices is that they tend to have smaller surfaces. Furthermore, they do not allow for walking back and forth with sudden turns, or abrupt changes in speed. For such more natural walking behavior a bigger, flat, and static floor is more appropriate and will be used in our research. One system that also makes use of pressure sensitive floors is the *Playware* (interactive tiles). The system was used in multiple rehabilitation and therapy settings. *Playware* consists of mobile modular tiles of 30cmx30cm, one force sensitive sensor, 8 circular placed RGB

[1]http://ledgo.tv/home/129-updates/202-eurovision-2015-met-ledgo-s-black-spinal, last visited at 12-2-2016

[2]http://www.forcelink.nl/index.php/product/c-mill/, last visited at 12-2-2016

[3]http://www.motekmedical.com/products/caren/, last visited at 12-2-2016

[4]http://www.roessingh.nl/nieuws/Interactief-spelen-bij-het-Roessingh, last visited at 12-2-2016

LEDs; the tiles are typically arranged in a grid like structure [136]. Training balance was addressed in some of the games for this platform. For this they not only had a set of tiles on the floor but also a row put against the wall to be pushed with the hands. The tiles had to be pushed with either the right or left arm and on the floor with the right or left leg depending on the color it was emitting [136].

With some of the games for the *Playware* installation the authors managed to heighten the heart rate for cardiac arrest patients, increase motivation and showed significant improvement in different physical measurements for the elderly [109, 134, 136]. An important feature for such movement-based interactive technology in therapy is the ability to set difficulty according to the user [244].

Changes in behavior can also be reached with more reflective systems that uses other types of ambient intelligence, such as an interactive picture frame responding to (in)correct posture. For such a picture frame, Obermair et al. proposed to use a human instructor (explaining how to sit and why) with the reflection supporting capabilities of an interactive system (continuous monitoring) leading to awareness of the (un)healthiness of current behavior [187]. Furthermore, they pointed out that using a personalized approach (using known people) can be beneficial.

9.3 Our Approach and Games for Interactive Gait Rehabilitation

Our approach was to develop a *suite* of games, adaptable by the therapist, that together facilitate training for many aspects of gait. The reported success and availability of several interactive game-based gait rehabilitation tools gives us reason to believe that modifiable games on a pressure sensitive LED floor can lead to a promising gait rehabilitation tool. With the ability to use detailed graphics as a way of giving feedback in normal walking conditions (a floor instead of a treadmill), it could be possible to target different kinds of activities (e.g. more towards balancing exercises instead of those focusing on strength and endurance). Furthermore, the more detailed graphics allow for different types of games compared to systems such as the above mentioned *Playware*. Our system might increase reflection of the user, and allow more flexibility in steering the in-game behavior or persuading people to perform certain actions.

Based on our experience with gait rehabilitation therapy, we decided on a set of dimensions that could be addressed by such games. First, all the games should be able to motivate the user and push their boundaries. Other than that, they could help train on: coordination, walking speed, balance, strength & endurance, rhythm, reaction time, attention & memory, and/or vision & focus. We developed a set of games in order to cover (different combinations) of these training goals. The games are intended to train normal walking behavior. Therapists can either train this as a whole, or focus on the specific dimensions in order to work towards normal walking behavior. For instance, one game targets all these goals a little at once and another game is designed to specifically target the latter more cognitive training goals (reaction time, attention & memory, and vision & focus).

We also made the individual games modifiable to different types of users. These adaptable features were included to be able to optimize the training of the rehabilitant, providing a challenge that was just within the reach of the rehabilitant. This does not only involve configurable difficulty levels but also adaptation to the rehabilitant's current gait characteristics, such as track width, stride length, or the affected leg. We implemented these settings from the therapists' point-of-view, so in order to

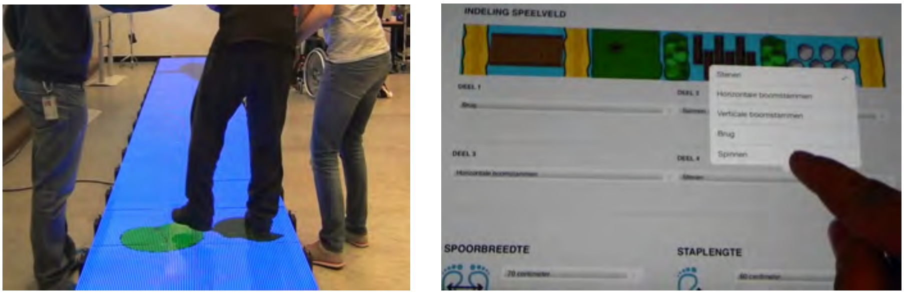

Figure 9.1: One of our gait rehabilitation games in use by a rehabiltant (left) and personalization of the game on a tablet (right).

make a game suitable for a specific user the therapist could set the appropriate track width, stride length, number of obstacles, duration, and speed. These settings would then translate to settings of certain game mechanics. We incorporated these ways for personalization (games and such settings) via a tablet that interacted with the floor. This allowed us to quickly set the next type of game and to make modifications within the game, as shown in Figure 9.1.

We have chosen a size of eight by one meters for the floor to suit these training goals, the one meter width allows for support from the sides by therapists for those rehabilitants needing this, see Figure 9.1. We will now explain the games developed fitting this size on this floor, and explain the settings we used for personalization of the games and the game mechanics that steered the gait and movement in certain ways.

9.3.1 PadWalk

The first game consists of walking over leaves (lily pads) on water, see Figure 9.1. The gait of the user can be steered through the placement of the lily pads. To keep players standing on the lily pads, in order to train coordination and balance, we used sound effects and we added a shark that would attack within a configurable duration after stepping in the water instead of on a lily pad. Rhythm and speed of the user's gait, were influenced by the appearance rate of new lily pads and a controlled decay (disappearance) of the currently visible lily pads.

The game can be played in two main modes: random placement and forward placement of lily pads. The random mode mainly focuses on training coordination, balance, endurance, reaction time, attention, and pushing boundaries. The normal game mode focuses more on training normal walking patterns. In this mode the appearance and disappearance rate of the lily pads train walking rhythm and walking speed to improve the gait.

Both variations of the first game have the possibility to set a limited number of parameters to fit the game to the rehabilitants. These parameters include the difficulty (time a lily pad stays visible, and the allowed time in the water), the step size (distance between lily pads), speed (time between appearance of lily pads), and the game difficulty for the random version. After each game a score is shown containing (where applicable) the difference in time between standing on their left leg compared to their right leg, percentage of time needed to finish the game, and percentage of time the player correctly stood on the lily pads. In this way rehabilitants are steered

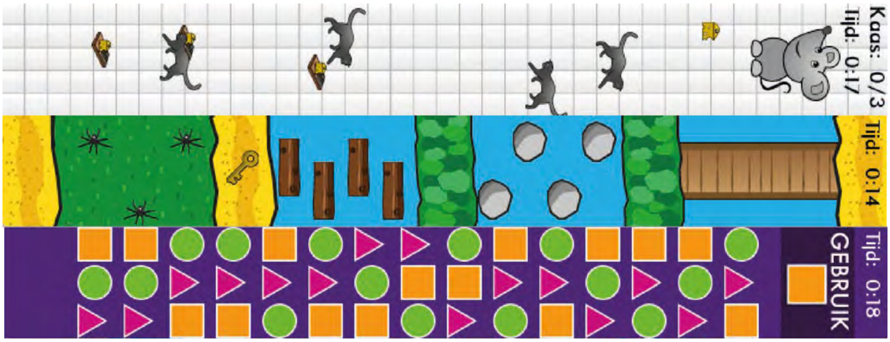

Figure 9.2: Three screen shots of the games used in the second set of tests: on the top *Swiss Cheese*, in the middle *Tresasure Hunt*, and on the bottom *Crazy Object*.

towards normal gait patterns but are also triggered to reflect on the abnormalities in their gait; a similar approach can be seen in the other games.

9.3.2 Swiss Cheese

The second game consists of a tiled floor with a randomly positioned small piece of cheese, see Figure 9.2. The player gathers this piece of cheese by standing exactly on it, then deliver it to the mouse at the end of the floor. Every new piece has to be delivered to this mouse in the same way. This requires the user to make a full rotation of the body while keeping in balance. The game thus keeps triggering the alternation of rotation and straight walking. Especially for people that suffer from a stroke, dealing with the proper orientation is an important part of rehabilitation. To trigger training of vision and focus, the pieces of cheese are always placed at random position somewhere on the floor. Reaction time and coordination of the players are triggered with the introduction of to-be-avoided objects (moving cats and static mouse traps) that could require an abrupt stop by the user. The therapist can select the duration (number of pieces that have to be collected), the number of obstacles (number of cats and mouse traps), and the speed (influencing the score and the speed with which the cats move).

9.3.3 Treasure Hunt

In the third game, a player has to cross a treasure island from one side to the other while carefully standing only on the right spots, see Figure 9.2. The position of objects to stand on (in the form of rocks and trunks) and them breaking down/sinking, are intended to enforce a certain rhythm of walking and an increase of speed. Again balance can be trained during walking and standing on the small objects. In order to trigger the reaction time (and some vision & focus) spiders move over the grass and tree trunks move up and down the water, see Figure 9.2.

The therapist can adapt the game to the gait characteristics of the user. Setting stride length influences the number of rocks and tree trunks, and the distance between consecutive rocks and tree trunks in the walking direction. The second setting is the track width, which sets the distance between rocks and between the tree trunks. The third setting is to account for which leg is affected by a stroke (where appropriate), which is used in the game to allow for a slightly longer time before an object disappears for that foot. Finally, the therapist can set the speed of the game which influences 1) the time a rock and a tree trunk can be stepped on before they sink, and 2) the movement speed of moving tree trunks and spiders.

9.3.4 Crazy Object

The fourth game consists of a grid of shapes in which the user is only allowed to step on one specific shape to reach the end of the floor (e.g., only stepping on squares as shown in Figure 9.2). This game is primarily intended to focus more on the cognitive aspects, reaction time, attention & memory, and vision & focus. The proper shape to step on is indicated at the end of the floor. This can change during the game, steering players to change their vision & focus and respond quickly. To stimulate motivation, the game can also be played in a multiplayer mode. Both players start at their side of the floor and move towards each other. In order to account for different types of users the therapist can set—for both users individually—the number of different figures (requiring less cognitive resources to stand on the right one as the decision space is reduced), the step length (influencing the number of objects and distance between them), the speed (changes the time with which a target object changes and the offset time before the player has to step on the right type), and select which leg is affected (influencing the placement of the first correct object).

9.4 User Study

We carried out two sets of user tests in order to explore the engagement, to explore whether these games were suitable for therapy, and whether a wide range of participants could make use of this set of games and their possibilities for personalization. We tested for two and a half days (± 18 hours) with the 'PadWalk' and three and a half days (± 25 hours) with the other games. Therapists were informed with personal communication, mail and posters about the user test. The therapists were free to enter the room with their rehabilitant and to participate. Sessions took roughly between 5 and 30 minutes, mainly depending on the endurance of the rehabilitant and if other participants were already waiting for their turn. The settings were explained to the therapists, after which they could change them (or instruct the facilitator to do so if therapists needed their attention to be on the rehabilitant at that time). The participants received explanation on how the game was played, after which they (or their legal guardian present) had to give their consent in order to participate.

9.4.1 User Study 1: PadWalk

We performed a first small user test with the PadWalk game with 19 patients, ranging from 10 to a 73 year-old and equally balanced over a 3-level ability indication. This included six level-1 patients, not able to walk or stand without support; seven level-2 patients (able to walk without support, but still having exercise goals - the patient does not walk flawlessly); and six level-3 patients walking well and mainly training strength and endurance. Besides the rehabilitants we also included six physical therapists in the user test, including Joep Janssen one of the authors of the original paper. At the end of the study these therapists also filled in an online questionnaire. After the play was finished the patient participated in a semi-structured interview.

9.4.1.1 Rehabilitants' Response

All but one of the patients stated they liked the game more than the normal therapy session. A 40-year-old woman for instance stated *'It is addicting to improve your scores. You want to do better every time.'*. The one patient with no clear preference, normally played sports games and was already functioning on a high level. All rehabilitants seemed to understand the game properly and were able to play the game. Similarly to normal rehabilitation sessions some rehabilitants needed physical assistance of the therapists, one of these rehabilitants indicated in the interview that he was not yet able to play the game properly. Two rehabilitants (functioning on the highest level) indicated that the game was too easy, others either indicated the difficulty was good or it was quite hard. However, no one thought it was frustrating. Most players indicated they put in the same effort during the game as during normal exercises, but four players stated they had put in more effort. All players, indicated they would like to play the game again. Some of them also did this during another day of the tests.

Observations showed that especially the rehabilitants below the highest level of functioning were eager to finish the game and improve their scores. Many of these players displayed clear indications of tiredness, transpiration, and heavy breathing. Around 80% of the rehabilitants were clearly enthusiastic and smiled. A young girl at level-2 ($\pm$10 years) also indicated that the game triggered the to-be-trained movements *'You are forced to use your 'wrong' leg in the random game mode, that is very good!'*.

There was a great interest by the higher level functioning players to improve their scores. However, most other rehabilitants still lacked in speed and they mainly focused on their non-speed (gait distribution) scores.

9.4.1.2 Therapists' Response

All but one therapist answered they could train everything they normally did. One therapist required more space in which more dynamic exercises could be done. All therapists also indicated there were not too many settings, although one of them missed the flexibility to change types of paths or even personally place the lily pads.

All therapists indicated they would like to use the game in their rehabilitation sessions. Several therapists also stated that they were at times surprised about how their rehabilitants performed. One therapist also noticed this performance increase when he was working on the floor with a rehabilitant with aphasia ($\pm$ level-2 and 40-year-old), *'I never get him to run, he just does not want to. Now he is just running and he enjoys it too!'*. Two therapists mentioned that the dimensions can be trained with many other things but this platform would be a nice addition especially because of its novelty. Other positive points that were mentioned about the game were the appeal, challenging people to move and one therapist stated *'I don't know any other games where I can use this many relevant parameters'*.

Negative points were the lack of space, the need to look down, inability of training certain specific muscles instead of complete movements. Suggestions for improvement included a bigger variation of games; tracking personal (high) scores; enabling the use of body weight support systems such as a bar, crutches, walkers, or a harness; more sounds; adjusting the (width of the) walking path; a variety of themes for children; more flexible settings including smaller changes in step length and addressing asymmetry in walking; and adding cognitive challenge/learning elements.

9.4.2 User Study 2: Swiss Cheese, Treasure Hunt, and Crazy Object

We performed a second user test with the three other games. In total 37 patients played on one or more of the games. These players again varied in their ability (ranging from pediatric to trauma rehabilitants). Furthermore, 30 therapists, interns and other interested people observed or played, or accompanied their own patients. The majority of the therapists participated in multiple sessions. Direct observations were used to see how the games were experienced by the players (enjoyment, confusion, frustration) and see how therapist used the platform. Patients were also interviewed afterwards where possible.

9.4.2.1 Rehabilitants' Responses

Clear expressions of joy were observed. Some patients even started the game again directly after the previous game finished. Furthermore, almost all patients indicated in the interview they liked the games. The majority of the patients would like to play the games again during therapy (33 out of 37). However, the games were too easy for a small number of patients, who therefore did not see the benefits of playing again (4 out of 37). Some patients indicated the games would add to the variety offered in their therapy.

There was no clear preference for one game over the others. Some players indicated they liked the dynamic aspect of a game: jumping over objects (*Treasure Hunt*), to suddenly stop to avoid stepping on the cats and turning around (*Swiss Cheese*). Moreover, they liked that they always had to pay attention to what happened around them, having to avoid certain (moving) elements. Several patients preferred *Treasure Hunt* as it contained different actions in the different sections of the game. For instance, they liked being challenged to retain their balance on the rocks and trees in the game. A few players indicated this game was a bit childish. In general, *Crazy Object* was seen as the most difficult game, and probably therefore preferred by the participants with a higher level of ability indication. Also, this game was seen as least childish, due to the abstract objects and the lack of narrative. Patients liked the multiplayer version as well, but no one preferred the multiplayer version over the single player version.

The scoring aspect of the games seemed to be quite important and really helped the rehabilitants to push their boundaries. Therapists and other bystanders also encouraged the players to perform better or faster. For a few young toddlers the score aspect was not that important, since they did not really seem to understand the scores. Due to two technical limitations the scores were sometimes inaccurate frustrating those that were triggered by the scores.

Some of the rehabilitants indicated they became tired when playing the game (giving an indication that it might also train the strength and endurance of users). A lot of the patients wanted to continue after a small break, since they had the feeling they could perform better than they showed before this break.

Even though we incorporated personalization in several ways, patients often indicated and showed that a game was not on the correct level for them. On the one hand, the lowest level was sometimes too difficult for patients with more severe disabilities. On the other hand, the highest level was too easy for patients with only limited walking disabilities. Limited cognitive abilities of the users could also limit the playing experience for some players. For instance, some players were unable to incorporate the target object from *Crazy Object* appropriately in the game. However, the people with higher abilities liked this game, since it was challenging. They said that especially performing two tasks at the same time, physically and cognitively, made it challenging for them. All in all, it seems a range of games is needed to suit a range of patients.

9.4.2.2 Therapists' Responses

In general, the therapists liked the games. However, not all therapists were convinced the games contain functionality that can train therapy aspects outside normal therapy. Other therapists indicated they would use the games as an addition to normal therapy, since they noticed their patients enjoyed the games and were motivated by the games. The majority of the therapists said the games could indeed add variety to therapy.

One aspect of the platform, which is part of more dynamic training that therapists preferred, were the tasks triggering physical actions and requiring cognitive resources as included into *Crazy Object*. However, many therapists indicated they would like the games to be even more dynamic. *Treasure Hunt*, for example, always has a straight walking pattern and does not trigger the patient to speed up or to react to a sudden change. Instead many therapists preferred *Swiss Cheese*; the player had to pay attention to what was happening around him/her.

Therapists were positive about the possibility for personalization of the games. However, the games did not suit the patient sufficiently sometimes, since the range of difficulty of the games was too limited. Therefore, many therapists also indicated they would have liked to have even more games, to ensure that the right game suited the patient; both cognitively and physically. Ideally, they would have liked to select some training dimensions they wanted to train with the patient, upon which the relevant games would be displayed and could be selected to play.

9.5 Discussion

We believe that our work shows the potential of a combination of a robust and mature hardware platform with a suite of configurable games to cover a range of training goals. Although several LED floor platforms for gait rehabilitation exist, we believe that the reasonably high resolution of both the display and recognition help in increasing an immersive and challenging experience as well as adding opportunities for modifying variables such as target step size. When we compare interactive floors to the treadmill based platforms, training on a floor can train more on random steps and steps to the sides. Furthermore, walking on the interactive LED floor also resembles the actual movement to be trained, where walking on a treadmill introduces different resistance forces of the rotating floor. Nonetheless, a treadmill system might be better to train other dimensions, such as endurance.

Games for the interactive floor could offer a challenging experience that will motivate most users. The inclusion of applicable parameters that can be tailored manually but quickly to the user could be a key reason for its future success. We also think it would be essential that the therapists could select a game targeting certain dimensions of rehabilation fitting the kind of user, both for the cognitive and physical aspects. We intend to start follow up projects, to add more games containing more cognitive challenges and dynamic training, especially for older people that have suffered from a stroke. Furthermore, in the end we plan to do longer term studies with the suite of games to investigate the actual benefits of the platform on a larger user group over a longer time. In such studies, measuring therapists' intention of use and actual use of the platform will also play an important role.

During our tests we made use of steering the behavior of rehabilitants with game elements. For instance, by placing lily pads further apart we made them change their gait, basically using attractiveness as a way for tunneling design in order to lead the user through a certain course of activities repetively [184]. By showing the users their scores and performance afterwards they were also informed about their actual behavior. Especially after a stroke several rehabilitants do not recognize their own coping strategies and imperfections in their gait (e.g. unbalanced, asymmetric, or arrhythmic). Steering behavior can be an ethically inappropriate method for many systems [116], in contrast we think that for this use case and our implementation it is an appropriate and transparent tool to use. Steering is here similar to traditional therapy where users also have to perform actions in a certain way. Our interactive floor can also help the users to reflect on their behavior (*awareness*) and be persuaded in that way to change their gait. We agree with Smids' view that *ends* do not justify (inappropriate) *means*, such as *coercion*, *manipulation* or *deception* [231]. Although the games use steering mechanisms and are intended to be played in one way, we do not *coerce* users with overwhelming or annoying feedback and only offer the exercises as an optional (alternative) way of delivering therapy, both for therapists and the users. Although steering mechanisms can control behavior of people [260], we try to prevent *manipulation* by keeping the users aware of the rehabilitation setting, for instance, with the therapists' instructions and reflective feedback. Our rehabilitants are also informed that the games are intended to improve their gait in certain ways; this provides more complete information and differs from a *deceptive* approach. In discussions with therapists we even got the feeling that making this link with existing therapy exercises and goals more explicitly would not only lead to more transparency but might also help to increase the acceptance of the system.

9.6 Conclusions

Most rehabilitants of the 46 participating in our studies, with a wide range of gait characteristics skills and limitations, reported a positive experience with the games. However, during the PadWalk user study two rehabilitants indicated discomfort, a sore neck and over-stimulation of reflective light. Furthermore, during the other games, we saw that even with the personalization not all game sessions had an appropriate level of difficulty. We did see several rehabilitants that showed (and also indicated) that they had put in more or equal amounts of effort compared to their traditional therapy. Therapists responded mainly positively in their remarks; they indicated that most targeted dimensions could be trained in the game to the same degrees, or better than with normal therapy. However, proper quantitative tests should be done first to verify this with a wider variety of games. We think that the interactive floor for gait rehabilitation can be a powerful additional tool for gait rehabilitation. We also think tthat several improvements could and should be made, where it remains essential to keep working together with therapists and end users to better tailor the tool for longer term use.

Outro Play for Gait Rehabilitation

I applied play to create a motivating gait rehabilitation experience in this Part. To this end we used the interactive pressure sensitive LED floor from LedGo. Similar to the other parts of this thesis we created the games for this platform based on the discussions we had with therapists, the observations of traditional therapy, and a combination of several existing games and therapy activities. This resulted in a suite of games which we could tailor to the users. This formed an application of steering interactive play behavior in yet another context. In this part I did not yet do a systematic effect study that could verify whether we managed to achieve our set out goal of developing a new tool for gait rehabilitation that is effective, enjoyable, and motivating. Our first user studies do give a promising impression of the applicability in gait rehabilitation of a suite of games that can be tailored to the user.

In the next and final Part (Part IV), I will discuss the added value of the work I did, discuss directions for future work including some pre-liminary work I was involved in, and will end with a short conclusion on the possibilities and effect of steering interactive play behavior.

Part IV

Conclusion

10
Discussion

We know so little.
How many of you know 5 geniuses in your field that you disagree with?
– John, Man from the Earth (2006)

I have shown a variety of applications of interactive play and how I could apply steering the behavior of the players in an attempt to improve the experience, increase the amount of movement, increase levels of alertness, and motivate people more to do certain gait rehabilitation excercises. I have tested this with children, students, healthy adults, gait rehabilitation patients, and profound intellectual and multiple disabled (PIMD) people.

The 'tangible' results so far include 14 publications, two permanent virtual playground installations in our Design Lab and one in the SmartXP lab, an interactive LED floor in the Design Lab, platform(s) allowing students to create simple games within a day, hours of joyful play sessions with 1500+ participants, leading an international workshop [259], over 9 finished student group projects, 10 related Bachelor's theses, a master thesis, and this PhD thesis.

In this Chapter I discuss our results and insights on a more general level, instead of this tangible level. I have already mentioned in each chapter that the studies have some possible limitations, but this is also the case on a higher level regarding the overall approach we chose. I will start this chapter by discussing these limitations. I will then turn to what the gathered insights actually mean and what effect they can have. In this chapter I do this by summarizing the three main parts of the thesis from this perspective, and providing several recommendations for future research related to our findings. I will finish this chapter by discussing how I addressed aspects of intervention based research in this thesis, an approach I already introduced in Chapter 2.

10.1 Limitations of this Thesis

In this section I will discuss some limitations of how I approached the research.

Guidelines The thesis does not contain a clear set of guidelines on how to design for steering behavior in interactive play. Previous studies by other researchers that introduced new systems often also proposed new best practices of creating systems in the form of guidelines, or the other way around: in papers introducing new guidelines it is explained how to apply these with the design of (their new) interactive systems [20, 100, 177]. Doing more research into the *design methodology* that generates a basis for such guidelines would have allowed less time to look into the spectrum of possibilities of steering interactive play behavior. My contribution is aimed more at a research level instead, and less on such a design level. It contains information on what aspects can be researched, and how this can be done. Researchers and developers interested in similar topics and design methodology might still be helped by reading my endeavors, and use, change, or omit the ways in which I approached these to their own liking, especially once they compare this to their own experiences.

New System(s) A focus of related projects is to develop a revolutionarily new system and show and evaluate its unique points. Although most of our applications are new combinations, seen from the current state of the art, some reviewers and colleagues were tempted to remark that the systems are not revolutionarily different. I have to agree that there are interactive playgrounds based on projectors and cameras, that there are interactive balls for leisure, and that there are motivating interactive gait rehabilitation systems. I believe that our systems *are* innovative and *do* add to the current state of the art. In each Chapter I have tried to explain what makes our system and focus of research different from what has been done before and why this combination is of interest. The way I *copied, transformed, and combined* design techniques, existing interactive technologies, user-groups, and evaluation methods is in my opinion sufficiently new[1].

Generalization Due to the number of users and specific technologies I used it is hard to make claims that allow for generalization. I showed it is possible to steer interactive play behavior to certain directions, in certain contexts, with certain technology, and with certain users. Whether this will transfer to other situations is hard to tell; I can only speculate whether it will be applicable for other settings such as self-initiated play sessions, sessions with a different duration, installations based on other interactions, or other implementations of similar steering mechanisms. More general statements are problematic, the choices for implementation, the often technology oriented test group, the size of our test group, first-time use, and the maturity of a system could all influence the outcome of a test. As I suggested in Chapter 2, long-term testing with wide-spread commercial systems might be one way to address this.

10.2 Contributions per Part

I was able to show certain possibilities of steering interactive play systems, these main contributions are summarized per part below with some additional suggestions.

[1] I like to refer to Kirby Ferguson's video *Everything is a Remix* for an interesting view on how science, interactive technology and music evolves over time based on previous work. I copied the three *basic elements of creativity* from this video (min. 17): `https://vimeo.com/139094998`, last visited on 9-6-2016.

1. It is possible to steer interactive play behavior with targeted (adaptive) interventions, and even with non-functional in-game upgrades in the form of embellishments. This can help to attain certain goals.

    - *Distributed interactive team play combined with collocated play is an interesting context to research steering behavior.*
    - *Future research could profit from applying embellishment-based steering in interactive playgrounds, as it can contain several beneficial properties.*

2. It turned out to be possible to provide an interactive leisure activity for several people with PIMD, that encourages alertness, generates positive effects on affective behavior, or stimulates movement. During our research several staff members and the literature pointed to a personalized approach, in which staff picks goals and selects the right users for a product or the right products for a user.

    - *Similar to Snoezelen [90] it seems interactive leisure activity will never be a one-suits-all solution. Therefore, especially in this domain one has to design a system that can be individualized to still make it suitable for as many users as possible. In the design and evaluation process staff members can be included [130] and staff members should be able to address suitable goals with the product. Even then, in cooperation with staff members and after some sessions, we should eventually probably only select a sub-selection of users that will benefit from that specific leisure activity.*

3. It is possible to provide an entertaining experience on an interactive pressure sensitive LED floor with an appropriate game from a suite of games, that have adjustable parameters that can tailor the game to the user by a therapist. Such a game can be based on observations and experience in current (traditional) practice and seems to be relevant for the players' gait rehabilitation.

    - *The responses of several therapists indicated that continuation in this direction will lead to games that successfully address relevant gait rehabilitation goals. As is suggested by Bongers and Smith such interactive rehabilitation games could lead to enjoyable sessions with increased motivation and therefore similar or even improved effects for gait ability [32]. Being able to select a game, from a suite of games on such a platform, might be of added value to target relevant goals.*

10.3 Towards Intervention Based Research

In this thesis the studies have been directed towards *intervention based play research*: introducing *interventions* to *an end*. I tried to find useful or interesting goals/ends based on discussions with experts, observations of possible users, and based on the literature. I then looked at attainable and measurable parts of these goals. We created new interactive *interventions*: (parts of) interactive systems that contribute towards these goals. Especially in Part I these interventions were clearly defined, and easy to recognize as separate aspects of the larger system. In Part II and Part III, instead, the entire system (or one game against another in a suite of games) was the intervention.

It seems that especially the type of interventions that are created as an add-on alternative, on top of an existing system, are a very suitable approach for intervention based play research. These alternatives allow for a clear comparison, and in some forms for better transfer to other system implementations.

10.3.1 Adaptive Interventions

Where possible I made the intervention in such a way that I could easily switch them on or off, literally with the press of a button. Our ITP could introduce power-ups by pressing *P*, adaptive arrows by pressing *A*, and adaptive circle size by pressing *V*. This makes it clear that the interventions are either adaptive, or could easily be made adaptive. I envision an ITP that, based on the play of children (e.g. limited amount of movement and sounds), could automatically change the game (introduce power-ups). I implemented such an adaptive system for the arrow intervention (pointing towards the player (ID) with the least amount of time as a tagger). I also tested a similar intervention with regard to balancing the game with circle size in Chapter 5. Although I only tested short play sessions in the ITP, I believe that these adaptive systems could help to keep players engaged for a longer time, and at times could help to include those players that are not really part of the game. Unfortunately, I could not yet show such a system in working but we envision an interactive playground where, with a subtle intervention, in a positive way and without the need for adult intervention, the shy child in the corner could become the empowered center of attention.

10.3.2 Testing Interventions

With the selection of useful, measurable, and attainable goals, in combination with a specific intervention, the evaluation also becomes more straightforward. It requires selection of the appropriate user group, sometimes in several phases: it can be beneficial to first test technology with students and only then proceed to test it with a specific user group (see Part I and Part II). It also requires suitable measures fitting the chosen goals. For instance, the use of automatic measures for changes in positions [153], manual annotations based on observations to systematically interpret behavior taking into account the idosyncratic behaviors of people with PIMD [90], or with people with higher cognitive skills a combination of automatic measurements, questionnaires, observations and (semi-structured) interviews to investigate the experiences [260]. Doing pilot studies or repeating structured tests allows one to alter, scale, or improve an intervention (see Chapter 6). Ideally in such intervention based research we can turn off a certain part which we designed to be responsible for a certain goal (see Chapter 5 and 6). Once we turn that part on/off, we can evaluate this systematically, and see if this indeed influences the measurements regarding the targeted goals; it will provide stronger evidence that the chosen interventions are responsible for attaining the targeted goals.

This approach can be seen in each part of this thesis. I defined attainable goals and explained why these mattered, based on research from other domains. I created interventions based on our observations of similar systems or contexts, (sometimes) based on literature, and tested if it had the anticipated effect (preferably with quantitative measures). We selected appropriate measures and altered existing ones where needed. I did tests with different kinds of users and systems: this varied between 14 people with PIMD playing with a ball and 1500+ people (children and students) playing with the IPP. I preferred to test a number of conditions, based on the kind of intervention, kind of user group, and time available to us and the participants. I then made conservative conclusions, and pointed out the possible applicability or ways it could be used in other research.

The study designs, including which condition(s) each participant engaged in, also depended on these aspects in combination with possible learning effects.

- Students from Chapter 4 that played in the Distributed Interactive Pong Playground, children playing in the ITP in the art gallery from Chapter 6, and some rehabilitants from Chapter 9, tested only one condition.

- Children in the field trip visit to our university from Chapter 6 engaged in two conditions. The children visiting the art-gallery engaged in three conditions. The students from Chapter 5 even encountered even conditions.

- Some rehabilitants from Chapter 9 and people with PIMD from Chapters 7 and 8, participated in repeated sessions that were compared to their behavior during a related non-interactive baseline.

There are some differences between the parts regarding the scope in which I was able to test/compare our intervention. In the IPP (Part I) I really looked into elements that could either be left out or added: I changed social parameters or game-play in different ways (teammember vs opponent, distributed vs colocated, individual line vs connected line, baseline vs arrow/adaptive circle/power-ups/shields/aesthetic improvements). For the interactive ball (Part II) due to the complications with the user group, I only tested for the possible effect of the entire system. In contrast, I did not really come to a systematic comparison yet for our interactive pressure sensitive LED floor but did test several types of games (Part III).

Testing interventions systematically allows others to more easily target the same goals, try to transfer the intervention to their system, apply the same way of evaluation, or incorporate the intervention as an adaptive element. In my view such a way of doing intervention based play research is likely to result in a good transfer of knowledge to other research(ers) and to further development by others.

11 Further/Future Work

You can't prove it won't happen
– Opening caption, Futurama s04e14 (2001)

Further research beyond our explorations presented in this thesis will be needed to show that intervention based research is indeed the best way to go. We have shown in this thesis that is *a* way to go and can lead to insightful results. Further research is also needed to go beyond the specific limitations we have indicated earlier on regarding these insights, both those mentioned in the individual chapters and the discussion.

Instead of going into more detail into such 'future work', this Chapter contains a number of directions for research into interactive play systems. In these explorations we did not yet reach a publishable level. In this section instead, we will simply highlight aspects that we deem interesting and worthwhile to further investigate, thus this Chapter mainly presents our exploratory *'further work'*.

11.1 Open-ended Play

In Part I and Part III we approached interactive play as if it were a game-like activity. We enforced rules, we steered behavior, and we let children play only for a short duration. In contrast in open-ended play it is about providing tools or toys with which children can create there own games.

We did not use such an open-ended approach and suggested that introducing rules and automatic supervision could prevent the *break-down of play*, children stopping the game due to conflicts or lack of interest [156]. For instance, due to conflicts that follow the uncertainty on who is '*it*'. A lack of interest could be the result of large differences in skills. To prevent such occasions of break-down of play, we let the system operate as a referee, and we balanced the game. The resulting game-like play experiences were entertaining, led to (regulated) physical activity [153], and also maintained certain social interactions such as performances (e.g. in the form of exagerated dances) [153].

When we observed play at the school playground both game-like and open-ended play occurred (Chapter 5): children created non-existing games, and children played the game of tag, played soccer, or were jumping rope. In some of the games children were not really participating, perhaps not being skilled enough. On another occasion an open-ended/invented game variation of the *ticking time bomb ball* seemed utterly unfair, having a subjective referee who would probably limit the time it would be played. On the other hand, in Part II the interactive ball presented the people with PIMD with a more open-ended style of play. As we deemed it more appropriate for this user group with such limited cognitive capabilities to have multiple but simple cause and effect interactions.

In one project a Bachelor's student, Simon Schilke, of ours also looked more into the open-ended play for children. He looked into instrumenting a ball-pit with interactive elements, to see if this would stimulate creativity/imagination[1]. Certain balls would emit light and vibrate if they were shaken, see Figure 11.1. He hypothesized that children would think of new games because the balls responded to certain inputs. He tested this with 5 groups of children, with a mix of boys and girls between 2 and 5-years old. It seemed in his (first-use) sessions of 15 minutes, that the children were intrigued by the balls, played calmer (fewer balls thrown out etc.), and would communicate with others more. Unlike his hypotheses, he could not see clear results regarding the number of games that were created and played, it seemed most groups actually played a few games less (7.8 vs 6.2) but did participate longer in game-like play. However, further, more structured studies (compensating for order effects) would be needed in this context to really allow for conclusions regarding the related effects of technological enhancements of such a ball pit.

11.2 Applications in Commercial Real-life Settings

We tutored two Bachelor's students that did an internship at Yalp, one of the few companies that create commercial interactive playgrounds for such contexts. Yalp mainly focuses on game-like interactive playgrounds for outdoor play. One student, Bouke Regnerus, was focusing on their interactive soccer wall *Sutu*, with a focus on introducing additional social-media-related game technologies, such as leader-boards, invitation to play with others, or personalization. In this project some online leader boards and aesthetic personalization strategies were added. It would be interesting to do further research on the effects of augmentation with additional technology in sequential activities of such games (using a phone before/after to improve the Sutu experience); and to measure with logs if such an optional addition of technologies results in (especially older/young-adult) users to maintain interest for a longer time.

Another student, Martijn Bruinenberg, focused on creating new games for the Yalp Memo platform. In his project he tried to identify several game characteristics in order to find opportunities for interesting new games. He created two games, based on anonymous log files of play on a test location, it was shown that one of these games was played more often than any of the existing games. An early example of how commercial game platforms and their logs, might also be applied in interactive play research.

Martijn Bruinenberg also introduced a high-score in one of his games. He concluded that this not only stimulated running as hard as possible, but also steered away from certain types of cheating. Another interesting suggestion he did during his project was to include a *ghost player*. A player that replays a previous play session,

[1] Similar to the interactive ball pit Bababa, by Chris Gruijters and Gijs Houdijk both students from Eindhoven University of Technology in 2012, where balls made sounds based on movement `https://vimeo.com/bababa`, last visited on 9-6-2016

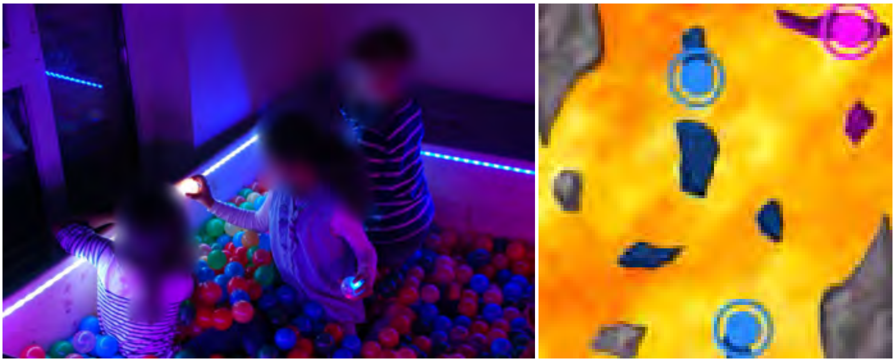

Figure 11.1: On the left, three children playing with the interactive balls in a ball-pit, and on the right, the interactive jump game called the floor is lava.

for example, as if it were an opponent. This would also be an interesting approach to stimulate children to start playing on their own, and later on be joined by others that see the child playing. It seems to be one way to 'lure' children to actively play with other children. It seems these are just a few of the many very interesting topics to do future research on, in order to further our knowledge about strategies to steer and stimulate interactive play in real-life settings.

11.3 Augmenting Other Traditional Games: a Jump Game

One game that we also would have liked to augment, based on our observations, was a jump-based game. Jump-rope games especially showed possibilities to tap into: the sedentary spectators, the negative feedback loop of failing resulting in less play time, and the limited amount of concurrently playing players. Similar to the chosen game of tag, it did show promising social interactions, intense physical activity, and enjoyment during play.

We had a Bachelor's student Clemens Grunewald looking into the creation of a jump-based game. Instead of a jump-rope game, he created a jump based game by augmenting the game of the '*the floor is lava*' and combining it with a '*capture-the-flag*' game mechanic. The game worked as follows: players were assigned to a team. Players had to capture as many stones as possible for as long as possible. To do this they had to jump on a stone and stand on it for a second to change it to their color. If players would stand/move too long in the lava they would no longer be able to change the stone's color, and had to return to their home base to recharge, see Figure 11.1. Unfortunately we never managed to finish the game beyond a prototype and only did a pilot test with some children. One interesting point was that even though we could not yet measure children jumping in the Interactive Playground Platform, with adding the context and game mechanics that fitted the floor is lava, we were able to steer children to jump over the lava. It is useful to remember that current limitations of a tracking system do not one-on-one need to limit the type of activities that can be triggered. Following several other researchers in the field, we also believe future work into interactive playgrounds can benefit from looking at traditional playground games to see how they could be augmented in order to attain certain goals [141, 156].

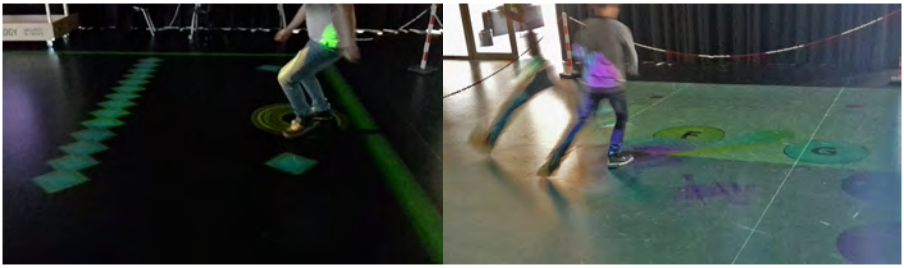

Figure 11.2: On the left, a game on the IPP exploring the effect of music on perceived difficulty, someone is avoiding a wave of virtual objects that are approaching. On the right a game on the IPP intended to teach children about musical notes.

11.4 Incorporating Music

In most of our games we used sounds but often we did not incorporate music elements. Only in Part II were some short tunes (instead of shorter sounds) played and in Part III during some of the gait rehabilitation games music was played in the background. We know that for some people with profound intellectual and developmental disabilities music therapy can lead to enjoyable interpersonal encounters [248]. We also know that music can be applied in games in such a way that it changes if the game intensifies [131].

We had one Master's student, Robin Knuppe, explore whether players would experience a game with more intense music to be more difficult. We set out to create a game with two conditions, in both the difficulty would increase in the first half and remain constant after half the game. In one condition the music would increase in intensity in the first half and also keep constant in the second half. In the other condition the players would play a game in which the intensity of the music would increase up to the end. To this end he created a game with the IPP in which objects moving towards the player had to be avoided, see Figure 11.2. Unfortunately there were several shortcomings in how the evaluation was done, including how (perceived) difficulty was measured, and in the end he did not find clear effects. Nonetheless, we think it would be interesting to add music to the IPP but perhaps also to the rehabilitation games, and to do further research to see if and how one could steer behavior with musical elements in similar interactive playgrounds.

11.5 Educational Play

In Chapter 2 we shared the insights of Malinverni & Parés that a form of educational interactive play, or what they call *'FUll-Body Interaction Learning Environments (FUBILEs)'*, is a promising direction for future research [141].

Martijn Bruinenberg, the student working on the MEMO platform, also created an educational Quiz game for the platform. Children had to link countries to their capitals by walking towards the appropriate pole. His findings suggested that such knowledge-based learning could be triggered successfully, and would even be engaged in voluntarily outside school-time.

Some student projects incorporating the IPP also explored topics for learning. In one installation students tried to facilitate the learning of music theory with such interactive elements, which has been succesfully attempted several times before [12, 91, 270]. The projection had one part in which color coded notes on a staff moved from the right to the left. Children had to stand on the right note (location in the IPP) at the right moment, similar to the game of Guitar Hero, see Figure 11.2. Another group of students attempted to create a game for the IPP that explained the basic operations of boolean calculus. Children had to stand on circles in order to switch their state between true and false. Both projects unfortunately had serious flaws in their game design and evaluations, invalidating any conclusions about motivation, the design, or the success in attaining the learning goals. We do believe that the IPP might be applied to target such educational goals as well, to some extent the ideas and the resulting game concepts, taking into account their short implementation time of only a few days work of a few second year Bachelor's students, point towards such possible applications.

Besides these 'evaluations' investigating such systems intended to teach something to their users, we will continue this section with observations of interactions that strengthen the belief that the IPP could function as an educational tool.

11.5.1 Peer-tutoring and a Conversation Piece

During several demos of interactive play installations, we noticed that people often explained the workings of the system to their peers or discussed how they thought it could work. In one student project we created an interactive bar representing an underwater world: *Anemone*[1]. It consisted of an interactive projection on the bar in which users could scare away moving creatures with quick (arm) movements and with slow movements or placing objects could grow anemones (that in turn attracted the creatures), see Figure 11.3. The interactions resulted in things happening especially between users' positions, in an attempt to stimulate interaction between users while they were waiting at a bar. Especially in this context we noticed several occasions in which the users started explaining the system to each other, the system functioning as a trigger to converse with each other and stimulating one user to explain it to another. A similar kind of peer-tutoring happened when we demoed our ITP installation at a large demo-event with our ICT project-partners.

Malinverni & Parés already pointed out that with regard to FUBILEs a certain multiple user design '*facilitates discussion and shared decision making*' [141, p107]. Hof et al. also noticed that in the first session with their *ColorFlare* communication was about explaining the object and functionality [192]. Morrison et al. found that their open-ended interactive art works could lead to '*situated social play through the work, where [..] communication is mediated through the work as a proxy*' [159]. Therefore, we think it is worthwhile to do more research (into steering interactive play) in an educational context using such a peer-tutoring eliciting effect and triggering discussions/interactions.

11.5.2 Triggering Interest and Passers-by

During our evaluations we observed that several children would be curious about and became interested in how the interactive playground platform worked. Several governments currently try to stimulate interest in Science, Technology, Engineering,

[1]For an impression see `https://youtu.be/BmrlLz3GzP0`, last visited on 9-12-2016

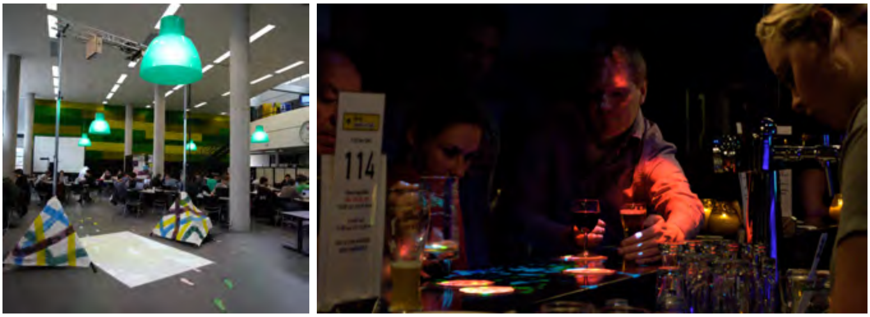

Figure 11.3: On the left, the interactive canvas *WeFloor* on which people could virtually paint by walking over it. The screen, footsteps and a ghost-player were added interventions to invite more users. On the right, users interacting with *Anemone*, an interactive virtual under-water world projection on a bar. The red glow represents the 'added' energy, the white blobs are creatures and the colored shapes are different kinds of anemone.

and Maths, similar to Malinverni & Parés [141], we believe interactive playgrounds could help to trigger learning goals or interests related to these topics.

However, if we want to trigger interactions and stimulate use outside school hours, it is important to design our installations in such a way that users will start to interact with them. In one student project we tried to investigate some possible ways to encourage passersby to interact with an interactive installation. In this *WeFloor* project an interactive floor projection was created, where passersby could draw on the floor by walking over it, see Figure 11.3. Remarkably and totally unexpectedly, in a first pilot study we had seen a passerby at our university climbing over a nearby chair to prevent walking over the interactive floor. In other user studies they tried out different interventions to trigger interaction: ghost players triggering interest, placing paper cut-out footsteps nearby, placing/removing a dedicated (projection) screen on the floor (which improved the quality of the floor projection but could introduce an additional barrier). Unfortunately the results were not conclusive regarding the effects of such interventions. Nonetheless, during the project we did see that in about 60% of the 2080 passerby instances such a system did not trigger interaction. This made us (re)realize that it is important, but not trivial, to design and test the appropriate ways to initiate interaction and make passersby curious [61, 249]. We believe further research into such aspects could be very worthwhile, especially for an extra curricular educational setting.

11.5.3 Learning by Simulation

A final interesting aspect for research into interactive play for educational purposes is the use of simulation. In one student project at our research group an interactive ceiling was created, *the Thingy Cloud*[1]. Users would have a personal amoeba-like avatar following them on the ceiling. Once they came close to another creature these would merge and transform into another life-form. The interactions contained an evolutionary tree, and a variety of resulting visualizations, see Figure 11.4. This project and its interactions show it could be possible to also simulate more complicated topics

[1]Unlike the other examples, I was not part of (tutoring and helping in) this project.

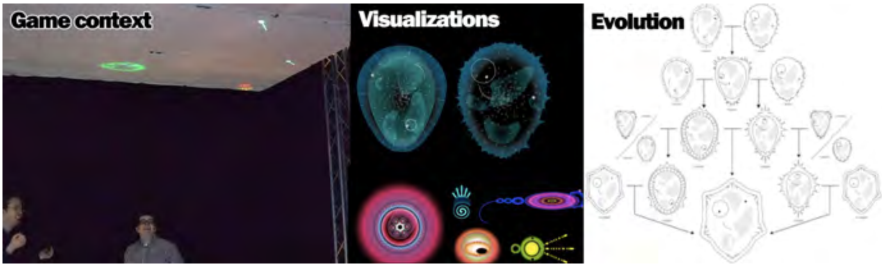

Figure 11.4: Thingy Cloud, an interactive ceiling installation. Personal avatars merge and transform once players come physically close to each other, and will split up if players take distance from each other again.

such as evolution[1]. Children would be able to try out several interactions and in an iterative manner investigate a topic, similar to the field of serious games. As a final suggestion for this Chapter, we believe it would be interesting to further research in what way simulation (quite open-ended instead of goal-directed games) would be able to be incorporated in interactive playgrounds for educational purposes.

11

[1]Evolution was also a central topic for the *Looking for Life* installation by Snibbe interactive `http://www.snibbe.com/looking-for-life/`, last visited 9-12-2016

12 Conclusion

We could just enjoy it for a little bit.
I mean, look at how crazy it is.
I mean, Morty, when's the next time you're gonna
see something like this?
I mean, soak it in, you know?
It's..it's pretty neat. It's pretty interesting.
– Rick, Rick and Morty s01e06 (2014)

In this thesis I have shown several significant and relevant effects of our user studies into (steering) interactive play behavior. I have also highlighted several aspects to investigate, I have shown why these were worthwhile to address, and I explained the way I investigated this. To this end we have designed various interactive play systems and games:

- a distributed interactive pong playground, a camera-projection system with a pong game to investigate steering coordination, and research the effect of team distribution on social presence in mixed collocated-distributed interactive play;
- an interactive tag playground, a camera-projection system with game variations to balance the time one is a tagger, steer the choice of a tagger, and steering proximity between the tagger and runners;
- an interactive moving ball responding to the upper-body of the player, intended as a leisure activity for people with profound intellectual and multiple disabilities (PIMD), to increase alertness, improve the amount of shown positive/negative affect, and increase the amount of (suitable) movement;
- and several games on a pressure sensitive interactive floor for rehabilitation purposes.

I started with an overview of many interactive play systems. I categorized their goals, I summarized the type of systems, the way evaluations were approached, and the kind of research contribution that were sought after. I then showed that many researchers from all main lines of interactive play research approach research with an experimental design approach, which I then described as *intervention based play research*. I also mentioned two aspects of this research that seemed to fit this approach: *steering interactive play* and to go *beyond first time use*. For the latter we also identified that automatic measurements could be a worthwhile tool.

I applied this *intervention based play research* approach in many of the studies. I showed that steering behavior can be done in various ways using our Interactive Playground Platform. With various game (versions) I successfully steered movement coordination between players, the time someone is a tagger (towards a more equal distribution), the choice who was going to be tagged, and the distance towards the tagger. Included in the ways of steering is what I called an *enticing steering* to change behavior. A type of steering behavior that uses rewards in the form of aesthetically pleasing avatar embellishments for certain actions. The interactions to obtain these rewards are not needed to play the game, the game would still be similar to the existing game if players do not incorporate it in their game play. If they do incorporate in their game play, the rewards are non-functional with regard to a pre-existing main game goal, and do not have a positive effect on such goals. This brings forward several possible advantages: the non-enforcing more libertarian character for steering behavior, the ability to turn it off and on, and an easier transfer to other playgrounds.

I showed that there is a need for interactive leisure activity especially for people with severe disabilities. We created an interactive ball to address some goals that were set out regarding alertness, shown affect, and amount of movement. I explained the difficulties inherent in doing research with such a user group: doing research on interventions for people with PIMD leads to profound methodological challenges due to the small number of people with homogeneous conditions, fluctuating health differences, contextual differences, and the longer treatment time that is required [248]. I showed that there were large differences in the responses to the ball, three of our nine participants included in the ten sessions showed positive effects on one or more of the targeted measures. Overall each targeted goal was reached for one or more participants. I then suggested based on our experience with the user group, literature that I found, and discussion with the care staff, that most interactive play systems for people with PIMD will likely not be a 'one-fits-all' solution, and for successful deployment will often need larger amounts of tailoring.

Finally I showed how an interactive play system can be used in a gait rehabilitation setting. I suggested that providing several games (a suite of games), each building on existing exercises and capable of being easily adapted, might provide a motivating and suitable interaction for a wide range of rehabilitants.

Most importantly I showed how one might approach interactive play research with *intervention based play research*, combine different ways for evaluating, and use *steering play behavior* to work towards predefined properly grounded goals.

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About the Author

I don't think that there's anything worse than being ordinary.
– Angela Hayes, American Beauty (1999)

I am a researcher at the Human Media Interaction (HMI) group of the University of Twente. I received an MSc degree in Human Media Interaction and an MSc in Industrial Design Engineering (Emerging Technology Design track). My combined Master's thesis focused on the design of a tangible rehabilitation game for children with a hemi-paresis and this resulted in a full paper for ICEC 2012.

I am currently employed as a tutor/lecturer and researcher at HMI. These educational activities mainly involve Bachelor's students from Creative Technology and Master's students from the Human Media Interaction programme at the University of Twente. In the study year 2016-2017, I have taught the course Game Design, and have been involved in the course Design of Persuasive Health Technologies and the module Intelligent Interaction Design. This latter module is related to UX and focuses on grounded design decisions and evaluations of interactive systems. In this course Bachelor's students from Business & IT and Technical Computer Science programmes also participate. Together with Dennis Reidsma I (co-)supervise a number of BSc and MSc students on topics related to interactive play and gaming. In total I have currently tutored 9 student projects, 10 related Bachelor's theses (9 Creative Technology and 1 Computer Science student), and 1 Master's thesis, from which three projects have led to peer-reviewed full papers. Occasionally I also gives guest lectures on other topics, such as designing for people with special needs, or the use of pervasive technology.

I was (co-)initiator and (co-)author of two accepted grant proposals (1.5 fte years). The first project builds upon student projects that I initiated by contacting and starting cooperation with LEDGo, which in turn led to cooperation with Rehabilitation Centre De Hoogstraat. This project (GREAT) focused on motivating adaptive interactive gait rehabilitation with games on an interactive LED floor, which had a clear link with my work on interactive playgrounds, and which was included as Part III of this thesis. At the end of 2014 I also initiated the *Bot project. 'StarBot' was a project investigating the impact of telepresence robots in everyday life, done part-time with Merijn Bruijnes over a period of over a year. The project focused on investigating the opportunities and the social, ethical, and technical issues that come forward when we start using these 'Skype on wheels'-robots in our every-day lives.

Overall my research focuses on combining the benefits of play, with the engagement of gaming, and the possibilities of exergaming technology. In which I address relevant, attainable, and measurable outcomes. During the design I am always looking at what is technically feasible, what has been done in related literature, and looking at what stakeholders (currently) do and want. For this latter aspect both discussions and observations are applied. During the evaluation I prefer to combine the use of automatic measurements, (direct) observations, discussions, and questionnaires. Preferably, by means of comparative studies (of interventions) where such combined results can convincingly show effects of certain (game) design elements.

The list of publications that were part of this Ph.D. thesis can be found below:

- R. W. van Delden, A. M. Moreno, R. W. Poppe, D. Reidsma and D. K. J. Heylen "A Thing of Beauty: Steering Behavior through Embellishment in an Interactive Playground" *CHI '17 Extended Abstracts on Human Factors in Computing Systems*, TBA-TBA, 2017.

- R. W. van Delden, A. M. Moreno, R. W. Poppe, D. Reidsma and D. K. J. Heylen "Steering gameplay behavior in the interactive tag playground" in *Proceedings of the European Conference on Ambient Intelligence (AmI 2014)*, pp. 145–157, 2014.
- R. W. van Delden, S. Gerritsen, D. Reidsma and D. K. J. Heylen, "Distributed Embodied Team Play, a Distributed Interactive Pong Playground", in *Proceedings of 8th International Conference on Intelligent Technologies for Interactive Entertainment (Intetain 2016)*, pp. 140–149, 2016.
- R. .W. van Delden, D. Reidsma, W. M. W. J. van Oorsouw, R. W. Poppe, P. van der Vos, A. Lohmeijer, P. J. C. M. Embregts, V. Evers, and D. K. J. Heylen "Towards an interactive leisure activity for people with PIMD" in *Proceedings of The 14th International Conference on Computers Helping People with Specific Needs (ICCHP)*, 276-282, 2014.
- R. .W. van Delden, J. Janssen, S. ter Stal, W. Deenik, W. Meijer, D. Reidsma, and D. K. J. Heylen. "Personalization of Gait Rehabilitation Games on a Pressure Sensitive Interactive LED Floor. " in *Proceedings of the International Workshop on Personalization in Persuasive Technology (PPT16)*, 2016.
- *to be submitted* R. W. van Delden, S. Wintels, W. M. W. J. van Oorsouw, V. Evers, D. K. J. Heylen, and D. Reidsma "Do we get your attention? Looking into alertness, movement and indicators of happiness of people with PIMD upon introduction of a playful interactive product", TBA.
- *under review* R. W. van Delden, S. Gerritsen, D. Reidsma and D. K. J. Heylen, "Pervasive Play-spaces: Past, Present and Perspectives", TBA
- (partly included) A. M. Moreno, R. W. van Delden, D. Reidsma, R. W. Poppe, and D. K. J. Heylen "Augmenting Playing Spaces to Enhance the Game Experience: A Tag Game Case Study" in *Entertainment Computing* 16, pp. 67–79
  - A. M. Moreno, R. W. van Delden, D. Reidsma, R. W. Poppe, and D. K. J. Heylen "Augmenting traditional playground games to enhance game experience" in *Proceedings of the 7th International Conference on Intelligent Technologies for Interactive Entertainment (INTETAIN)*, pp. 140-149, 2015.

Beside these publications that were part of this Ph.D. thesis I also provided a significant contribution to other papers that were written and published during this Ph.D research:

- R. W. van Delden and D. Reidsma "Meaning in life as a source of entertainment" in *Proceedings of the 10th Intenational Conference on Advances in Computer Entertainment (ACE)*, pp 403-414, 2013.

- R. W. van Delden, A. M. Moreno, C. Ramos, G. Carrasco, D. Reidsma, and R. W. Poppe "Hang in There: A Novel Body-Centric Interactive Playground" in *Innovative and Creative Developments in Multimodal Interaction Systems*, Springer Berlin Heidelberg, pp. 160-178, 2014.

- R. W. van Delden, P. B. Aarts, and E. M. A. G van Dijk "Design of tangible games for children undergoing occupational and physical therapy" in *Proceedings of the International Conference on Entertainment Computing (ICEC)*, pp. 221-234, 2012.

- R. W. Poppe, R. W. van Delden, A. M. Moreno, and D. Reidsma "Interactive playgrounds for children" in *Playful User Interfaces*, Springer Verlag, pp. 99-118, 2014.

- A. M. Moreno, R. W. van Delden, D. Reidsma, R. W. Poppe, and and D. K. J. Heylen "An annotation scheme for social interaction in digital playgrounds" in *Proceedings of the International Conference on Entertainment Computing (ICEC)*, pp. 85-99, 2012.

- A. M. Moreno, R. W. van Delden, D. Reidsma, R. W. Poppe "Socially aware interactive playgrounds Pervasive Computing: Sensing and inducing social behavior" in *Pervasive Computing 12*, 3, pp. 40-47

- T. Beelen, R. Blaauboer, N. Bovenmars, B. Loos, L. Zielonka, R. W. van Delden, G. Huisman, "The art of tug of war: investigating the influence of remote touch on social presence in a distributed rope pulling game" in *Proceedings of the 10th Intenational Conference on Advances in Computer Entertainment (ACE)*, pp. 246-257, 2013.

- R. W. van Delden "Towards a socially adaptive digital playground." in *Proceedings of the 11th International Conference on Interaction Design and Children (IDC)*, pp. 355-358, 2012.

- *to be submitted* S. Wintels, R. W. van Delden, D. Reidsma, V. Evers, D. K. J. Heylen, W. M. W. J. van Oorsouw, and P. J. C. M. Embregts "Watching TV or playing with an interactive ball? Exploring a new leisure activity for people with PIMD" TBA

Furthermore, during my research I co-organized two workshops on leisure activity for people with PIMD, and co-instigated an international workshop for Persuasive Technologies. I followed several courses on teaching. I was an invited speaker on "interactive technology for health applications" at the annual symposium of regional health care organization Aveleijn. The projects I was involved in also attracted several forms of media attention, it has appeared in several newspapers (AD, Telegraaf), TV-shows (AT5, RTV-oost News en Uit de Kunst), a radio broadcast (Radio 1 EnVandaag), and the national news (NOS).

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26 Matthijs Aart Pontier (VUA) *Virtual Agents for Human Communication: Emotion Regulation and Involvement-Distance Trade-Offs in Embodied Conversational Agents and Robots*
27 Aniel Bhulai (VUA) *Dynamic website optimization through autonomous management of design patterns*
28 Rianne Kaptein (UvA) *Effective Focused Retrieval by Exploiting Query Context and Document Structure*
29 Faisal Kamiran (TUe) *Discrimination-aware Classification*
30 Egon van den Broek (UT) *Affective Signal Processing (ASP): Unraveling the mystery of emotions*
31 Ludo Waltman (EUR) *Computational and Game-Theoretic Approaches for Modeling Bounded Rationality*
32 Nees-Jan van Eck (EUR) *Methodological Advances in Bibliometric Mapping of Science*
33 Tom van der Weide (UU) *Arguing to Motivate Decisions*
34 Paolo Turrini (UU) *Strategic Reasoning in Interdependence: Logical and Game-theoretical Investigations*
35 Maaike Harbers (UU) *Explaining Agent Behavior in Virtual Training*
36 Erik van der Spek (UU) *Experiments in serious game design: a cognitive approach*
37 Adriana Burlutiu (RUN) *Machine Learning for Pairwise Data, Applications for Preference Learning and Supervised Network Inference*
38 Nyree Lemmens (UM) *Bee-inspired Distributed Optimization*
39 Joost Westra (UU) *Organizing Adaptation using Agents in Serious Games*
40 Viktor Clerc (VUA) *Architectural Knowledge Management in Global Software Development*
41 Luan Ibraimi (UT) *Cryptographically Enforced Distributed Data Access Control*
42 Michal Sindlar (UU) *Explaining Behavior through Mental State Attribution*
43 Henk van der Schuur (UU) *Process Improvement through Software Operation Knowledge*
44 Boris Reuderink (UT) *Robust Brain-Computer Interfaces*

45 Herman Stehouwer (UvT) *Statistical Language Models for Alternative Sequence Selection*
46 Beibei Hu (TUD) *Towards Contextualized Information Delivery: A Rule-based Architecture for the Domain of Mobile Police Work*
47 Azizi Bin Ab Aziz (VUA) *Exploring Computational Models for Intelligent Support of Persons with Depression*
48 Mark Ter Maat (UT) *Response Selection and Turn-taking for a Sensitive Artificial Listening Agent*
49 Andreea Niculescu (UT) *Conversational interfaces for task-oriented spoken dialogues: design aspects influencing interaction quality*

2012

1 Terry Kakeeto (UvT) *Relationship Marketing for SMEs in Uganda*
2 Muhammad Umair (VUA) *Adaptivity, emotion, and Rationality in Human and Ambient Agent Models*
3 Adam Vanya (VUA) *Supporting Architecture Evolution by Mining Software Repositories*
4 Jurriaan Souer (UU) *Development of Content Management System-based Web Applications*
5 Marijn Plomp (UU) *Maturing Interorganisational Information Systems*
6 Wolfgang Reinhardt (OU) *Awareness Support for Knowledge Workers in Research Networks*
7 Rianne van Lambalgen (VUA) *When the Going Gets Tough: Exploring Agent-based Models of Human Performance under Demanding Conditions*
8 Gerben de Vries (UvA) *Kernel Methods for Vessel Trajectories*
9 Ricardo Neisse (UT) *Trust and Privacy Management Support for Context-Aware Service Platforms*
10 David Smits (TUe) *Towards a Generic Distributed Adaptive Hypermedia Environment*
11 J. C. B. Rantham Prabhakara (TUe) *Process Mining in the Large: Preprocessing, Discovery, and Diagnostics*
12 Kees van der Sluijs (TUe) *Model Driven Design and Data Integration in Semantic Web Information Systems*
13 Suleman Shahid (UvT) *Fun and Face: Exploring non-verbal expressions of emotion during playful interactions*
14 Evgeny Knutov (TUe) *Generic Adaptation Framework for Unifying Adaptive Web-based Systems*
15 Natalie van der Wal (VUA) *Social Agents. Agent-Based Modelling of Integrated Internal and Social Dynamics of Cognitive and Affective Processes*
16 Fiemke Both (VUA) *Helping people by understanding them: Ambient Agents supporting task execution and depression treatment*
17 Amal Elgammal (UvT) *Towards a Comprehensive Framework for Business Process Compliance*
18 Eltjo Poort (VUA) *Improving Solution Architecting Practices*
19 Helen Schonenberg (TUe) *What's Next? Operational Support for Business Process Execution*
20 Ali Bahramisharif (RUN) *Covert Visual Spatial Attention, a Robust Paradigm for Brain-Computer Interfacing*
21 Roberto Cornacchia (TUD) *Querying Sparse Matrices for Information Retrieval*
22 Thijs Vis (UvT) *Intelligence, politie en veiligheidsdienst: verenigbare grootheden?*
23 Christian Muehl (UT) *Toward Affective Brain-Computer Interfaces: Exploring the Neurophysiology of Affect during Human Media Interaction*
24 Laurens van der Werff (UT) *Evaluation of Noisy Transcripts for Spoken Document Retrieval*
25 Silja Eckartz (UT) *Managing the Business Case Development in Inter-Organizational IT Projects: A Methodology and its Application*
26 Emile de Maat (UvA) *Making Sense of Legal Text*
27 Hayrettin Gurkok (UT) *Mind the Sheep! User Experience Evaluation & Brain-Computer Interface Games*
28 Nancy Pascall (UvT) *Engendering Technology Empowering Women*
29 Almer Tigelaar (UT) *Peer-to-Peer Information Retrieval*
30 Alina Pommeranz (TUD) *Designing Human-Centered Systems for Reflective Decision Making*
31 Emily Bagarukayo (RUN) *A Learning by Construction Approach for Higher Order Cognitive Skills Improvement, Building Capacity and Infrastructure*
32 Wietske Visser (TUD) *Qualitative multi-criteria preference representation and reasoning*
33 Rory Sie (OUN) *Coalitions in Cooperation Networks (COCOON)*
34 Pavol Jancura (RUN) *Evolutionary analysis in PPI networks and applications*
35 Evert Haasdijk (VUA) *Never Too Old To Learn: Online Evolution of Controllers in Swarm- and Modular Robotics*
36 Denis Ssebugwawo (RUN) *Analysis and Evaluation of Collaborative Modeling Processes*
37 Agnes Nakakawa (RUN) *A Collaboration Process for Enterprise Architecture Creation*
38 Selmar Smit (VUA) *Parameter Tuning and Scientific Testing in Evolutionary Algorithms*
39 Hassan Fatemi (UT) *Risk-aware design of value and coordination networks*
40 Agus Gunawan (UvT) *Information Access for SMEs in Indonesia*
41 Sebastian Kelle (OU) *Game Design Patterns for Learning*
42 Dominique Verpoorten (OU) *Reflection Amplifiers in self-regulated Learning*
43 Anna Tordai (VUA) *On Combining Alignment Techniques*
44 Benedikt Kratz (UvT) *A Model and Language for Business-aware Transactions*
45 Simon Carter (UvA) *Exploration and Exploitation of Multilingual Data for Statistical Machine Translation*
46 Manos Tsagkias (UvA) *Mining Social Media: Tracking Content and Predicting Behavior*
47 Jorn Bakker (TUe) *Handling Abrupt Changes in Evolving Time-series Data*
48 Michael Kaisers (UM) *Learning against Learning: Evolutionary dynamics of reinforcement learning algorithms in strategic interactions*
49 Steven van Kervel (TUD) *Ontologogy driven Enterprise Information Systems Engineering*
50 Jeroen de Jong (TUD) *Heuristics in Dynamic Sceduling: a practical framework with a case study in elevator dispatching*

2013

1 Viorel Milea (EUR) *News Analytics for Financial Decision Support*
2 Erietta Liarou (CWI) *MonetDB/DataCell: Leveraging the Column-store Database Technology for Efficient and Scalable Stream Processing*
3 Szymon Klarman (VUA) *Reasoning with Contexts in Description Logics*
4 Chetan Yadati (TUD) *Coordinating autonomous planning and scheduling*
5 Dulce Pumareja (UT) *Groupware Requirements Evolutions Patterns*

6 Romulo Goncalves (CWI) *The Data Cyclotron: Juggling Data and Queries for a Data Warehouse Audience*
7 Giel van Lankveld (UvT) *Quantifying Individual Player Differences*
8 Robbert-Jan Merk (VUA) *Making enemies: cognitive modeling for opponent agents in fighter pilot simulators*
9 Fabio Gori (RUN) *Metagenomic Data Analysis: Computational Methods and Applications*
10 Jeewanie Jayasinghe Arachchige (UvT) *A Unified Modeling Framework for Service Design*
11 Evangelos Pournaras (TUD) *Multi-level Reconfigurable Self-organization in Overlay Services*
12 Marian Razavian (VUA) *Knowledge-driven Migration to Services*
13 Mohammad Safiri (UT) *Service Tailoring: User-centric creation of integrated IT-based homecare services to support independent living of elderly*
14 Jafar Tanha (UvA) *Ensemble Approaches to Semi-Supervised Learning Learning*
15 Daniel Hennes (UM) *Multiagent Learning: Dynamic Games and Applications*
16 Eric Kok (UU) *Exploring the practical benefits of argumentation in multi-agent deliberation*
17 Koen Kok (VUA) *The PowerMatcher: Smart Coordination for the Smart Electricity Grid*
18 Jeroen Janssens (UvT) *Outlier Selection and One-Class Classification*
19 Renze Steenhuizen (TUD) *Coordinated Multi-Agent Planning and Scheduling*
20 Katja Hofmann (UvA) *Fast and Reliable Online Learning to Rank for Information Retrieval*
21 Sander Wubben (UvT) *Text-to-text generation by monolingual machine translation*
22 Tom Claassen (RUN) *Causal Discovery and Logic*
23 Patricio de Alencar Silva (UvT) *Value Activity Monitoring*
24 Haitham Bou Ammar (UM) *Automated Transfer in Reinforcement Learning*
25 Agnieszka Anna Latoszek-Berendsen (UM) *Intention-based Decision Support. A new way of representing and implementing clinical guidelines in a Decision Support System*
26 Alireza Zarghami (UT) *Architectural Support for Dynamic Homecare Service Provisioning*
27 Mohammad Huq (UT) *Inference-based Framework Managing Data Provenance*
28 Frans van der Sluis (UT) *When Complexity becomes Interesting: An Inquiry into the Information eXperience*
29 Iwan de Kok (UT) *Listening Heads*
30 Joyce Nakatumba (TUe) *Resource-Aware Business Process Management: Analysis and Support*
31 Dinh Khoa Nguyen (UvT) *Blueprint Model and Language for Engineering Cloud Applications*
32 Kamakshi Rajagopal (OUN) *Networking For Learning: The role of Networking in a Lifelong Learner's Professional Development*
33 Qi Gao (TUD) *User Modeling and Personalization in the Microblogging Sphere*
34 Kien Tjin-Kam-Jet (UT) *Distributed Deep Web Search*
35 Abdallah El Ali (UvA) *Minimal Mobile Human Computer Interaction*
36 Than Lam Hoang (TUe) *Pattern Mining in Data Streams*
37 Dirk Börner (OUN) *Ambient Learning Displays*
38 Eelco den Heijer (VUA) *Autonomous Evolutionary Art*
39 Joop de Jong (TUD) *A Method for Enterprise Ontology based Design of Enterprise Information Systems*
40 Pim Nijssen (UM) *Monte-Carlo Tree Search for Multi-Player Games*
41 Jochem Liem (UvA) *Supporting the Conceptual Modelling of Dynamic Systems: A Knowledge Engineering Perspective on Qualitative Reasoning*
42 Léon Planken (TUD) *Algorithms for Simple Temporal Reasoning*
43 Marc Bron (UvA) *Exploration and Contextualization through Interaction and Concepts*

2014

1 Nicola Barile (UU) *Studies in Learning Monotone Models from Data*
2 Fiona Tuliyano (RUN) *Combining System Dynamics with a Domain Modeling Method*
3 Sergio Raul Duarte Torres (UT) *Information Retrieval for Children: Search Behavior and Solutions*
4 Hanna Jochmann-Mannak (UT) *Websites for children: search strategies and interface design - Three studies on children's search performance and evaluation*
5 Jurriaan van Reijsen (UU) *Knowledge Perspectives on Advancing Dynamic Capability*
6 Damian Tamburri (VUA) *Supporting Networked Software Development*
7 Arya Adriansyah (TUe) *Aligning Observed and Modeled Behavior*
8 Samur Araujo (TUD) *Data Integration over Distributed and Heterogeneous Data Endpoints*
9 Philip Jackson (UvT) *Toward Human-Level Artificial Intelligence: Representation and Computation of Meaning in Natural Language*
10 Ivan Salvador Razo Zapata (VUA) *Service Value Networks*
11 Janneke van der Zwaan (TUD) *An Empathic Virtual Buddy for Social Support*
12 Willem van Willigen (VUA) *Look Ma, No Hands: Aspects of Autonomous Vehicle Control*
13 Arlette van Wissen (VUA) *Agent-Based Support for Behavior Change: Models and Applications in Health and Safety Domains*
14 Yangyang Shi (TUD) *Language Models With Meta-information*
15 Natalya Mogles (VUA) *Agent-Based Analysis and Support of Human Functioning in Complex Socio-Technical Systems: Applications in Safety and Healthcare*
16 Krystyna Milian (VUA) *Supporting trial recruitment and design by automatically interpreting eligibility criteria*
17 Kathrin Dentler (VUA) *Computing healthcare quality indicators automatically: Secondary Use of Patient Data and Semantic Interoperability*
18 Mattijs Ghijsen (UvA) *Methods and Models for the Design and Study of Dynamic Agent Organizations*
19 Vinicius Ramos (TUe) *Adaptive Hypermedia Courses: Qualitative and Quantitative Evaluation and Tool Support*
20 Mena Habib (UT) *Named Entity Extraction and Disambiguation for Informal Text: The Missing Link*
21 Kassidy Clark (TUD) *Negotiation and Monitoring in Open Environments*
22 Marieke Peeters (UU) *Personalized Educational Games: Developing agent-supported scenario-based training*

23 Eleftherios Sidirourgos (UvA/CWI) *Space Efficient Indexes for the Big Data Era*
24 Davide Ceolin (VUA) *Trusting Semi-structured Web Data*
25 Martijn Lappenschaar (RUN) *New network models for the analysis of disease interaction*
26 Tim Baarslag (TUD) *What to Bid and When to Stop*
27 Rui Jorge Almeida (EUR) *Conditional Density Models Integrating Fuzzy and Probabilistic Representations of Uncertainty*
28 Anna Chmielowiec (VUA) *Decentralized k-Clique Matching*
29 Jaap Kabbedijk (UU) *Variability in Multi-Tenant Enterprise Software*
30 Peter de Cock (UvT) *Anticipating Criminal Behaviour*
31 Leo van Moergestel (UU) *Agent Technology in Agile Multiparallel Manufacturing and Product Support*
32 Naser Ayat (UvA) *On Entity Resolution in Probabilistic Data*
33 Tesfa Tegegne (RUN) *Service Discovery in eHealth*
34 Christina Manteli (VUA) *The Effect of Governance in Global Software Development: Analyzing Transactive Memory Systems*
35 Joost van Ooijen (UU) *Cognitive Agents in Virtual Worlds: A Middleware Design Approach*
36 Joos Buijs (TUe) *Flexible Evolutionary Algorithms for Mining Structured Process Models*
37 Maral Dadvar (UT) *Experts and Machines United Against Cyberbullying*
38 Danny Plass-Oude Bos (UT) *Making brain-computer interfaces better: improving usability through post-processing*
39 Jasmina Maric (UvT) *Web Communities, Immigration, and Social Capital*
40 Walter Omona (RUN) *A Framework for Knowledge Management Using ICT in Higher Education*
41 Frederic Hogenboom (EUR) *Automated Detection of Financial Events in News Text*
42 Carsten Eijckhof (CWI/TUD) *Contextual Multidimensional Relevance Models*
43 Kevin Vlaanderen (UU) *Supporting Process Improvement using Method Increments*
44 Paulien Meesters (UvT) *Intelligent Blauw: Intelligence-gestuurde politiezorg in gebiedsgebonden eenheden*
45 Birgit Schmitz (OUN) *Mobile Games for Learning: A Pattern-Based Approach*
46 Ke Tao (TUD) *Social Web Data Analytics: Relevance, Redundancy, Diversity*
47 Shangsong Liang (UvA) *Fusion and Diversification in Information Retrieval*

2015

1 Niels Netten (UvA) *Machine Learning for Relevance of Information in Crisis Response*
2 Faiza Bukhsh (UvT) *Smart auditing: Innovative Compliance Checking in Customs Controls*
3 Twan van Laarhoven (RUN) *Machine learning for network data*
4 Howard Spoelstra (OUN) *Collaborations in Open Learning Environments*
5 Christoph Bösch (UT) *Cryptographically Enforced Search Pattern Hiding*
6 Farideh Heidari (TUD) *Business Process Quality Computation: Computing Non-Functional Requirements to Improve Business Processes*
7 Maria-Hendrike Peetz (UvA) *Time-Aware Online Reputation Analysis*
8 Jie Jiang (TUD) *Organizational Compliance: An agent-based model for designing and evaluating organizational interactions*
9 Randy Klaassen (UT) *HCI Perspectives on Behavior Change Support Systems*
10 Henry Hermans (OUN) *OpenU: design of an integrated system to support lifelong learning*
11 Yongming Luo (TUe) *Designing algorithms for big graph datasets: A study of computing bisimulation and joins*
12 Julie M. Birkholz (VUA) *Modi Operandi of Social Network Dynamics: The Effect of Context on Scientific Collaboration Networks*
13 Giuseppe Procaccianti (VUA) *Energy-Efficient Software*
14 Bart van Straalen (UT) *A cognitive approach to modeling bad news conversations*
15 Klaas Andries de Graaf (VUA) *Ontology-based Software Architecture Documentation*
16 Changyun Wei (UT) *Cognitive Coordination for Cooperative Multi-Robot Teamwork*
17 André van Cleeff (UT) *Physical and Digital Security Mechanisms: Properties, Combinations and Trade-offs*
18 Holger Pirk (CWI) *Waste Not, Want Not!: Managing Relational Data in Asymmetric Memories*
19 Bernardo Tabuenca (OUN) *Ubiquitous Technology for Lifelong Learners*
20 Loïs Vanhée (UU) *Using Culture and Values to Support Flexible Coordination*
21 Sibren Fetter (OUN) *Using Peer-Support to Expand and Stabilize Online Learning*
22 Zhemin Zhu (UT) *Co-occurrence Rate Networks*
23 Luit Gazendam (VUA) *Cataloguer Support in Cultural Heritage*
24 Richard Berendsen (UvA) *Finding People, Papers, and Posts: Vertical Search Algorithms and Evaluation*
25 Steven Woudenberg (UU) *Bayesian Tools for Early Disease Detection*
26 Alexander Hogenboom (EUR) *Sentiment Analysis of Text Guided by Semantics and Structure*
27 Sándor Héman (CWI) *Updating compressed column-stores*
28 Janet Bagorogoza (TiU) *Knowledge Management and High Performance: The Uganda Financial Institutions Model for HPO*
29 Hendrik Baier (UM) *Monte-Carlo Tree Search Enhancements for One-Player and Two-Player Domains*
30 Kiavash Bahreini (OUN) *Real-time Multimodal Emotion Recognition in E-Learning*
31 Yakup Koç (TUD) *On Robustness of Power Grids*
32 Jerome Gard (UL) *Corporate Venture Management in SMEs*
33 Frederik Schadd (UM) *Ontology Mapping with Auxiliary Resources*
34 Victor de Graaff (UT) *Geosocial Recommender Systems*
35 Junchao Xu (TUD) *Affective Body Language of Humanoid Robots: Perception and Effects in Human Robot Interaction*

2016

1 Syed Saiden Abbas (RUN) *Recognition of Shapes by Humans and Machines*
2 Michiel Christiaan Meulendijk (UU) *Optimizing medication reviews through decision support: prescribing a better pill to swallow*
3 Maya Sappelli (RUN) *Knowledge Work in Context: User Centered Knowledge Worker Support*
4 Laurens Rietveld (VUA) *Publishing and Consuming Linked Data*

5 Evgeny Sherkhonov (UvA) *Expanded Acyclic Queries: Containment and an Application in Explaining Missing Answers*
6 Michel Wilson (TUD) *Robust scheduling in an uncertain environment*
7 Jeroen de Man (VUA) *Measuring and modeling negative emotions for virtual training*
8 Matje van de Camp (TiU) *A Link to the Past: Constructing Historical Social Networks from Unstructured Data*
9 Archana Nottamkandath (VUA) *Trusting Crowdsourced Information on Cultural Artefacts*
10 George Karafotias (VUA) *Parameter Control for Evolutionary Algorithms*
11 Anne Schuth (UvA) *Search Engines that Learn from Their Users*
12 Max Knobbout (UU) *Logics for Modelling and Verifying Normative Multi-Agent Systems*
13 Nana Baah Gyan (VUA) *The Web, Speech Technologies and Rural Development in West Africa: An ICT4D Approach*
14 Ravi Khadka (UU) *Revisiting Legacy Software System Modernization*
15 Steffen Michels (RUN) *Hybrid Probabilistic Logics: Theoretical Aspects, Algorithms and Experiments*
16 Guangliang Li (UvA) *Socially Intelligent Autonomous Agents that Learn from Human Reward*
17 Berend Weel (VUA) *Towards Embodied Evolution of Robot Organisms*
18 Albert Meroño Peñuela (VUA) *Refining Statistical Data on the Web*
19 Julia Efremova (TUe) *Mining Social Structures from Genealogical Data*
20 Daan Odijk (UvA) *Context & Semantics in News & Web Search*
21 Alejandro Moreno Célleri (UT) *From Traditional to Interactive Playspaces: Automatic Analysis of Player Behavior in the Interactive Tag Playground*
22 Grace Lewis (VUA) *Software Architecture Strategies for Cyber-Foraging Systems*
23 Fei Cai (UvA) *Query Auto Completion in Information Retrieval*
24 Brend Wanders (UT) *Repurposing and Probabilistic Integration of Data; An Iterative and data model independent approach*
25 Julia Kiseleva (TUe) *Using Contextual Information to Understand Searching and Browsing Behavior*
26 Dilhan Thilakarathne (VUA) *In or Out of Control: Exploring Computational Models to Study the Role of Human Awareness and Control in Behavioural Choices, with Applications in Aviation and Energy Management Domains*
27 Wen Li (TUD) *Understanding Geo-spatial Information on Social Media*
28 Mingxin Zhang (TUD) *Large-scale Agent-based Social Simulation - A study on epidemic prediction and control*
29 Nicolas Höning (TUD) *Peak reduction in decentralised electricity systems -Markets and prices for flexible planning*
30 Ruud Mattheij (UvT) *The Eyes Have It*
31 Mohammad Khelghati (UT) *Deep web content monitoring*
32 Eelco Vriezekolk (UT) *Assessing Telecommunication Service Availability Risks for Crisis Organisations*
33 Peter Bloem (UvA) *Single Sample Statistics, exercises in learning from just one example*
34 Dennis Schunselaar (TUe) *Configurable Process Trees: Elicitation, Analysis, and Enactment*
35 Zhaochun Ren (UvA) *Monitoring Social Media: Summarization, Classification and Recommendation*
36 Daphne Karreman (UT) *Beyond R2D2: The design of nonverbal interaction behavior optimized for robot-specific morphologies*
37 Giovanni Sileno (UvA) *Aligning Law and Action - a conceptual and computational inquiry*
38 Andrea Minuto (UT) *MATERIALS THAT MATTER - Smart Materials meet Art & Interaction Design*
39 Merijn Bruijnes (UT) *Believable Suspect Agents; Response and Interpersonal Style Selection for an Artificial Suspect*
40 Christian Detweiler (TUD) *Accounting for Values in Design*
41 Thomas King (TUD) *Governing Governance: A Formal Framework for Analysing Institutional Design and Enactment Governance*
42 Spyros Martzoukos (UVA) *Combinatorial and Compositional Aspects of Bilingual Aligned Corpora*
43 Saskia Koldijk (RUN) *Context-Aware Support for Stress Self-Management: From Theory to Practice*
44 Thibault Sellam (UVA) *Automatic Assistants for Database Exploration*
45 Bram van de Laar (UT) *Experiencing Brain-Computer Interface Control*
46 Jorge Gallego Perez (UT) *Robots to Make you Happy*
47 Christina Weber (UL) *Real-time foresight - Preparedness for dynamic innovation networks*
48 Tanja Buttler (TUD) *Collecting Lessons Learned*
49 Gleb Polevoy (TUD) *Participation and Interaction in Projects. A Game-Theoretic Analysis*
50 Yan Wang (UVT) *The Bridge of Dreams: Towards a Method for Operational Performance Alignment in IT-enabled Service Supply Chains*

2017

1 Jan-Jaap Oerlemans (UL) *Investigating Cybercrime*
2 Sjoerd Timmer (UU) *Designing and Understanding Forensic Bayesian Networks using Argumentation*
3 Danil Harold Telgen (UU) *Grid Manufacturing; A Cyber-Physical Approach with Autonomous Products and Reconfigurable Manufacturing Machines*
4 Mrunal Gawade (CWI) *MULTI-CORE PARALLELISM IN A COLUMN-STORE*
5 Mahdieh Shadi (UVA) *Collaboration Behavior*
6 Damir Vandic (EUR) *Intelligent Information Systems for Web Product Search*
7 Roel Bertens (UU) *Insight in Information: from Abstract to Anomaly*
8 Rob Konijn (VU) *Detecting Interesting Differences:Data Mining in Health Insurance Data using Outlier Detection and Subgroup Discovery*
9 Dong Nguyen (UT) *Text as Social and Cultural Data: A Computational Perspective on Variation in Text*