Hearing touch in ball games

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MASTER'S THESIS

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Abstract

For children with blindness, ball games can be very challenging, as most ball games depend on quick perception of a multitude of things which are by people with good vision in general perceived through vision. The currently available aids for making ball games more accessible for people with blindness, most in the form of audible balls, leave room for improvement.

The central aim in this thesis is to develop and evaluate a concept for a digitally enhanced audible ball system that seeks to provide a better ball game experience for children with blindness. Employing a human-centered design approach, the developed concept is based on the needs and requirements that are identified through an initial user study, literature studies and through several prototyping and user testing iterations.

The final concept is based on providing electronic sound from the ball, as well as audible feedback about ball possession by means of a touch sensor system. For evaluation, a prototype implementing the concept is tested with users from the target user group. The concept is appreciated by the users and is concluded to indeed provide some means for achieving a better ball game experience for children with blindness.

Keywords: blindness, visual impairment, sports, ball games, interaction design, user experience design

Sammanfattning

För barn med blindhet kan bollspel vara väldigt utmanande, eftersom de flesta bollspel kräver att man snabbt uppfattar många olika företeelser — företeelser som av personer med god syn brukar uppfattas med hjälp av synen. De hjälpmedel som idag finns för att göra bollspel mer tillgängliga för personer med blindhet, framförallt i form av ljudbollar, lämnar utrymme för förbättring.

Det främsta syftet med detta examensarbete är att utveckla och utvärdera ett koncept för ett ljudbollssystem som med digital teknik förbättrar upplevelsen i bollspel för barn med blindhet. Med en människocentrerad designmetodik (human-centered design) utvecklas detta koncept utifrån de behov och krav som identifieras genom en inledande användarstudie, litteraturstudier och iterationer med prototyparbete och användartester.

Det slutliga konceptet bygger på att bollen utrustas med elektroniskt ljud och en beröringssensor som ger hörbar feedback på om någon håller i bollen eller inte. Konceptet utvärderas genom användartester av en prototyp, där användare från målgruppen är testdeltagare. Konceptet uppskattas av användarna, och slutsatsen dras att konceptet har potential att förbättra upplevelsen i bollspel för barn med blindhet.

Nyckelord: blindhet, synnedsättning, idrott, bollspel, interaktionsdesign, UX-design

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Contents

List of acronyms and abbreviations

HCD	human-centered design
ISO	International Organization for Standardization
SPSM	Specialpedagogiska skolmyndigheten [The National Agency for Special Needs Education and Schools, Sweden]
SVI/BL	severe visual impairment or blindness

1 Introduction

This chapter presents the background to the project, the project's aims and the structure of the report.

1.1 Background

Many common ball games, such as soccer, basketball and dodgeball, can be very challenging for children with blindness. The most obvious challenge is locating the ball. By using a beeper ball or bell ball, localization of the ball can be done by hearing. However, ball games in general depend on quick perception of a multitude of things beyond the ball's whereabouts — such as one's own location relative to the playfield, the other players' positions, and vocalized intentions and calls to action. With very limited or no vision, perceiving the required information accurately and quickly enough to perform a relevant action can be very hard.

Children with severe visual impairment or blindness (SVI/BL) report, regarding physical education in school, that their own participation feels pointless because the games are simply too fast and complex (Bredahl, 2013); that they feel uncomfortably disoriented during the games (Andersson, 2011; Lieberman, Lepore, Lepore-Stevens, & Ball, 2019); that the use of audible balls or modified rules make them feel bad because their sighted peers complain (Lindqvist & Gräslund, 2011); and that they are actually often excluded from ball games (Gräslund et al., 2018; Yessick & Haegele, 2019).

Ball games are nevertheless common activities in school. A recent inspection of the physical education in 7th to 9th grade classes in Sweden, conducted by Skolinspektionen [the Swedish Schools Inspectorate] (2018), showed that just under a third of all the total lesson time is spent on ball games. During recess, ball games also dominate as choice of activity (Haapala et al., 2014; Martínez-Andrés, Bartolomé-Gutiérrez, Rodríguez-Martín, Pardo-Guijarro, & Martínez-Vizcaíno, 2017).

Although often associated with tough challenges, many children with blindness enjoy ball games (Wallin, Ekstrand, & Nilsson, 2018). In a guide published by the Swedish Association of the Visually Impaired, exposing visually impaired children to ball activities is also encouraged, since balls for example tend to stimulate physical activity and social contact (Wallin et al., 2018).

While fully satisfied participation of children with blindness in all ball games may be an impossibility, there is room for improvement of the games played, the attitudes and the equipment. A few projects on improving the equipment have resulted in digitally enhanced audible balls. A prominent example is the I-Ball project, in which a ball has been equipped with a digital system that enables non-visual communication of the ball's velocity, and can thereby let children with blindness get more engaged in the game (Singh, Pounds, & Kurniawati, 2013).

Against this background, and based on a previous knowledge about the poor functioning of the audible balls that are currently available for children with blindness, it was decided to explore further possibilities of improving the ball game experience through digital enhancements of the ball.

1.2 Aims

The main aim of this project was

> **to develop and evaluate a concept for a novel digitally enhanced audible ball system for a better ball game experience for children with blindness.**

The definition of *ball game* was kept quite broad, including all play or sports activities that are focused around physical displacement of balls. What was considered a *better* ball game experience was investigated and determined through the literature studies, data gathering and testing. The use of the term *ball system* was chosen to articulate that the ball is the central and essential artifact in the interaction in the game, while additional artifacts aiding in this interaction are also conceivable as constituents of the emerging product. So the emerging product was called a system, as to not definitely delimit the problem and the conceivable product to "a ball". However, to already at this stage define the emerging product as a *physical artifact* was a way to delimit and define the design space — the emerging product could not be allowed to be solely a new *service* or *procedure*, which are other conceivable ways to improve the ball game experience. This delimitation had a quite personal reason: the author is doing their master's degree in mechanical engineering and technical design, and designing a physical artifact therefore allows for utilizing and demonstrating a fuller spectrum of the skills acquired in this programme.

Another important aim was

> **to contribute with new knowledge about ball game interaction for children with blindness.**

While this thesis is mainly a product design project, it also encompasses areas that are normally associated with the field of special education.

This interdisciplinarity was embraced — it was considered interesting and valuable to contribute to the special education field from a technical perspective, and vice versa. The findings in this thesis would hopefully be useful for future projects on ball game interaction for children with blindness in both of these fields.

Regarding the term *children with blindness*; although people with blindness often have some measure of vision (see section 2.4.5), it is their *lack of vision* that justifies the validity of this thesis. Thus, while visual interaction was also somewhat considered, the focus was set on the *non-visual interaction* in ball games.

1.3 Design process and structure of the report

While the activities described in this report may seem sequential as in the order presented, they are in reality chronologically intertwined. Design processes, especially processes like this one which have a pronounced intention to be iterative (see section 2.1.1), are non-linear, intertwined and repetitive by nature, as indicated by Sharp, Preece, and Rogers (2015). Requirement specification is for instance not one isolated activity that is carried out only prior to development activities, but happens *in* the development activities as well (Sharp et al., 2015). An overview of the design process in this project is presented in Figure 1.1. This overview is very simplified, but shows the general flow in between activities, and the most prominent iterative patterns in the process.

For the sake of good disposition, the activities in this project are described in an order that fits common standards for academic writing in general. While this order does not correspond with the *actual* order in the process, it provides good readability.

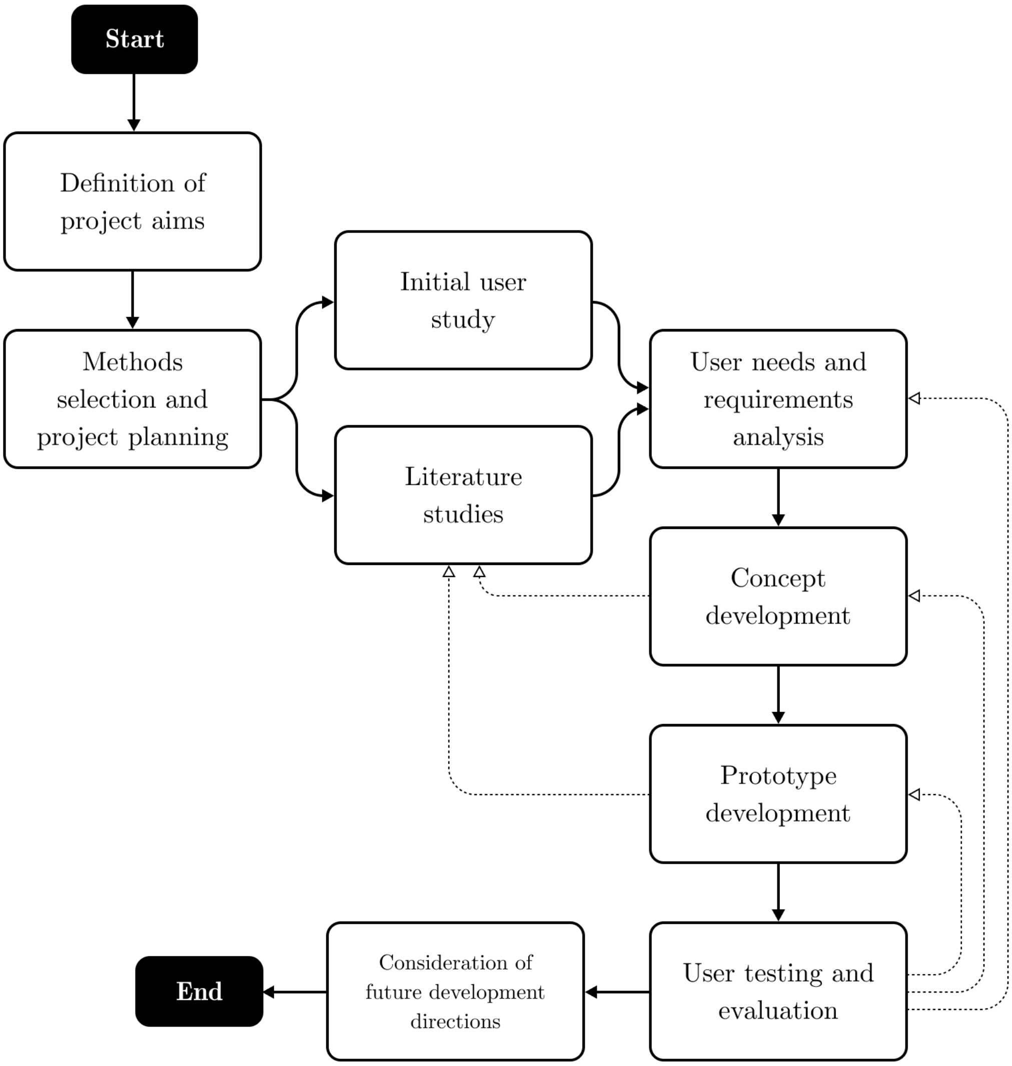

Figure 1.1: Overview of the design process

2 Methodology

This chapter treats the methodology applied in the project. Beginning with a description of the design methodology guiding the process as a whole, the chapter then presents the methods used for literature and user studies, requirement specification, concept development, prototyping and user tests.

2.1 Design methodology

2.1.1 Human-centered design

The core approach for the project is human-centered design (HCD). The International Organization for Standardization (ISO) standard 9241-210:2010(E) describes that HCD focuses on users, their needs and requirements (International Organization for Standardization [ISO], 2010). The approach is effective for development towards human well-being, accessibility and sustainability (ISO, 2010), and thus fits well with the aims of this study.

The term *user-centered design* is often used as a synonym to human-centered design. As exemplified in the ISO standard, the two different terms can be used to emphasize a stricter user perspective or a perspective that acknowledges a wider range of human stakeholders (ISO, 2010). That is the way the two terms are used in this thesis.

Based on the recommendations given in ISO 9241-210:2010(E), the intention was to iteratively work with

- understanding users, use and context,

- requirement specification,
- concept and prototype development, and
- evaluation of concepts and prototypes based on user tests,

roughly according to Figure 2.1 (ISO, 2010).

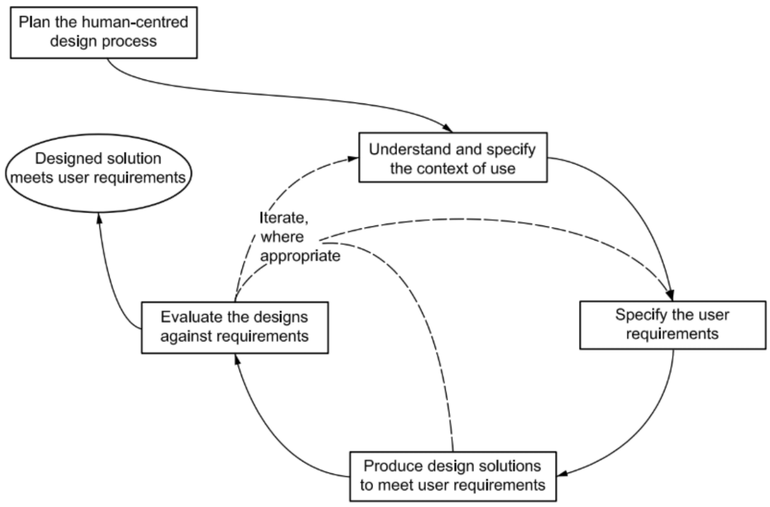

Figure 2.1: Human-centered design process according to ISO 9241-210:2010(E) (ISO, 2010).

As stated in ISO 9241-210:2010(E), HCD should address the *whole* user experience, and include a multi-disciplinary design team (ISO, 2010). These two principles of HCD are not implemented in this design process. The reasons for this are quite pragmatic. Some aspects of the user experience deal with things such as product support, maintenance, financial cost and branding, which lie beyond the scope of this thesis — there is just not enough time to consider all these aspects. Regarding the multi-disciplinary design team, it is quite self evident that one person cannot make a team. The process is still very multi-disciplinary, which is challenging, but also quite suited to the author's multi-disciplinary education in mechanical engineering with industrial design.

Table 2.1: Interpretation of elements of the human-centered design process

Element of HCD	Interpretation in this project
Understanding the users	Understanding what children with blindness think about ball games
	Understanding the possibilities and challenges for children with blindness in ball games
Understanding the use	Understanding what characterizes a good ball game experience for children with blindness
	Understanding the equipment used in ball games today when children with blindness are participating, its possibilities and limitations
	Understanding how children with blindness interact in ball games today, how they would like to interact, and which interaction they would benefit from
Understanding the context	Understanding the social and educational aspects of the situations in which children with blindness engage in ball games
	Understanding the needs of sighted children in a ball game together with a peer with blindness
	Understanding the physical environments in which children with blindness engage in ball games

2.1.2 Implementation of human-centered design

To specify what *understanding users, use and context* meant in the implementation of HCD in this project, these elements of the HCD process were interpreted with regard to the project aims, according to Table 2.1. The meaning of the other elements of the HCD process; requirement specification, concept and prototype development, and evaluation, are more straight-forward and considered to not require such a specification — their implementations are addressed later. The interpretations in Table 2.1 have served as general research questions, directing the focus of the literature studies, user study and data analysis.

2.2 Literature studies

2.2.1 Aims

One aim of the literature studies was

> **to review the previous work that has been done on development of ball systems intended to aid people with blindness in ball games.**

The purpose of this was to establish an understanding of the current state of this particular research field, to acquire insights from others who have studied the same things, and make sure to continue the line of research only in unexplored directions.

Another aim was

> **to look into the special education literature relating to this project.**

This was intended to provide secondary data and insights about the users, use and context — thus adding to the insights from the data gathering — as this literature contains a lot of relevant observations, experiences and knowledge on the subject. In addition to the user needs that could be identified from the data gathering sessions of this project, there are more general special needs of children with blindness which are relevant and treated thoroughly in this literature. The special education literature is the prime source for guidelines on approaching the special needs of children with blindness, so consulting it was essential as to direct the development with regard to already established knowledge.

2.3 Expert consultation

2.3.1 Aims

Expert consultation was carried out with the aim

> **to get professional, personal accounts of the situation for children with blindness in ball games.**

Whereas the literature studies provides a vast base of knowledge about the studied subject, an expert could assumingly give more of a pinpoint account with regard to the specific interests of the researcher.

Consulting experts was also considered a way

> **to brainstorm on ideas with experienced and knowledgeable people.**

2.3.2 Methods

Two telephone interviews were conducted with experts on physical education for children with blindness. One of the experts was currently employed at SPSM (The National Agency for Special Needs Education and Schools, Sweden) as a specialist in physical education for children with visual impairment. The other expert was formerly employed in the same role, at the same national agency, but was now retired.

2.4 Initial user study

2.4.1 User study overview

To understand users, usage and context, the HCD process advocates collecting data *directly from the users* (Jönsson, 2005).

In the initial user study, the following were conducted:

- Five in-school observation and interview sessions with children with blindness
- One observation of a goalball practice
- One telephone interview with a young adult with blindness

2.4.2 General considerations

Ethnographic methods

A lot of the data collection methodology commonly used in field studies in ethnography is encouraged and rewarding for use in HCD (Ji-Ye, Vredenburg, Smith, & Carey, 2005; Sharp et al., 2015), and was applied to a great extent in this project. According to Sands (2011), the ethnographic methodology is critical in sports equipment design, for understanding the user in terms of behaviour, needs and expectations. Getting this kind of understanding aids the designer in defining more accurate requirements, and increases the possibility of improving the user experience in sports (Sands, 2011).

Focus on actions

Questionnaires and interviews are often not sufficient for satisfying data collection in human-centered design projects, and some things cannot even be expressed in words, but only in actions (Jönsson, 2005). Requirement specifications are often more properly compiled if they are based on people's actions, rather than just their thoughts (Jönsson, 2005). Therefore, emphasis was put on using observations and user tests for data collection. As a supplement to this, interviews were conducted in conjunction with the observation sessions.

Bias

An intention in the data collection was to try not to contaminate the collected data with own expectations about what may be present in the observed situations. The use of written observation and interview guides is likely to have introduced additional bias to the collected data, which could have undermined its quality. At the same time, the guides should be based on the aims of the user study — which are formulated according to an expectation of some challenges, related to the participants' blindness, to be found in the studied situations. Fetterman (2009) comments this concern in ethnographic field studies as follows:

> "The ethnographer enters the field with an open mind, not an empty head. [...] The ethnographer [also] begins with biases and preconceived notions about how people behave and what they think—as do researchers in every field. Indeed, the choice of what problem, geographic area, or people to study is in itself biased." (p. 1).

Fetterman concludes that while uncontrolled bias can compromise the quality of the research, a *controlled* bias can focus and delimit the research effort. Keeping this in mind, bias was sought to be controlled at all times; when formulating the observation and interview guides, during the data collection sessions, and in the processing and analysis of the data.

2.4.3 Observation

Observations were conducted of various ball games in which people with blindness participated. Five observation sessions were conducted at physical education lessons at schools, where baseball, handball, basketball and a couple of other ball games were played. One observation session was conducted at a goalball practice. All observations were based on the same methodology.

Fly-on-the-wall observation

The observations were conducted using a *fly-on-the-wall* method. This observation method aims to reduce bias and influence which may result from the observers' involvement in the observed situation (Martin & Hanington, 2012). In this project this method was implemented as follows: the observer sitting quietly on the side of the court, observing and taking notes of the ball game being played on the court.

Hawthorne effect

There is a risk that people will change their behavior slightly if they are aware that they are being observed — the so-called Hawthorne effect (Martin & Hanington, 2012). Given this, it was considered preferable to limit the observer's personal intrusion into the situation being observed. But since observations had to be planned and allowed in consultation with the young people, parents and schools, keeping the participants unaware of being observed was impossible.

Observation guide

A guide for the observations, presented in Appendix A, was worked out. The *AEIOU* framework was kept in mind for the content of the guide. AEIOU is a mnemonic to remind an observer to note features of *Activities, Environments, Interaction, Objects* and *Users* during an observation (Martin & Hanington, 2012). The developed guiding questions, it can be claimed, each embrace multiple elements of the AEIOU framework.

2.4.4 Interviews

Interviews were conducted on the occasions of the observation sessions. In addition, a telephone interview was conducted with a young adult with blindness.

Unstructured interviews

The interviews were planned to be *unstructured*. As Sharp et al. (2015) describe, open interviews often have an exploratory character, and can often reach deep and unexpected insights. This was exactly what was sought after in the beginning of the process — without much prior knowledge about the situation under investigation, *exploring* it was the reasonable way to start. Above all, the participant's *subjective* experiences were of interest, and with the unstructured interview method allowing the participant to themselves *define the phenomena* concerning ball games in their lives, the participant's subjective view of the *importance* of these phenomena could be captured, as proposed by Lantz (2013). The unstructured interview is about listening, empathic engagement in what the participant says, and digging deeper into the mind of the participant through well suited follow-up questions (Lantz, 2013).

Interview guide

Even though the participant is given a great influence over the content of an unstructured interview, and the follow-up questions are impossible to specify beforehand, the interview should have a plan to ensure that all desired areas are covered, as Lantz (2013) underlines. A guide (see

Appendix B) was developed for the interviews in this project, which consisted of a definition of areas to cover and a corresponding set of example questions, which were supposed to lead the interview into those desired areas. To fully utilize the possibilities of the unstructured interview method, questions should be formulated in line with *"What do ball games mean to you?"* or *"Tell me about ball games in your life!"*, to really get the participant to themselves define the involved phenomena, implementing Lantz' (2013) suggestions. However, considering that some of the participants were around 10 years old, such broad or profound questions can be difficult to at that age answer in a meaningful way. The questions were hence adapted to every participant, although the desired areas were always covered. When a broad question was not satisfyingly answered, questions more narrowed towards the area of interest were asked subsequently, a strategy for interviewing children recommended by Doverborg and Pramling Samuelsson (2000).

Some example questions also in reality provoke answers that cover more than one of the areas in the interview guide. Many times, after asking one of the planned example questions, other questions were answered at the same time.

2.4.5 Population sampling

This section focuses on the population sampling for the primary data collection in the *in-school studies*. The sample, which consists of five children with SVI/BL, corresponds to the actual target population of *children with blindness*. For the goalball observation and the interview with the young adult with blindness, no particular sampling method was applied.

Convenience sampling

The target population was sampled using a convenience sampling method. In convenience sampling, the participants are not chosen strategically to be statistically representative of the whole target population (Sharp et al., 2015). Rather, the participants who are willing and available at the time of the study, are chosen (Sharp et al., 2015). The slightly intrusive character of the in-school studies made participant consent essential, complying with the Swedish Research Council's ethical guidelines (Vetenskapsrådet [Swedish Research Council], 2017).

Location limitation

For practical and economical reasons, only participants in a delimited geographical area of Sweden were considered.

Age limitation

As the main interest in this project lies in improving children's and young people's experiences in play and physical activity, primarily children and young people were wanted as participants. The participants with SVI/BL in the in-school studies were exclusively school-age children.

Visual impairment limitation

Blindness is a condition which is often perceived by the public as *not being able to see anything*. In medical terms, however, blindness encompasses a spectrum of severe visual impairments. People with blindness often have some measure of vision. The degree of visual impairment varies between different people with blindness and also takes different forms.

The key subject of interest in this project was the non-visual interaction in ball games. In order to access the specific needs that exist in this area, it would possibly have been beneficial to define the visual impairment limitation of the people chosen for the sample as something in line with *people who cannot identify a red ball, of diameter 30 cm, located 1 m away from the feet, on a green ground surface, in daylight, with the help* *of sight.* Judging a person's ability in this way is hard, not within the scope of this project, and possibly offensive towards the person with visual impairment. Also, due to the fact that contact with the population had to go through the gatekeeper (see the next section), it became too complicated to make a specific requirement of this kind. Therefore, the participants were instead sampled from the group of *underage pupils in the certain delimited geographical area of Sweden who have such severe visual impairment that they are recommended to read braille.* According to the gatekeeper, people who are recommended to read braille in general have a visual impairment that ranges between *Category 3: Blindness* and *Category 5: Blindness* according to the WHO classification of severity of visual impairment (see Appendix C). Thus, the sample should correspond quite well with the target population of *children with blindness.* The actual diagnoses of the participants have not been known to the researcher, to protect the integrity of the participants. Whether any participant's visual impairment is diagnosed as something other than *blindness* was considered irrelevant for the validity of this study. Furthermore, the fact that all participants are recommended to read braille is a sign that they have such severe visual impairment that the difference from blindness is not easily distinguishable, according to the gatekeeper.

2.4.6 Access to the field

Access to the field means access to research participants and other necessary people, places and events — requisites for conducting the research (Ahrne & Svensson, 2011; Denscombe, 2014). Beyond physical access to these assets, access to the field means enjoying sufficient social acceptance to conduct the study (Ahrne & Svensson, 2011; Denscombe, 2014). The in-school studies of children with blindness required particular deliberation of the access to the field, because the participants' minority and conditions make them especially vulnerable.

Contact with the young adult participant with blindness for the telephone interview was established through the gatekeeper. For the goalball practice observation, the Association of Sports for the Disabled, FIFH, in Malmö, was contacted. The rest of this section deals with the in-school studies.

Gatekeeper

To get in contact with participants for the in-school studies, assistance was provided by a contact person at Resurscenter Syn [Resource Center Vision], SPSM. This person acted as what is in ethnography called a *gatekeeper* — a person who has the relevant authority and network to grant access to the field (Ahrne & Svensson, 2011; Denscombe, 2014). Denscombe (2014) underlines that in as well as granting physical access, the authoritative gatekeeper can become a kind of ”guarantor for the *bona fide* status of the researcher” (p. 86), which is important to actually be trusted and respected in one's role as a researcher. Ahrne and Svensson (2011) argue that a good gatekeeper is interested in understanding what the researcher wants to understand, and is sufficiently engaged as to ”sell the idea” of the study to the necessary people. That can certainly be said about the gatekeeper at SPSM.

Participants' perception of the researcher

Like Denscombe (2014), Ahrne and Svensson (2011) claim that an important aspect of getting access to the field is how the participants perceive the presence of the researcher. If the researcher is seen in a bad light by the participants, the participant may provide less valuable information or even reject further participation (Ahrne & Svensson, 2011). A child with blindness in a group of sighted peers is already exposed as unique in the group, and is thus vulnerable when a researcher comes to the physical education to observe the child because of their visual impairment. While this issue couldn't be overcome completely, it was sought to be coped with in the best way possible. The gatekeeper guaranteeing the status of the researcher was one part in this. The emphasis on confidentiality in the contact with the participants, and the ambition to keep the observations and interviews low-profile, hopefully also made the participants feel less negatively exposed.

Informed consent

As mentioned earlier, due to the slightly intrusive and exposing character of the in-school studies, obtaining informed participant consent was considered essential, complying with the Swedish Research Council's ethical guidelines (Vetenskapsrådet [Swedish Research Council], 2017). This was accomplished through providing a written informed consent form to the children and their parents or legal guardians. The correspondence was managed by the gatekeeper at SPSM, to keep the personal data of the prospective participants undisclosed until consent was given.

2.5 User needs analysis and requirements specification

2.5.1 Analysis overview

The user needs situation was analyzed based on the insights from the literature studies and the data from the initial user study. From the identified needs, requirements were specified. As new insights and ideas were gained along the way, the needs analysis and requirements specification were continually revised.

2.5.2 Merging insights

Key insights and secondary data from the literature studies were merged with the insights from the data. The purpose of this was to form a coherent description of the knowledge about the users, use and context, based on all foregoing research in this project. From this merged set of insights, user needs and requirements were identified and specified.

2.5.3 Affinity diagramming

To systematically process and analyze the primary data and insights, affinity diagramming was employed as method. Affinity diagramming, as described by Martin and Hanington (2012), works by clustering details of different parts of the data together, to form themes and patterns. From these themes and patterns, "a story emerges about people, their tasks, and the nature of their problems" (Martin & Hanington, 2012, p. 12). In practice, the affinity diagramming was done by writing insights, observations and concerns on digital sticky notes, which were then organized in the aforementioned clusters on a digital whiteboard.

2.5.4 User needs structure

The user needs were structured into four different areas: Perception, Ball handling, Game design and Other. The reason for using these areas was mostly a matter of achieving clarity and readability, and of pointing out the main themes in the identified needs.

2.5.5 Requirements structure

Requirements were specified in a functional and a non-functional part, a useful partitioning in interaction design (Sharp et al., 2015). While the functional requirements related directly to the functioning of the emerging design, the non-functional requirements sought to address matters such as the look and feel, and usability requirements that don't fit as functional requirements (Sharp et al., 2015). The distinction between functional and non-functional is not always clear. Some requirements can reasonably fit under either of the categories, but it was regarded as a beneficial partitioning, especially because it allowed the ideation activities to have an initial focus on the *functional* part.

Each requirement was assigned a requirement class — "desirable", "necessary" or "main function" — as suggested by for example Löwgren and Stolterman (2004) and Eckhardt (2012). This requirement classification meant that although they were all called *requirements*, not every one of the stated requirements was considered an absolute *necessity* — the requirement classification used also allowed for *desirable* features.

The functional requirements were derived from the identified needs, formulated in a *Verb — Noun phrase* format, assigned a requirement class, and presented in a table, as suggested by for example Löwgren and Stolterman (2004) and Eckhardt (2012).

The non-functional requirements were partially derived from the identified needs, but also from insights from the literature studies. The headlines in the table of non-functional requirements (Table 5.3) were extracted from the *Volere Requirements Specification Template*, presented by Sharp et al. (2015).

2.6 Concept development

2.6.1 Personas

To serve as an aid in the concept development, two personas were developed (presented in Appendix D). Personas are detailed descriptions of fictional, but realistic, potential users. The description often includes how they are as persons, what their goals are, a picture and a full name. Throughout the development, the persona can be referred to as the user of the emerging product. When making design decisions, or testing ideas, one can ask for example "Would this work for our persona X? Would they like this solution? Why? Would they benefit from this solution? How?". The use of personas is a well-proven tool among interaction designers (Sharp et al., 2015). Martin and Hanington (2012) suggest that personas *humanize design focus* — as Sharp et al. (2015) imply, imagining a realistic potential user allows for the designer to *empathize* with the user and understand their needs in a personal way, and this facilitates imagining how certain solutions would work for that very person.

The personas that were developed for this thesis were not given any explicit gender. This was done on purpose, to not be influenced by unnecessary bias about stereotypical personalities of a specific gender. The personas were not given a photo, but instead an androgynous illustration, to humanize them while avoiding to genderize them. Using pictures of children can also be sensitive, and this issue was avoided by using illustrations.

2.6.2 Ideation

Having defined the requirements of the emerging product, the next step was to identify possible means to satisfy these requirements. The requirements were considered one by one as well as in smaller groups of requirements. For although the necessary (N) requirements must be satisfied, and as many of the desirable (D) requirements as possible are sought to be satisfied, looking at all requirements at once was not perceived to effectively create a free space for exploring options.

Pen and paper were used as tools for sketching, mind-mapping and storyboarding. Getting the ideas on paper is essential in design work — for communicating with oneself and others and for realizing the contents and implications of an idea (Buxton, 2007). The ideas were matured and developed by researching online, contemplation and further sketching. New ideas sprung from previous ones in an iterative process.

2.7 Prototyping

Prototypes, also at an early stage, play an important role in a human-centered design process (Jönsson, 2005). Jönsson (2005) reckons that only when a *physical representation* of a concept is available to a user, can they actually make clear what they think and want. Therefore, a prototype was iteratively developed and tested throughout the process. The prototype was developed according to the user needs and requirements that had been identified in the literature and user studies, and then further developed according to new insights that were gained in each user test.

2.8 User tests

2.8.1 Aims

The main aim of the user tests was

> **to gather relevant test data for evaluation of the impact of the proposed concept on the ball game experience for children with blindness.**

The hypothesis that was sought to be tested in the user tests was that the prototype met at least some of the requirements defined in the analysis section, and thereby improved the interaction and the test participant's experience of the studied situation.

The testing was also aimed to be a way

> **to get new ideas and insights.**

Handing a prototype to a user can reveal unthought-of possibilities and problems. As Jönsson (2005) implies, prototypes can function as a language between designer and user. Jönsson exemplifies how a technical artifact can be a way of asking "Is this what you want to do? In this way?". The testing session is a great opportunity to come up with new ideas, brainstorm and gather ideas from the test participants.

Another aim was

> **to test the technical functionality of the prototype.**

Apart from the interaction aspects of the prototype, it was also of interest to evaluate how the sensors, battery, physical durability and other technical functions seemed to perform in a realistic setting.

2.8.2 Test participants

The test participants were the same five children with SVI/BL who had already participated in the in-school observations. The first tests were individual, while the later tests were conducted in groups. In the group tests, sighted children also participated, as well as teachers or parents of the children with SVI/BL.

2.8.3 Test design

The tests were designed to in the most clear and simple way possible enable evaluation of the developed concept's impact on the interaction. Since the emerging product was to be used in play and games, the tests were conducted in a playful, informal manner, consisting of various passing games. In fact, there was an aspiration to have the test sessions turn into spontaneous play, to facilitate discovery of possible games and ways to use the product.

To let the test participants familiarize themselves with the prototype, they were first handed the prototype to touch and try at their own pace. When they seemed to feel comfortable and familiar with the prototype, they were invited to play different passing games. The actual games of the testing sessions differed a bit from one test to another. In the end of every testing session, interviews were conducted with the group of participants in the group tests and individually with the user with SVI/BL.

The testing is presented in more detail in Chapter 8.

2.8.4 Documentation

The test sessions were filmed for later review, except for a few cases where consent for this could not be obtained. By filming the sessions, the researcher could engage in the situation — without being distracted by taking notes. The video material was, and will be, accessible for the researcher only.

2.8.5 Scope

The test sessions were sought to be short. Keeping the sessions short was to not take too much of each test participants' time, and in that way hopefully keeping them engaged in the test, and interested in participating in the next round of tests. Conducting tests with many different test participants was a way to get a decent amount of test data, and to get an as wide as possible spectrum of data.

While the sessions were kept short, they had to be long enough to be meaningful — both for the researcher and for the test participants. A suitable test duration was determined to be 10 minutes for the individual tests and 20 minutes for the group tests.

3 Related work

This chapter briefly introduces the most relevant knowledge and ideas from the related work that has been encountered in the literature studies of this project. The first section presents literature from the engineering field about development of ball systems for people with blindness. The second section encompasses the concept of inclusion *from the special education literature, which has implications for this project.*

3.1 Projects on development of ball systems for people with blindness

3.1.1 I-Ball

A key related work for this thesis is the research and development of the *I-Ball* project at the University of Queensland (UQ) in Brisbane, Queensland, Australia (Singh, Kurniawati, et al., 2014; Singh et al., 2013; Singh, Wilson, & Malicka, 2014). The I-Ball – short for *interactive ball* – is a foam soccer ball equipped with a programmable insert (see Figure 3.1). The I-ball can output tones and sounds that vary according to measurements from an inertial sensor (Singh et al., 2013). Varying tones according to sensor output is a novel and interesting way of communicating real-time information about a sporting ball. Unlike the standard rattle balls, bell balls, or beeper balls, which are commonly used by people with visual impairment, the I-Ball is able to more distinctly communicate adaptive feedback about the ball's acceleration and velocity (Singh, Kurniawati, et al., 2014).

Evaluation of one of the earlier prototypes shows that the I-Ball can be engaging and fun for people with SVI/BL as well as people with full vision (Singh et al., 2013). Both sighted test participants and test participants with SVI/BL state that after getting familiar with the I-Ball, it feels less distracting than a standard beeper ball (Singh, Wilson, & Malicka, 2014).

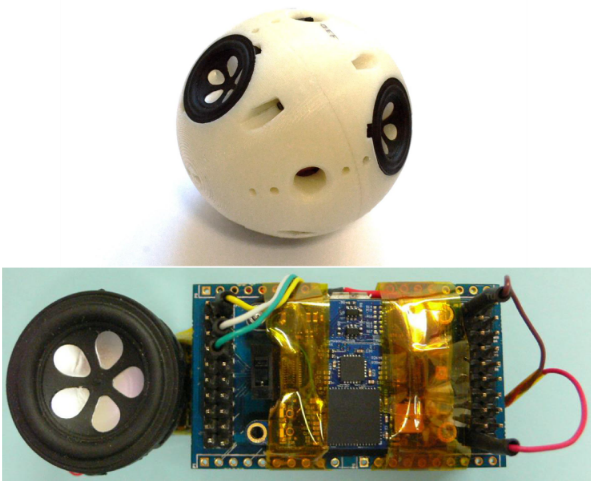

Figure 3.1: The I-Ball insert, and its inner electronics. From Singh, Wilson, and Malicka (2014).

3.1.2 The KTH ball

The bachelor thesis *Konceptutveckling av ljudkällor för blindfotboll* [Development of concepts for audible sources for a blind soccer ball] by KTH students Musleh and Karakoc (2016), presents several problems with the rattle-based ball currently used in blind soccer. The main problem identified with the rattle-based ball is that the ball stops sounding when it is stationary or when it spins very fast (Musleh & Karakoc, 2016). This is an issue with rattle- or bell-based balls in general, and is relevant also for other ball games than soccer. The KTH students arrive at a concept which utilizes a tiny Bluetooth-enabled audible device called

TrackR StickR (see Figure 3.2) (Musleh & Karakoc, 2016). The TrackR StickR is mainly intended for localizing belongings attached to the device, by activating a beeping sound when the user requests so from the interlinked smart-phone app. In the KTH students' concept, the TrackR StickR is placed in a protective housing on the inside of one of the leather pentagons of a soccer ball. Although the intended functions of the concept are actually not described in detail in the thesis, it is apparent that a device such as the TrackR StickR could (be modified to) produce a constant beeping for in-game use, as well as be activated temporarily and wirelessly to help locate a lost ball.

Figure 3.2: Apple Iphone and TrackR StickR.

3.2 Special education literature

3.2.1 Introduction

Within the field of special education, a quite substantial amount of work has been done on physical activity among children with blindness. Ball games are such common activities in physical education, and often present such tough challenges for children with blindness, that it is not surprising that ball games are frequently dealt with in these works. These works have provided valuable insights on how to approach inclusion of children with blindness in physical activities and especially ball games, from a special education perspective.

3.2.2 Inclusion

People with disabilities have a right to access to inclusive education, as is stated in the United Nations' Convention on the Rights of Persons with Disabilities (2007). The inclusion concept in the educational context is, according to Nilholm (2006), about providing a school that is designed to cater to the needs of every pupil and have every pupil participating in the common environments and activities. It is an especially common concept in the field of special education, and has evolved as a part of a vision of "a school for everyone" (Nilholm, 2006). Nilholm (2006) argues that the concept should be seen in the light of the segregating means by which children with special needs have been managed by the school systems historically; put in special classes, special courses and special schools. As this project is aimed at people with special needs in a social and often educational context, it is essential to consider the values and implications of the inclusion concept. More concretely, considerations regarding inclusion affect the direction and focus of the design process: *Should the aim be inclusion of the user in a common ball game such as soccer? Is the user maybe better off in ball games with a smaller group, segregated from the bigger group? Can a segregated ball game setting be inclusive?*

3.2.3 Is inclusion good or bad?

Nilholm (2006) describes that studies on "whether pupils with special needs benefit from inclusive environments" are often said to not provide basis for any general conclusion. As a response to this, Nilholm (2006) suggests the argument that when it "does not work well", it is not because the *idea* of inclusion is wrong, but rather the actual *implementations* of it. Irrespective of the science on "whether inclusion is beneficial", inclusion is a human right — declared in the United Nations' Convention on the Rights of Persons with Disabilities (2007) — for we must all get to be equal participants in the social part of human life.

3.2.4 Implementing inclusion in physical activities

Inclusion in physical activity is not about always having everyone do the same thing, according to Fröjd, Nygren, and Wedman (2003). Instead, Fröjd et al. (2003) suggest that what is central to inclusion is rather to take every participant's abilities into account and make sure everyone gets a good value out of their activity. In competitive physical activities, such as most team-based ball games, the differences between the abilities of the person with visual impairment and the peers can simply be too big. As a response to this, Nygren and Isaksson (1995) recommends physical education teachers to at times for example let the pupil with visual impairment participate in the technique practices, and during the actual match time engage in something else with a separate group. Letting a physical activity have a competitive character might not be appropriate for inclusion — the Swedish Schools Inspectorate discourages competitive settings in physical education since it often results in exclusion of "the inferior" (Skolinspektionen [the Swedish Schools Inspectorate], 2018).

Two common obstacles to inclusion in physical activities are large numbers of participants and the practice of letting the activities take place across large areas. In his 1996 study on the schoolyard interplay between pupils with visual impairment and their sighted peers, Janson found that the pupils with visual impairment often have difficulties with perceiving sequences of events that take place across large areas and involve many participants, for example in many ball games. According to Janson (1996), the participation of the person with visual impairment is often *tolerated* rather than *integrated* in these ball games. In contrast, small-scale activities which have fewer participants and afford a greater level of control for people with visual impairment, consistently demonstrate a more integrated participation (Janson, 1996). Pupils with SVI/BL and their teachers frequently mention ball games as an example where tuition in a small group can be beneficial for the pupil with SVI/BL (Gräslund et al., 2018).

4 Data from initial user study

This chapter presents the data from the initial user study — data from the user observations and user interviews.

4.1 Introduction

The relevant data from the user interviews and goal ball observation added a few new insights to what was already apparent in the observation data. But primarily this additional data was seen as means to strengthen the importance of certain pieces of the observation data. Therefore the data sets from all interviews and observations are collated and summarized together. The data is presented below in three categories: Catching, Throwing and Interplay/game. For each of the categories, the apparent *emotions, actions, experience* and *user needs* as perceived by the researcher are presented separately. While the user needs were identified more thoroughly in the analysis part of the project, it was considered valuable to during the data gathering take notes of some needs that seemed apparent, and therefore they are presented here as data.

4.2 Data

Catching

Emotions

- Frustrated by failing many catching attempts

- The risk of getting the ball in the face is scary
- Gratifying to catch the ball (Handball)

Actions

- Awaits the incoming ball with stretched arms, embraces it mechanically (Handball)
- Incorrect expectations of the incoming ball's height
- Late reactions, surprised when hearing the ball behind them

Experience

- The sound of the bounce is helpful
- Much easier, and more fun, to catch bouncing passes
- Nearly impossible to return a badminton serve
- Virtually impossible to catch a baseball

User needs

- Protection from getting the ball in the face
- Localization of the ball
- Distinct sound when the ball bounces
- Information on the teammate's whereabouts
- Suitable level of challenge

Throwing

Emotions

- Happy about dribbling (Handball)

Actions

- The direction of the throw is rather arbitrary (Dodgeball-like game)
- Asks about whether the ball went into the basket or not (Practicing basketball shots)
- Throws the ball too hard when passing
- The ball is not correctly placed in the palm while dribbling (Basketball)

Experience

- The sound of the bounce helps guiding
- The bell ball is skewed, doesn't bounce correctly. prefers the normal foam ball (Handball)
- The rattle and bell balls are not durable, they break and stop working after a while
- Underhand serves work great sometimes (Badminton)
- Virtually impossible to hit the ball with the bat (Baseball)

User needs

- A ball that bounces well
- Information about the direction and distance to teammates and the goal
- Time to practice throws

Interplay/game

Emotions

- Co-player gets tired of the ball being used (an oversized badminton ball)
- The peers get a little annoyed that it takes so long to do the exercises
- Co-player gets tired of the pupil with visual impairment missing too many serves, starts fooling around (Badminton)
- The pupil with visual impairment seems to feel like an annoyance
- Scared about the many balls flying around (Basketball warm-up)

Actions

- Uses the sound of the group to locate the ball
- Moves towards the shouts of other players, because the ball is probably there
- "Distinguishes a movement rather than a ball" — minimal visual perception can sometimes be enough
- Perception of the position of fellow players is delayed (needs them close range and straight ahead)
- Asks where the goal is (Basketball)
- Circulates around one specific person in the class to take shelter (Dodgeball-like game)
- Wanders around or stands still by themselves in the chaos of basketballs and shouts
- Invents a new game when the first one does not work well because of the visual impairment (Badminton)
- Does not want to let go of the ball (Handball)

- Uses the ball as support when standing up (Handball)
- More engaged and active in small-group games than in large-group games

Experience

- The game is too fast (Dodgeball-like game)
- Does not get enough information about the game (from co-players)
- Not sure in which direction teammate/the goal is (Handball)
- Passing game in group of two or three presents a much better level of challenge (Basketball)

User needs

- A slower and less perceptually complex game
- Smaller group
- Distinguish the sound of the ball from the sounds of the co-players
- Clear calls for action
- To play on equal terms
- Equipment and games that also work great for sighted peers
- Durability of the ball and its function
- Confidence in the ball's whereabouts

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5 User needs and requirements

This chapter presents the user needs and requirements that were identified in the analysis of the data from the initial user study.

5.1 User needs

The identified user needs are presented in their respective areas in Table 5.1.

5.2 Requirements

5.2.1 Functional requirements

The identified functional requirements are presented in Table 5.2 along with their respective requirement class.

5.2.2 Non-functional requirements

The identified non-functional requirements are presented along with their respective requirement class in Table 5.3 .

Table 5.1: Identified user needs

Area	**Needs**
Perception	Perception of co-players' positions
	Perception of the ball's spatial location and velocity
	Perception of how the game proceeds
	Perception of the location of the goal(s)
	Perception of when the ball bounces
	Perception of when the ball stops
Ball handling	Better catching technique
	Better throwing technique
	That the ball bounces well
	Large ball
Game design	Slow game
	Not perceptually complex game
	Suitable level of challenge
	Play on equal terms with the sighted peers
Other	Protection from painful impacts from the ball

Table 5.2: Functional requirements of the system to be developed

Function		Class
Afford	ball playability	MF
Communicate	spatial location of the ball (even when the ball is still)	MF
Engage	fun play on essentially equal terms	N
Present	a suitable level of challenge	N
Present	a suitable level of perceptual complexity	N
Afford	ball bounciness	D
Prevent	ball from hurting (the face)	D
Communicate	the occurrence of key events in the proceeding of the game	D
Communicate	location of co-player(s)	D
Communicate	location of any goals or other features integral to the game	D
Communicate	the event and location of a ball bounce	D
Communicate	whether the ball is still	D
Help improve	ball play skills	D

MF = main function; N = necessary; D = desirable

Table 5.3: Non-functional requirements of the system to be developed

Requirement	Class
Look and feel	
Bright, easily distinguishable color	N
Soft ball with soft texture	N
Ball large enough to be easily caught and grasped with the arms	N
Usability and humanity	
Interface discoverable and usable for a child with blindness	N
Interface adapted to children's cognitive capabilities	N
Sighted co-players need no blindfold	D
Performance	
Bounciness comparable to common skin-coated foam play ball (see Figure 5.1)	D
Weight comparable to common skin-coated foam play ball (see Figure 5.1)	D

N = necessary; D = desirable

Figure 5.1: Common skin-coated foam play ball, diameter 20 cm

6 Concept

This chapter presents the concept that was selected and implemented into the prototypes. The rationale for selecting that specific concept is then presented, followed by a summary of the ideation process.

6.1 Outline of the concept

The concept that was selected to be further developed and prototyped is based on linking the sound output of the ball to a system that senses whether any person is grabbing the ball.

In the concept, the ball is constructed so that it constantly outputs loud sound, and can therefore always be located in space by hearing. However, it has one type of sound when it is being grabbed, and a different type of sound when it is not — the system changes the sound automatically and instantly (see Figure 6.1). This means that a hearing person always can — without vision — determine whether the ball is held by somebody or not. The concept is aimed at ball games where the ball is played with the hands. The games can be common hand-based games like basketball, handball and dodgeball — but the concept is especially focused on simpler types of passing games with few participants. The storyboard in Figure 6.2 illustrates how the concept works in a variant of such a simple passing game with two participants with blindness.

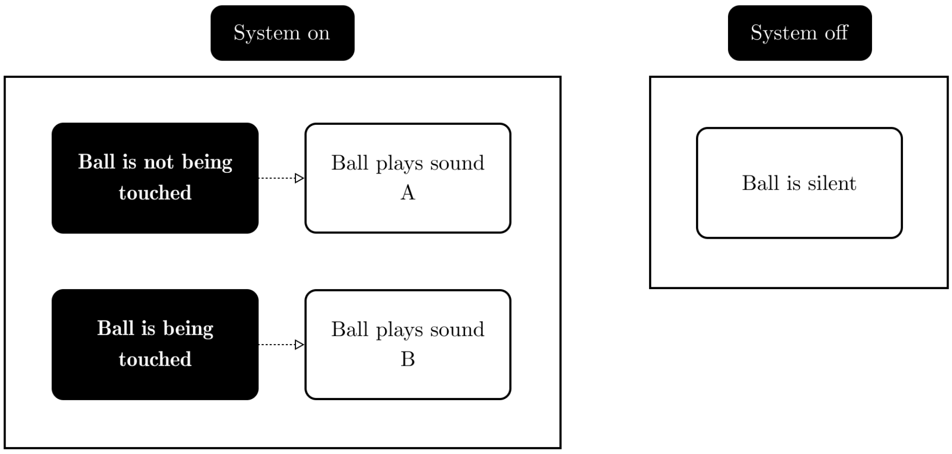

Figure 6.1: Diagram of the system's possible states and corresponding behaviour.

6.2 Implications

The system has several likely implications for the interaction of people with blindness in ball games. With this system, a person with blindness can *with certainty* tell:

- when somebody has caught the ball,
- whether somebody is holding the ball, and
- when the ball is released.

The sound constantly coming from the ball means the system always gives *strong indications* about

- where the ball is located in space in relation to the person themselves — even when the ball is still.

As a result of the above, the system can provide a person with blindness with *strong indications* — stronger or quicker than with existing solutions on the market — of such things as:

- that the ball is being thrown,

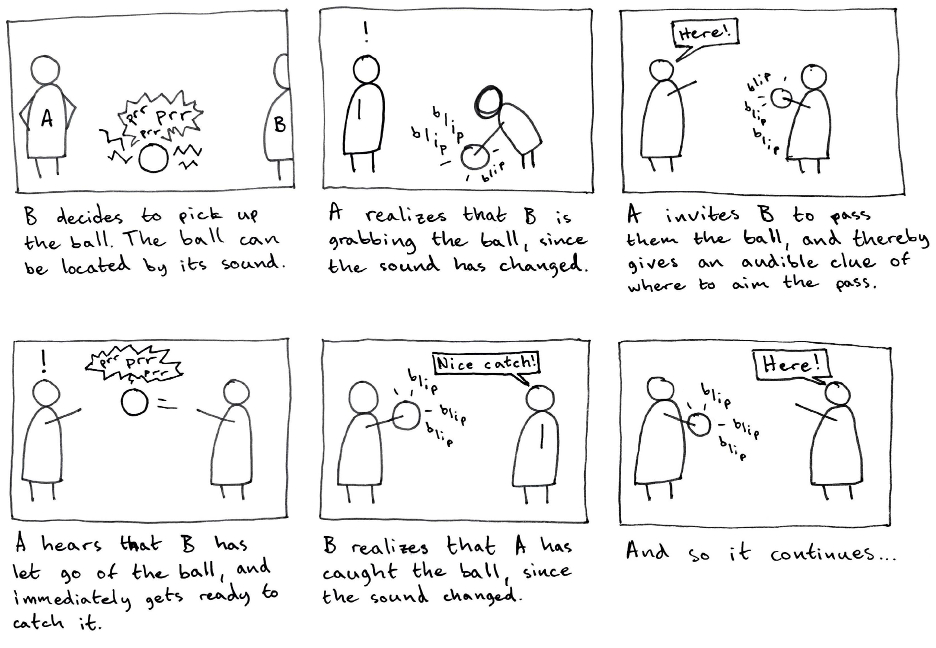

Figure 6.2: Storyboard of the selected concept. The ball outputs different sounds — "prr prr" or "blip blip" — depending on whether it is being grabbed or not.

- that a passing throw is made towards themselves,
- that a pass is accomplished in between co-players, and
- whether the ball is moving or not — even when in the hands of a co-player.

All the above mentioned features of the concept together provide an improved non-visual layer of real-time information about the game, which existing ball systems do not provide to the same extent. This enhanced information layer is supposed to let people with blindness be more involved, feel more confident about what happens, and be more inclined to take action, in the game. The concept was conceived to have the capability to satisfy a majority of the specified requirements, cater to most of the identified user needs, and make the games more inclusive.

6.3 Motivation

6.3.1 Needs in simple ball passing game

The most essential, common and basic feature of many ball games, is some form of passing game. Experts hence recommend that passing games are practiced frequently by children with blindness (Nygren & Isaksson, 1995; Scally & Lord, 2019). Furthermore, it is evident from the literature and user study that there is a general need for reduced complexity in the ball games being played, as well as a need for more practice of basic ball handling skills. Therefore, it was seen as valuable to focus the concept in this project on the most simple form of passing game; passing the ball back and forth in between two participants. Answers were sought to questions such as: ”In this most simple ball passing game, what are the needs of the participant with blindness?” and ”Which information in this game is currently inaccessible, or difficult to access, for a participant with blindness?”.

It was concluded from the user study that a piece of information that is crucial to the game — the feedback about whether the passes succeed in reaching the co-player or not — is today largely inaccessible for the participant with blindness. To know for sure that their pass reached the hands of the co-player, the co-player must verbalize this. Since as seen in the observations, co-players do not always do that, so the participant with blindness is left in doubt. Letting the system take care of this feedback instead — automatically and reliably — was proposed as a good way of letting the person with blindness be a more aware, equal, independent and included participant in the passing game. This was the main motivation for developing this specific concept.

6.3.2 The value of direct touch

For blind children, touch is a vital source of information about their physical environment (Heller & Ballesteros, 2006; Withagen et al., 2010). The tactile perceptual field is limited to the body's contact interface with an object, and thus to really apprehend an entire object by touch, the object must be explored by actively manipulating the contact interface around the object in a certain procedure (Hatwell, Streri, & Gentaz, 2003; Lederman & Klatzky, 1987). This procedure includes feeling its weight, texture, hardness and temperature (Lederman & Klatzky, 1987), which is assumed to be more accurately performed when using the hands directly than when using some kind of intermediary tool. Interacting with the ball *directly with the hands* was correspondingly assumed to be associated with a *clearer perception of the ball's physical existence in space* and a more confident sensation of *being in possession* of the ball, compared to interacting with the ball using for instance a badminton racket, a floorball stick or the feet. The observations indeed indicated that handling of the ball is more accessible when done directly with the hands. In the light of this, letting the concept cater specifically to *ball games that are played with the hands* seemed appropriate.

6.3.3 An accessible conceptual model

The conceptual model that the system provides is quite straightforward: when the ball is being grabbed, it makes one kind of sound; when it is not being grabbed, it makes another kind of sound. This conceptual model is simple and clear enough to be apprehended and shared by hearing people of nearly all ages, sighted and with visual impairment alike. As the same conceptual model can be shared by all, it provides potential for a shared experience and consensus about the system behaviour — which should promote inclusion.

The mapping of touch to sound is arguably a fairly natural mapping, that ought to be readily apprehended and accepted by any user as a foundation for their conceptual model. Things in general make some sound upon touch, provided that they are "touched" powerfully enough. More relevant comparisons can be made with musical instruments and many human-computer interfaces, where touch of a key or a touchscreen commonly produce a sound that is other, or louder, than the sound of the actual touch itself. Even humans and animals can be said to respond to touch in a way similarly to the concept — although they might not change their emitted *sound* upon being touched, they certainly respond by changing their emitted *emotion*. The ball could certainly be said to change its perceived emitted emotion when changing its sound.

6.4 Ideation process

Several concepts were developed and considered before selecting the one to continue further with. The most interesting discarded concepts are presented in Appendix E. The ideation process revolved around certain contexts and themes.

6.4.1 Contexts

The concepts were imagined to be implemented in a few plausible contexts:

- Ball games in recess at school
- Ball games in physical education classes
- Ball games in free time
- Ball sports in organized sport

All of these contexts imply use of the ball system in a group of children. In general, and as was assumed in this concept development process, the group consists of one child with blindness among children who all have full vision, which is the common composition in Swedish school classes where a pupil with SVI/BL is enrolled.

6.4.2 Ideation focus and general themes

With reference to the studied literature on inclusion, a better ball game experience for children with blindness was concluded to be closely linked to the degree of inclusion in the game. The observations showed that the children with SVI/BL were to a large extent excluded in the game because important information in the game is inaccessible for them, which certainly affected their experience negatively.

The most important information in almost any ball game is the location of the ball, what is happening with the ball and where the players are located. Therefore, the focus of the ideation was to generate concepts for how to communicate this information to a person with blindness.

A core idea that shines through in many of the different concepts that were conceived, is the use of sound to communicate the location of the ball, utilizing the capability of spatial hearing that most humans have. Lacking sight as a sense to locate an object at a distance, hearing is the most reasonable sense to use for locating a fast moving object such as a ball. Although some device that could communicate the ball's location in space via haptics is conceivable, it can very unlikely provide as accurate, quick and interpretable information in a ball game setting as sound coming from the ball.

A common theme throughout the ideation process is also the communication of key game events or the location of the players, by the use of sound or haptics.

7 Prototype

This chapter primarily presents the final design of the prototype. The key components are also presented individually with the respective rationale for choosing or developing each component. In the end of the chapter, the prototype development process is summarily presented.

7.1 Prototype overview

The final prototype (Figures 7.1 to 7.4) consists of a foam ball equipped with an electronic system that is contained within the ball. In accordance with the selected concept, the ball outputs sound, and changes its sound whenever somebody is touching the ball with their hands.

The touch sensing is carried out by an MPR121 capacitive touch breakout board, which senses touch from the touch pad consisting of conductive thread that is attached to the ball's surface. An Arduino Nano microcontroller receives events triggered by touch from the MPR121 and sends instructions about which sound to play to a DFPlayer audio playback breakout board. The audio is amplified and played through two speakers mounted near the surface of the ball. The sounds that are used in the prototype can be described as "organic repeating shaker sound" (when the ball is not touched) and "organic repeating xylophone chord sound" (when the ball is touched). A system diagram illustrating the relationships between the components and how the users interface with the system is presented in Figure 7.5.

Figure 7.1: The final prototype.

Figure 7.2: The final prototype.

Figure 7.3: The final prototype.

Figure 7.4: Speaker and power switch in the final prototype.

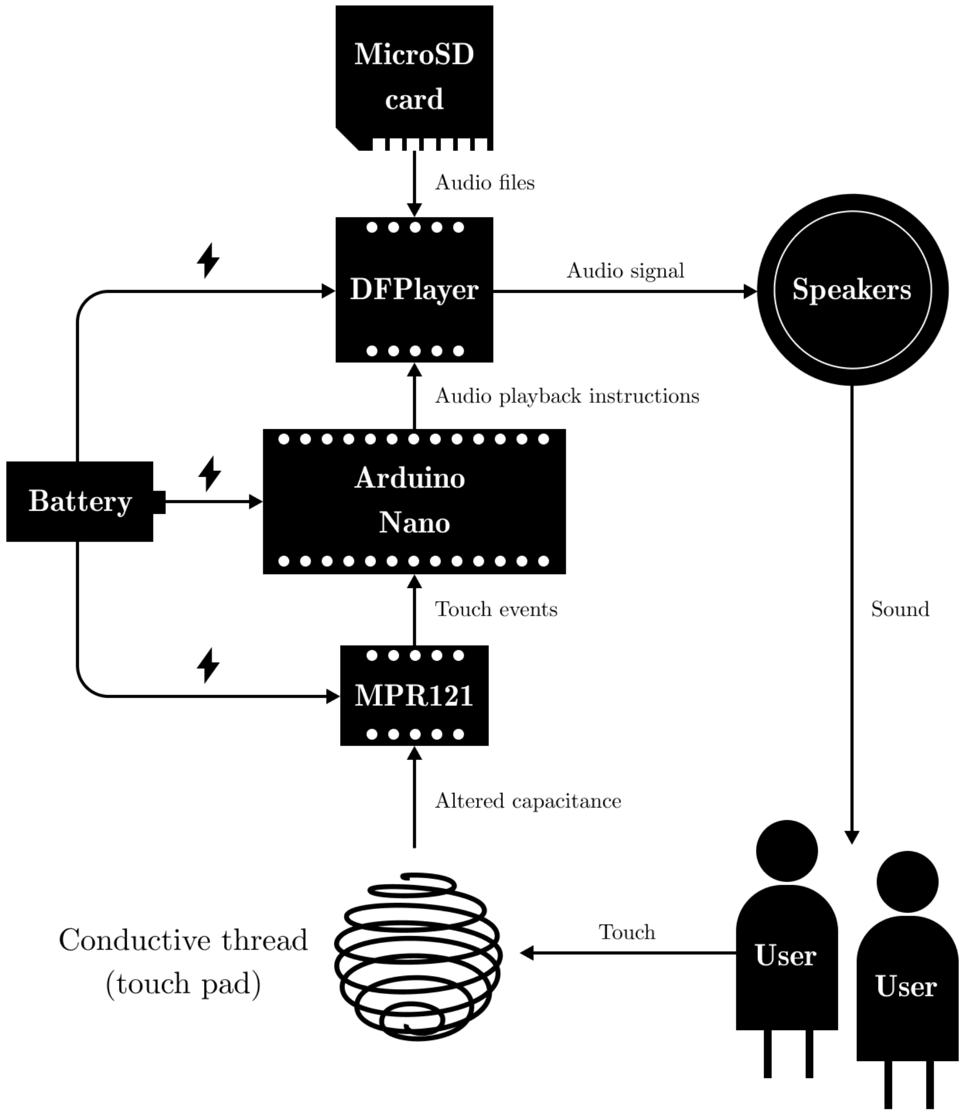

Figure 7.5: System diagram illustrating the relationships between the main components in the electronic system and how the users interface with the system.

7.2 Components

7.2.1 Main components

Foam ball

The foam ball that was used for the prototype is a soccer-like ball with a diameter of 22 centimeters (the standard size of soccer balls). The solid foam structure inside the foam ball provides the opportunity to easily carve out a hollow and insert electronics there. Compared to using for instance an air-filled soccer or basket ball, which have no solid inner structure to keep the electronics in place, this property of the foam ball makes prototyping much simpler. The ball was cut in half, and in each of the two halves a hollow was carved for the electronics insert (see Figure 7.6).

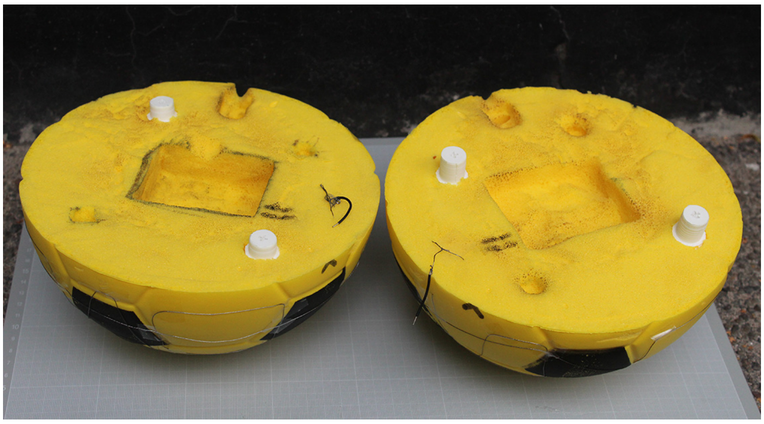

Figure 7.6: Foam ball cut in half, equipped with foam plugs and cutout for electronics

Arduino Nano microcontroller

For reasons of simplicity in use, small form factor, low cost, availability of online information resources and having some previous experience on the Arduino platform, the Arduino Nano (Figure 7.7) was chosen as the microcontroller to be used in the prototype. The Arduino platform makes prototyping electronics comparatively simple. The microcontroller is programmed using a high-level programming language, and there are many different compatible sensors for which there are off-the-shelf libraries available for Arduino implementation.

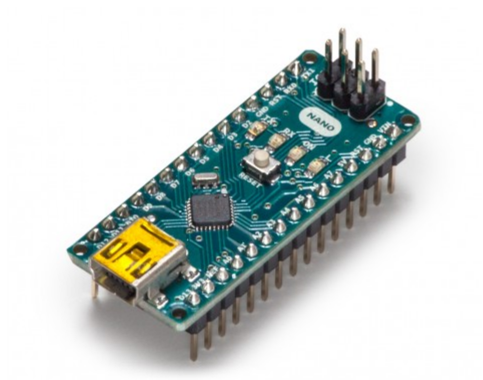

Figure 7.7: Arduino Nano

MPR121 capacitive touch sensor

As touch sensor, an Adafruit MPR121 capacitive touch sensor breakout board (Figure 7.8) was used. The MPR121 can communicate with an Arduino via a serial interface. Information that is commonly communicated to the Arduino is the event of a "touch" or a "release". It is also communicated *which* of its 12 different touch channels the event refers to. Each touch channel can thus be used as an individual binary touch pad. The touch channels can be connected to virtually any kind of small physical structure that is conductive, and thereby making that structure an electrode that functions as a touch pad.

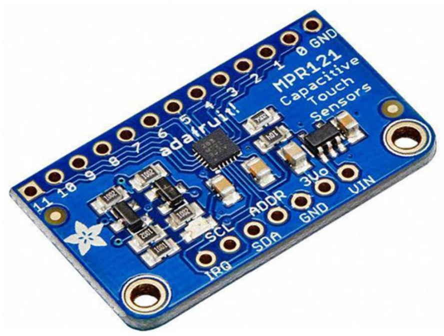

Figure 7.8: Adafruit MPR121 capacitive touch sensor breakout board

Conductive thread

For conductive touch pads on the ball, a thin conductive thread was used (Figure 7.9). The thread is made of stainless steel fibers and is thin like a normal cotton thread. It is smooth, strong and flexible and was therefore suitable as touch pad material. The touch pads of conductive thread were connected to the MPR121 and duct taped onto the ball surface.

DFPlayer audio player

In order to output audio from digital audio files, a small breakout board called DFPlayer (Figure 7.10) was used. DFPlayer can be controlled by an Arduino to play MP3 files from a MicroSD card, and output the audio to speakers via a built-in amplifier.

Battery

The prototype electronics were powered by a 3.7 V lithium-ion polymer (LiPo) battery with a capacity of 2000 mAh. This battery was chosen because it is compact, rechargeable and has enough capacity to last during a user test session. In fact, it has more than enough capacity to last during a test session. But the large capacity was very convenient when developing the prototype, never having to worry about power.

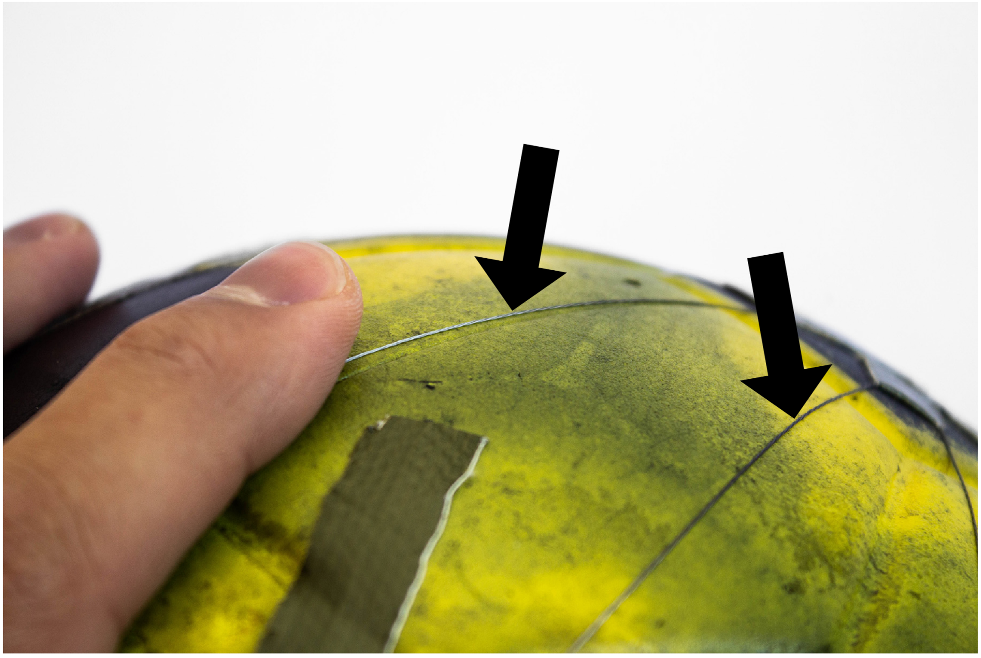

Figure 7.9: Conductive thread touch pad on the final prototype, pointed out with arrows.

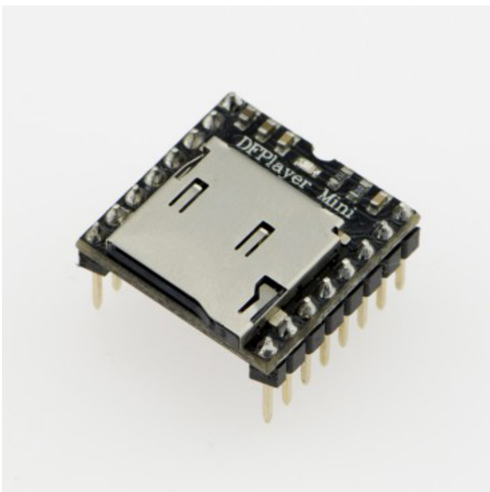

Figure 7.10: DFPlayer audio player breakout board

Especially in the beginning of the concept and prototype development processes, it was unclear which features were to be incorporated in the prototype. The large battery capacity meant there was headroom for adding any features with a higher power consumption.

7.2.2 Other, structural components

Electronics enclosure

To keep the electronics inside the ball together in a compact entity, a custom enclosure (see Figure 7.11) was drafted and 3D-printed in white PLA plastic. The enclosure was made to fit in a carved block-shaped hollow in the center of the foam ball. The battery was placed in the center of the enclosure, since the battery was the heaviest part of the electronics and the Arduino boards and breakout boards were placed fairly evenly around the battery's lengthwise axis. In this way the ball's center of mass and kinetic properties were not too much affected by the added mass. The Arduino Nano board was placed in a way that the USB port used for programming could be accessed even when the Arduino was fitted in the enclosure, to allow easy updating of the code.

Duct tape

The two halves of the ball, which had been cut apart, were rejoined with a few strips of duct tape. The duct tape was placed strategically along the cut, with one narrow strip permanently stuck onto each ball half, right along the edge of the cut, and a wider strip stuck onto the top surfaces of the other strips, locking the ball halves tightly together. In that way, the ball could easily be opened and closed, without damaging the surface of the ball, nor compromising the durability of the seal.

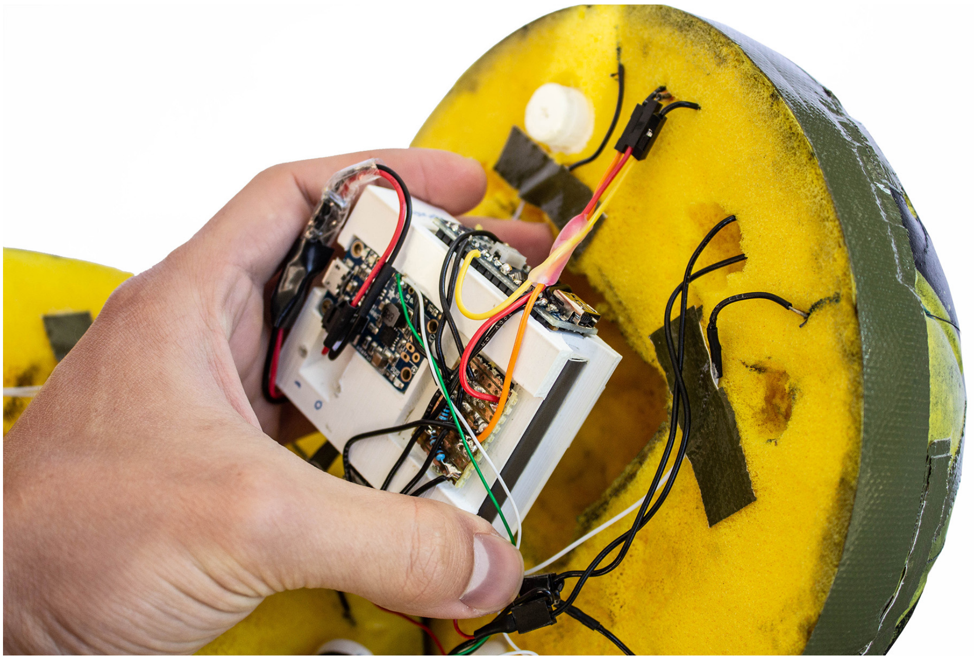

Figure 7.11: The electronics enclosure fitted with the electronics.

Foam plugs

When testing the durability of the duct tape closure solution, it was found that while the two ball halves were held together securely, they could be slightly sheared and rotated in relation to one another upon impact. To mitigate this, a few plugs (see Figure 7.12) were drafted and 3D-printed in white PLA plastic. The plugs consisted of a cylinder with a smooth end and an end with a large screw thread intended for gripping into soft materials such as foam rubber. The plugs were screwed into one half of the ball, and on the other half, corresponding holes were carved to connect with the smooth ends of the plugs (see Figure 7.6).

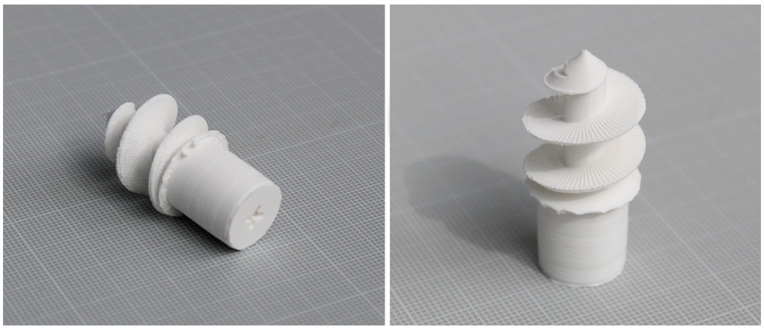

Figure 7.12: 3D-printed plugs for locking the foam ball halves more tightly together

Figure 7.13: The inside of the final prototype.

7.3 Development process

The prototype underwent several iterations of testing (see Chapter 8), researching and rebuilding. Getting the touch sensor system working in a satisfactory and stable manner was the central issue around which the prototyping process revolved. The other major focus of the process was the design of the audio output system, where suitable sounds, volume and response time were sought.

The prototype existed in three distinguishable versions, while the core of the concept and the key components remained essentially the same from start until end. The main differences between the three versions are presented in Table 7.1.

Table 7.1: Prototype versions comparison

Property	Prototype version		
	1	**2**	**3 (final)**
Touch pad material	Conductive paint	Conductive thread	Conductive thread
Touch sensor channels used on the MPR121	1	12	12
Estimated touch sensor functional consistency[1]	30%	60%	95%
Sound system	Arduino sine tones + piezo buzzer	DFPlayer MP3 player + speakers	DFPlayer MP3 player + speakers
Sounds	Artificial beep and cricket sounds	Organic shaker and xylophone sounds	Multiple different interchangeable sounds
On-off control	Double-tap on the ball (accelerometer)	Standard slide switch	Standard slide switch

[1]This is a rough estimation of how consistently the touch sensor worked in the tests, expressed as a percentage of the test duration where the touch sensor worked uninterruptedly as intended. More than as an absolute percentage, this is meant as a way to show the *difference* in functional consistency between the prototype versions.

8 User tests

The first section in this chapter describes how the user tests of the final prototype — version 3 — were conducted. The second section presents the design and results of the user tests of the earlier prototype versions — versions 1 and 2. The results of the user tests of the final prototype are presented in Chapter 9.

8.1 Tests of final prototype

8.1.1 Participants and setting

This final round of tests were carried out in groups of three to seven people, consisting of one child with SVI/BL, one or several sighted children and the researcher. The majority of the tests took place in an empty classroom or in a sports hall, at the children's school. One test was conducted in the home of the child with SVI/BL. A total of five final user tests were conducted, each with a different child with SVI/BL participating.

8.1.2 Test design

The key novel features that the concept introduces are the electronic sound and the touch sensor changing the sound. The test was therefore designed to as clearly as possible show the impact of *these two features* on the ball game interaction for the participant with SVI/BL. To make comparisons with existing solutions, some parts of the test were conducted using a normal non-audible ball and an audible bell ball, in addition to using the prototype.

The prototype did not bounce very well, and could likely break if it were to be bounced off the ground too hard or too many times. Thus, the test was designed to avoid any hard bouncing.

A test session proceeded in a few stages, as presented below.

Stage 1: Passing game in stationary circle

The test participants were invited to sit on their knees on the ground in a circle with a diameter of about five meters. The ball was then passed between the participants by rolling. The participants were allowed to pass whoever they like. Prior to passing, the participants were required to say the name of the intended recipient of the pass, and the recipient was required to respond "here!", to assist the participant with SVI/BL in locating their co-players. An illustration of this test activity is presented in Figure 8.1.

This passing game was done with

1. a normal non-audible ball
2. a commercial audible bell ball intended as an aid for people with SVI/BL
3. the prototype, using two different sound configurations

Each ball or sound configuration was tested during two minutes. The different sound configurations in the prototype can be described as "intermittent shaker- and bell-like sounds" and "continuous white noise and synth brass sounds".

In a variant of this activity, the passing game was also played *without* the name calling.

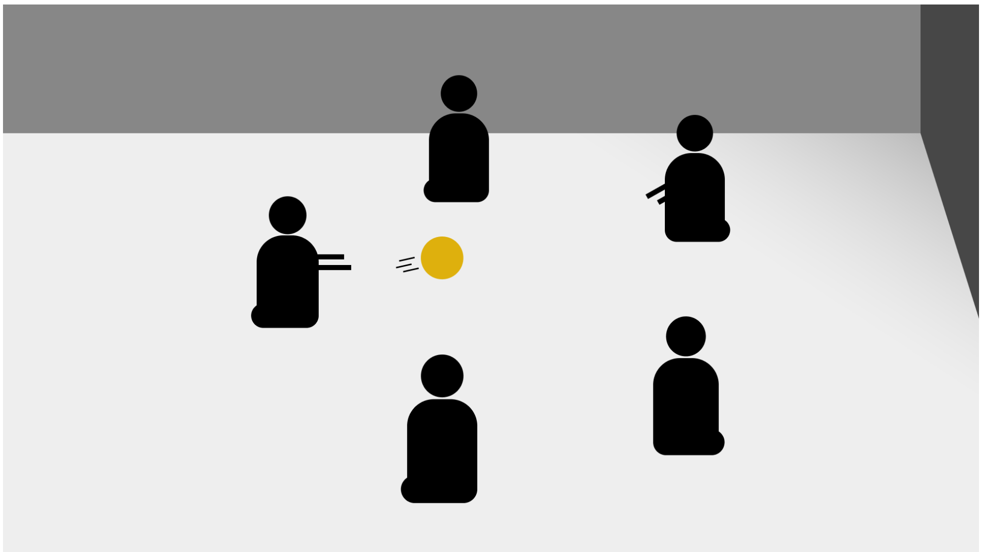

Figure 8.1: Passing game in stationary circle.

Stage 2: Passing game while moving around

The ball was here supposed to be passed between the participants just as in Stage 1 — to anyone, by rolling, requiring name calling — but with the difference that everybody was now supposed to walk around in the room at all times, except for when making or receiving a pass. This game was played with the prototype during about five minutes. An illustration of this test activity is presented in Figure 8.2.

In a variant of this activity, the passing game was also played *without* the name calling. In yet another variant the group was divided into teams and were suppose to keep the ball in the team's possession or intercept the other team's passing game (see Figure 8.3).

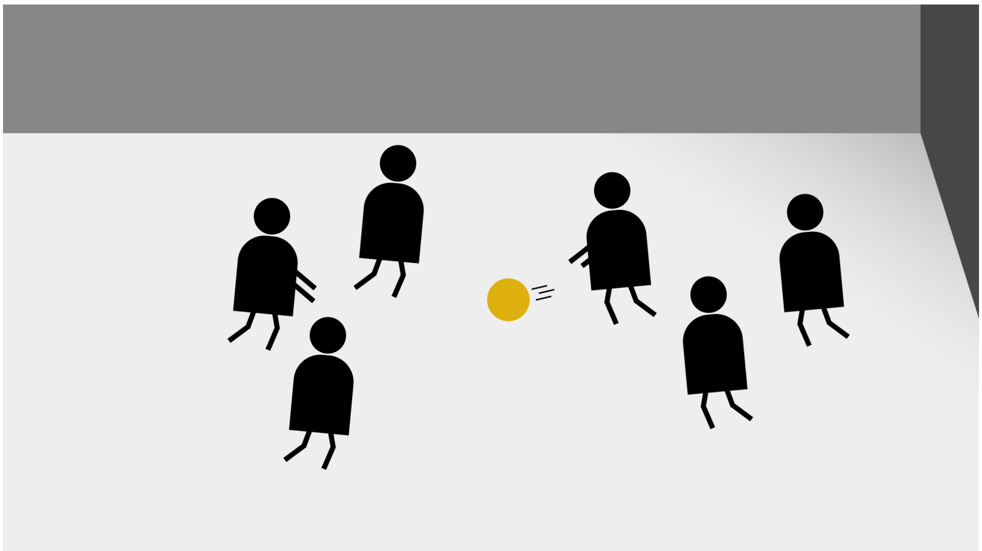

Figure 8.2: Passing game while moving around

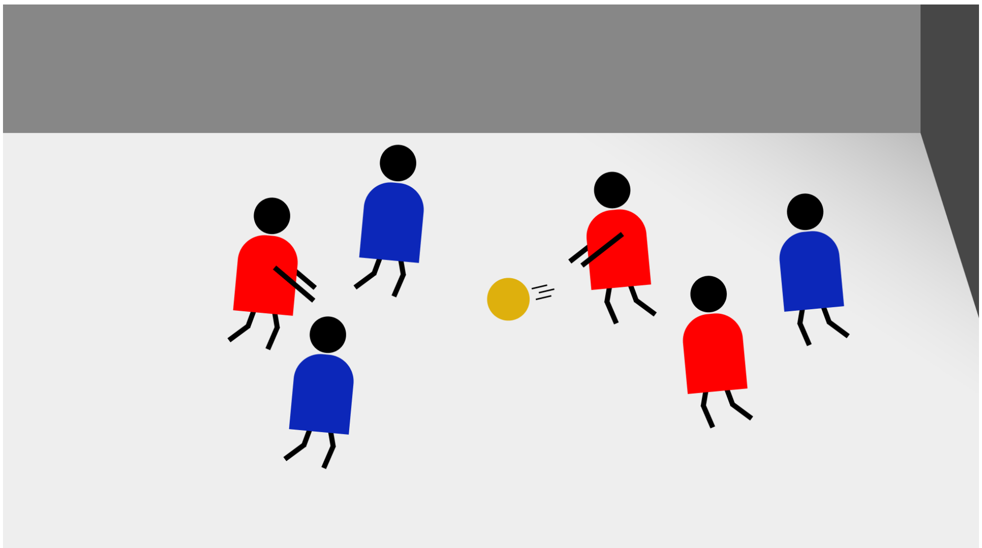

Figure 8.3: Team passing and interception game.

Stage 3: Group evaluation

As a conclusion to the group session, the group was gathered for an informal conversation to evaluate the test and the prototype. Questions like the following were asked to the group:

- How is playing with the new ball different?
- What games could the new ball be suitable for?
- Could you think of any new games using this ball?
- What do you think about the sounds of the new ball?

Stage 4: Individual evaluation

Finally, the participant with SVI/BL was interviewed individually. In this interview, other questions were asked:

- What is the difference for you in using the new ball, compared to using a normal ball? Compared to using a bell ball?
- What is the difference for you in using a bell ball, compared to using a normal ball?
- How do you think that the new ball affects your perception of the game?
- How do you think that the new ball affects your interaction in the game?
- What do you think about the sounds of the new ball?
- Are some sounds easier to locate than others?

8.2 Tests of earlier prototype versions

8.2.1 Version 1

The first version of the prototype was tested in one user test. As the prototype and the test design had not yet been tested with a user, this was seen as a pilot user test, sought to give rough overall feedback on the prototype, concept and test design. In the test, the ball was rolled between the user and the researcher in a passing game sitting on the knees on the floor (see Figure 8.4). This test revealed several problems with the prototype, which led to the development of version 2.

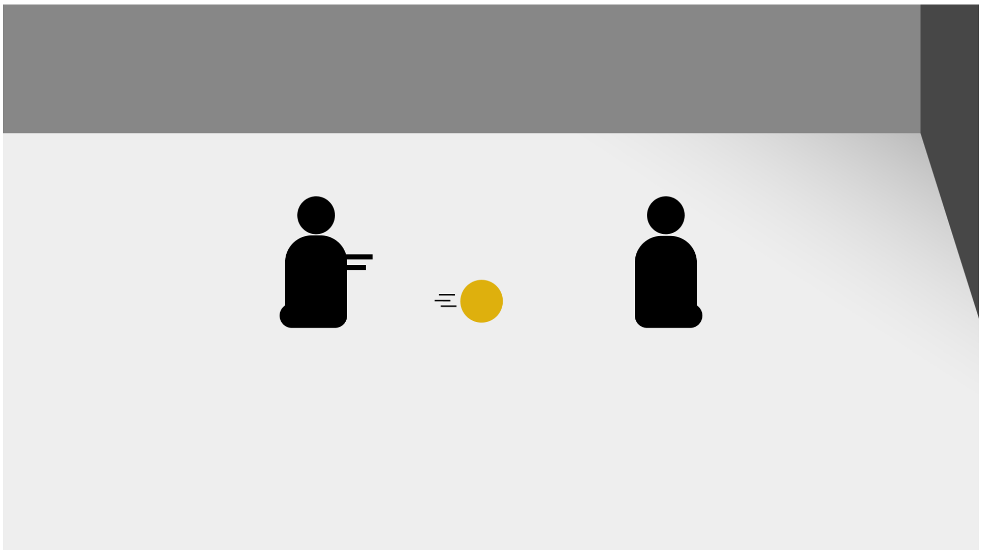

Figure 8.4: The passing game between the user and the researcher in the tests of prototype versions 1 and 2.

Test design

1. The test participant was invited to sit on their knees on the ground.
2. The sound of the ball was turned on by the researcher, and the

ball was handed to the test participant. (The possibility to turn the sound on and off by tapping the ball was not yet mentioned, to facilitate observation of the impact of one novel function at a time.)

3. After letting the test participant familiarize themselves with the sounding ball and the touch function, they were invited to pass the ball by rolling it towards the researcher, who was now sitting a couple of meters away from the test participant, them both facing each other.
4. The ball was then passed back to the test participant with a roll, and by doing so, a game was initiated.
5. After a few minutes of play, the function of turning the sound on and off by double-tapping the ball was demonstrated.
6. The test participant was invited to try turning the sound on and off by double-tapping the ball.
7. The ball was passed back and forth, and if new games or ways to play the game were initiated, that was welcomed by the researcher.
8. When there was a feeling of having played enough, the testing was stopped by the researcher.
9. The interaction, the prototype and the game were evaluated in an informal interview, which brought the session to a close.

Test results

The problems with the prototype were the following:

- The touch sensor did not seem to register every touch
- The touch sensor sometimes registered a touch although nobody was touching it
- The sounds did not switch rapidly enough upon touch or release of the ball

- The ball was often turned off involuntarily, by the accelerometer registering bumps or hard grabs of the ball as double taps
- The sounds were perceived as quite annoying and stressing

The most important insight from this test was that the touch sensor and the sound system did not work well enough to be able to test the interaction impact of the prototype as intended. That the prototype had issues with inconsistency in the touch-sound function was known before the test, but it was supposed to be working *good enough* to conduct a relevant test of the prototype's impact on the ball game interaction. But the problems turned out to be too severe to be overlooked.

It was obvious that the test participant could not conceive a useful conceptual model of the system. The test participant expressed that "I don't think I really get how it is supposed to work". The inconsistency in the functioning of the touch and sound system, the slow response of the sound, and the fact that the ball sometimes seemed to turn off by itself from simply touching it, probably inhibited the user from mapping *touch* to *sound change*. Without this mapping in place, the main goal of the test could not be achieved.

8.2.2 Version 2

Version 2 of the prototype was tested in two individual user tests employing the same test design that was developed for Version 1 (see Figure 8.4.

Test results

- The sounds and the touch function of the prototype were much appreciated by the users — they were eager to continue testing and praised the prototype
- The users described the novel features as helpful for locating the ball

- The users found that the novel features made them more aware about what happened in the game
- The fact that the accelerometer (double-tap on-off control) had been removed improved the functional consistency, but the touch sensor system was still having some hick-ups

9 Results

This section presents the results of the user tests of the final prototype and an assessment of whether the developed system fulfils each specified requirement.

9.1 Final prototype test results

The results of the user tests were the following:

Overall

- The prototype was very positively received by all participants, with reactions from the participants with SVI/BL such as "This is my favourite ball!" and "Why is there not such a ball available? There should be!"
- The concept could easily be grasped even by young school-age children
- The prototype was considered more fun to play with than the other balls

Locating the ball

- The prototype was by participants with SVI/BL perceived as easier to locate than a non-audible ball or a bell ball
- Some participants with full vision, too, expressed that the system increased their awareness about the ball
- Some participants with SVI/BL expressed that they found it harder to know when the prototype had stopped rolling, compared to

knowing when a bell ball has stopped rolling

- One participant with SVI/BL who normally experiences eye fatigue from intensely focusing on the ball with their very limited vision, expressed that they did not feel as exhausted when the prototype was used

Interplay

- Some participants with SVI/BL claimed to feel more confident in their passing and catching when the prototype was used
- All participants with SVI/BL expressed that they perceived the location of a co-player more clearly with the prototype (when the co-player was in possession of the ball)
- The games were enjoyed "even though" they were non-competitive

Sound

- The loud and constant sound of the ball was perceived by the participants with blindness as an improvement over a bell ball
- There were different opinions about which sounds would be the most appropriate
- A possibility to oneself change or select the sounds would be appreciated
- The sound volume should be adjustable or adaptive

Prototype performance

- The touch system worked consistently as intended during the whole test sessions, save for a few hick-ups
- The capacitive touch system in the prototype is dependent on dry floor without any conductive segments such as metal floor drains

9.2 Fulfilment of requirements

The requirements are here presented again, with an assessment of the developed system's fulfilment of each requirement, based on the results from the user tests and certain facts about the prototype. Table 9.1 presents the functional requirements and Table 9.2 presents the non-functional requirements, with each requirement's respective fulfilment rating. Although the degree of requirement fulfilment is in reality often more nuanced than "fulfilled" or "not fulfilled", this kind of binary rating system has been employed here for the sake of readability.

Table 9.1: Fulfilment of the functional requirements of the system

Function		Class	Fulfilled
Afford	ball playability	MF	Yes
Communicate	spatial location of the ball (even when the ball is still)	MF	Yes
Engage	fun play on essentially equal terms	N	Yes
Present	a suitable level of challenge	N	Yes
Present	a suitable level of perceptual complexity	N	Yes
Afford	ball bounciness	D	No
Prevent	ball from hurting (the face)	D	Yes
Communicate	the occurrence of key events in the proceeding of the game	D	Yes
Communicate	location of co-player(s)	D	Yes
Communicate	location of any goals or other features integral to the game	D	No
Communicate	the event and location of a ball bounce	D	No
Communicate	whether the ball is still	D	No
Help improve	ball play skills	D	Yes

MF = main function; N = necessary; D = desirable

Table 9.2: Fulfilment of the non-functional requirements of the system

Requirement	Class	Fulfilled
Look and feel		
Bright, easily distinguishable color	N	No
Soft ball with soft texture	N	Yes
Ball large enough to be easily caught and grasped with the arms	N	Yes
Usability and humanity		
Interface discoverable and usable for a child with blindness	D	Yes
Interface adapted to children's cognitive capabilities	D	Yes
Sighted co-players need no blindfold	D	Yes
Performance		
Bounciness comparable to common skin-coated foam play ball (see Figure 5.1)	D	No
Weight comparable to normal skin-coated foam ball	D	No

N = necessary; D = desirable

10 Discussion

This chapter presents a discussion on the project's methodology, process and future development directions.

10.1 Fulfilment of requirements

All requirements were not fulfilled in the developed concept and prototype. That was never the ambition, either. While it can be said that a *majority* of the requirements were fulfilled, that is quite irrelevant, since each requirement is of different importance, not solely relating to their designated requirement class. It is more relevant to draw a few conclusions regarding the fulfilment of *certain requirements*, which is done below.

Fun

One of the most important requirements apart from the main functions, was that the concept should be appreciated as *fun* by the users. As a concept for play, games and sports, the *fun* is the central part of the user experience. There was no doubt in the tests that the prototype was considered fun, for participants with SVI/BL and with full vision alike.

Communication of information

The main function of communicating the spatial location of the ball at all times, is clearly implemented by means of the constant sound of the ball. The prototype also communicates some information that was classed as desirable in the requirements: the occurrence of key events in the proceeding of the game and the location of co-players. Only certain key events are communicated — catches and releases of the ball – and the location of a co-player is only communicated while that co-player is holding the ball. But these pieces of information did indeed prove valuable for the experience of the target users, which was the aim.

Physical properties of the ball

Several of the non-fulfilled requirements are related to the physical properties of the ball such as its bounciness, weight and color. While a properly bouncing, light prototype would have been preferable, it was not considered crucial for assessing the overall effect of the touch-sound system on ball game interaction — that could be done even if the ball could only be *rolled* in the tests. The conclusions ought to be quite applicable also for passing games where the ball is bounced and thrown.

Regarding the color, the requirement is more relevant for a finished product, where it is certainly preferable with a clearly visible ball. In the tests, however, it would possibly even have been preferable with a *less* visible ball — to really understand the needs in the *non-visual* part of the interaction, which was the main interest in this project. In reality, the color of the prototype just happened by chance, without any real consideration.

Information on whether the ball is still

A user need that was identified in one of the later user tests, was the need to know when the ball is still rolling — and when it has stopped. While the silence of a bell ball that has stopped makes it hard to assess its location, a bell ball still communicates *the event of the ball stopping* — the bells stop sounding when the ball comes to a halt. The prototype does not communicate this event. This is a downside to the prototype compared to a bell ball, which would preferably have been addressed at an earlier stage.

10.2 Achievement of main project aim

The main aim of this project was stated as:

> **to develop and evaluate a concept for a novel digitally enhanced audible ball system for a better ball game experience for children with blindness.**

Assessing the achievement of the first part of this aim is quite simple: A concept for a novel digitally enhanced audible ball system was indeed developed and evaluated.

The second part, though, addresses the core value of this project: *Does the developed system make the ball game experience better for children with blindness?*

As argued in Sections 6.4.2 and 10.1, major constituents to the ball game experience are the *fun* and the *degree of inclusion* in the game. The *fun* part was in Section 10.1 concluded to likely be catered for by the developed concept. So does the concept lead to better inclusion? The test results showed that the system indeed does provide better real-time non-visual information about the game, which is key to inclusion. As the system automatically provides this information, the child with blindness may feel more independent — not being as dependent on verbal information from their sighted peers. Furthermore, as the prototype has the shape of a normal ball, does not require any additional artefacts, and has a simple and natural interface, it can arguably be quite easy to accept for people with visual impairment and people with full sight alike. The system could thus be smoothly introduced in groups of children, without hindering inclusion by seeming very strange or screaming "disability aid".

Suitable equipment is only a part of what makes a situation or an environment inclusive. But this concept has proven to have a good potential of being a valuable part in enabling inclusion, and make ball game experiences better for children with blindness.

10.3 Methodology

10.3.1 Data quality

This section presents a discussion on the reliability, representativeness and validity data that was collected in the initial user study.

Reliability

The reliability of a set of data is an assessment of whether the same data would repeatedly be encountered again if the same data gathering method were to be used again, in the same setting (Bell & Nilsson, 2006). The reliability of the observation data, when considered by itself, is quite low, since it is based on personal interpretation — another researcher could likely observe and interpret the situations in a different way. As the observations are based on the *interpretations* of the researcher, they represent the emotions, actions, experience and user needs *as perceived by the researcher* and should be taken with a grain of salt. The interview data was likely more reliable — if the respondents could be assumed to know their own experiences best themselves, and that these experiences were communicated accurately to the researcher. At the same time, there is a risk that the respondents were adjusting their answers to try to accommodate the interviewer — the ”social desirability” factor as Denscombe (2014) calls it — which according to Doverborg and Pramling Samuelsson (2000) often happens when interviewing children.

However, since the tendencies of the collected data could be confirmed by comparison with the literature on the same subjects, the reliability of the data is a bit better. Triangulation, mixing findings originating from different research methods, is a good way to improve the confidence in the accuracy of the findings, as Denscombe (2014) argues. In this study, the encountered studies pointing in the same directions regarding the situation and needs of children with blindness provided a reliable baseline from which the observations could be interpreted.

Representativeness

The sample used in this study was composed of five children with severe visual impairment or blindness, of ages around seven to around 15. It cannot be claimed that this sample is biased or otherwise unrepresentative in any apparent way — it is simply an arbitrary extract from the available school-age children with severe visual impairment in one particular geographical area of Sweden. The geographical location that is shared by the sample should not make the sample unrepresentative for the rest of Sweden.

Representativeness of the data generally increases with a larger sample — a large sample increases the chances that all variations that exist within the studied population are represented and captured in the data (Denscombe, 2014). In usability studies, which are closely related to the type of study of interaction and user experience that was conducted here, Nielsen (2012) suggests that *five* users participate. The main argument for this, says Nielsen (2012), is that each additional participant consumes resources from the study, and the return on investment for additional participants diminishes quickly after five participants. All in all, confidence about the representativeness of the data is good.

Validity

Validity of data is, in simplified terms, about whether a research effort really measures or describes what it is supposed to measure or describe, according to Bell and Nilsson (2006). As with the reliability, the fact that the researcher in this study has a great responsibility to interpret the observed situations and document relevant data means the validity is affected negatively. Other phenomenons might be measured or described instead of what was intended — the data is not made up of definite facts, but of personal, biased interpretations. Sands (2011) argues accordingly, regarding the use of observations for capturing the user experience in sport, that the need for interpretation is one of the method's limitations. The validity also decreases as reliability decreases, Bell and Nilsson (2006) states, and as the reliability for the data here is suboptimal, the validity of the data is further harmed by this.

Although the validity of the data might be quite limited, it is worthwhile to emphasize that this is a design project and not a study in social sciences. The point being, that the data is primarily used *to gain insights for driving the design* — which Nielsen (2012) argues should be the aim of user studies in general. The data is used to provide guidelines for approaching the development process in the right direction, rather than to present an accurate and certain account of the nature of ball game experience among children with blindness. After all, the aim is to develop a product that improves these ball game experiences, and whether that aim is fulfilled is determined in the final evaluation of the product, regardless of the validity of the data its development was based on.

10.3.2 Specifying game design needs

It was evident, especially from the observations, that current ball game situations in physical education persistently present too high a challenge for children with blindness. On one hand, it could be said that this is due to the games played being ill-suited or not well adapted. On the other hand, the level of challenge is also dependent on the child's ball handling skills, the attitudes and behavior of the co-players, and how well the equipment aids the child with blindness. The questions being asked here are in other words: Is there really a *user need* for certain game design? Are not the real user needs captured in the areas Perception, Ball handling and Miscellaneous? Is the area Game design proposing *a means of accommodating the other needs*, rather than presenting additional needs?

These concerns are valid and relevant. But observing the games played in physical education, it was obvious that some of the games are simply too perceptually complex to be played on equal terms without modifications of the actual design of the game. While achieving equal participation with the current game designs through compensating for the lack of vision by means of equipment alone maybe should not be claimed as an impossibility, it was not a reasonable aim within the scope of this project.

While some needs could and should be accommodated to some extent by improving the equipment, the current game designs clearly constituted an obstacle to a better user experience. Thus, while the game design needs *could* be derived from the other needs, declaring game design needs as a category of user needs was considered appropriate — to explicitly specify what the users need in terms of the design of the game. It was reasoned that if the game design was appropriate, the emerging ball system could be developed with this, more appropriate, situation in mind, and hence provide better opportunities to achieve the aims of this thesis.

It was this reasoning that in the end led to focusing the concept development and prototype testing around the *simple passing games*.

10.3.3 Ethics

Designing specifically for people with disabilities means exposing their disability. When conducting this project, this was a concern, since the children with SVI/BL got exposed in this way both in the observations and in the tests. Moreover, their sighted peers were present in these situations, which, as described in Section 2.4.6, could increase the feeling of being exposed because of their disability.

It would have been interesting to test the prototype in a group consisting exclusively of children with SVI/BL. In such a setting, it is likely that the interaction would be different, maybe more centered around the non-visual parts of the game. But this idea was rejected out of the ethical concern about exposing the participants to each other *on the basis of their visual impairment*, which would have felt inconsiderate.

Any negative sides of the exposure has to be weighed against the possible positive outcomes of the study, which could benefit the whole user group that is being studied. If disabilities could never be exposed, it would be difficult to conduct fruitful user-centered design projects. Still, the studies must be carefully planned to be tactful and respectful, which was certainly an aim in this study. The participants in this study gave their informed consent to participation, and they all expressed that they had enjoyed participating.

10.3.4 Risks

There were a few risks in the project, the most notable one being the fragility of the prototype. The quite complex electronic system could have been short-circuited or otherwise damaged, by for example sloppy soldering or reckless testing behaviour such as kicking of the ball. Several of the components had to be sourced from abroad, which would have meant long waits for replacements. The risk of damage to the prototype was one reason for only allowing rolling of the ball in the tests.

The low number of available people from the target population meant that there was a higher risk of not being able to conduct the user study and tests with target users — what if the five available target users had declined to participate?

Fortunately, the prototype did not break and the users all agreed to participate, but some kind of plan B could have been wise to have.

10.4 Prototyping

10.4.1 Functions limitation

While partially a matter of time constraints, focusing on one simple and distinct concept was also considered beneficial. For by isolating the prototype and the testing to studying the impact of *the touch-sound* *function only*, all the test results could be quite confidently determined to have a causal relationship with *that* function and nothing else. If more functions had been implemented, it would have been difficult to determine *which* functions that gave rise to certain results.

10.4.2 Difficulty in touch sensor implementation

The main difficulty in the prototyping was getting the conductive touch system working in a satisfactory manner. Indeed, developing capacitive systems of this kind have proved difficult for many others. In an extensive survey of past research in the field of capacitive sensing in human-computer interaction, Grosse-Puppendahl et al. (2017) conclude that "compact integrated end-to-end capacitive systems remain difficult to prototype". The problems that were encountered in this project of getting the touch sensor to work when powering the system with a battery, have for instance been a common issue for other researchers in the field. Grosse-Puppendahl et al. (2017) refer to several cases where a wearable prototype is equipped with external ground connections to work as a prototype, but could not work as a standalone, wireless wearable.

In the light of these past difficulties that others have encountered, the fairly well-working outcome of the prototyping in this project shall not be trivialized.

10.4.3 Electronic system complexity

The electronic system in the prototype (see system diagram in Figure 7.5) could have been simplified by using an all-in-one solution. The Bare Conductive Touch Board (Figure 10.1) integrates a microcontroller, an MPR121 conductive touch sensor and MP3 playback in one circuit board. This board could thus replace the Arduino, the MPR121 breakout board and the DFPlayer breakout board in the prototype, resulting in a system according to Figure 10.2.

The Bare Conductive Touch Board can in hindsight seem like a more reasonable option than the multi-part system that was used in the prototype — requiring less soldering and wiring, probably being more reliable and requiring less programming efforts. But the needs in the electronic system evolved and changed during the process — although the process as described in this report can seem quite linear — and the Arduino-centered system allowed for easier swapping of different sensors and breakout boards to test different ideas.

The focus was set on testing the selected concept, which could be satisfyingly achieved with the developed system. Therefore, implementing the Bare Conductive Touch Board was considered an unnecessary effort and cost in this project. However, if a new prototype were to be developed from scratch, the Bare Conductive Touch Board would probably be a wise choice.

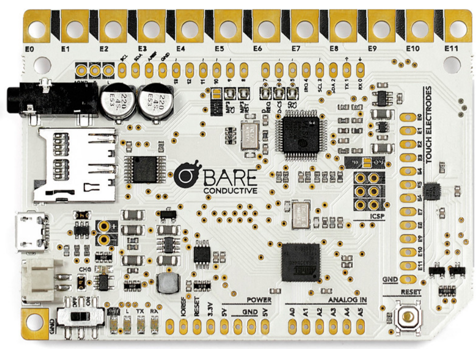

Figure 10.1: Bare Conductive Touch Board

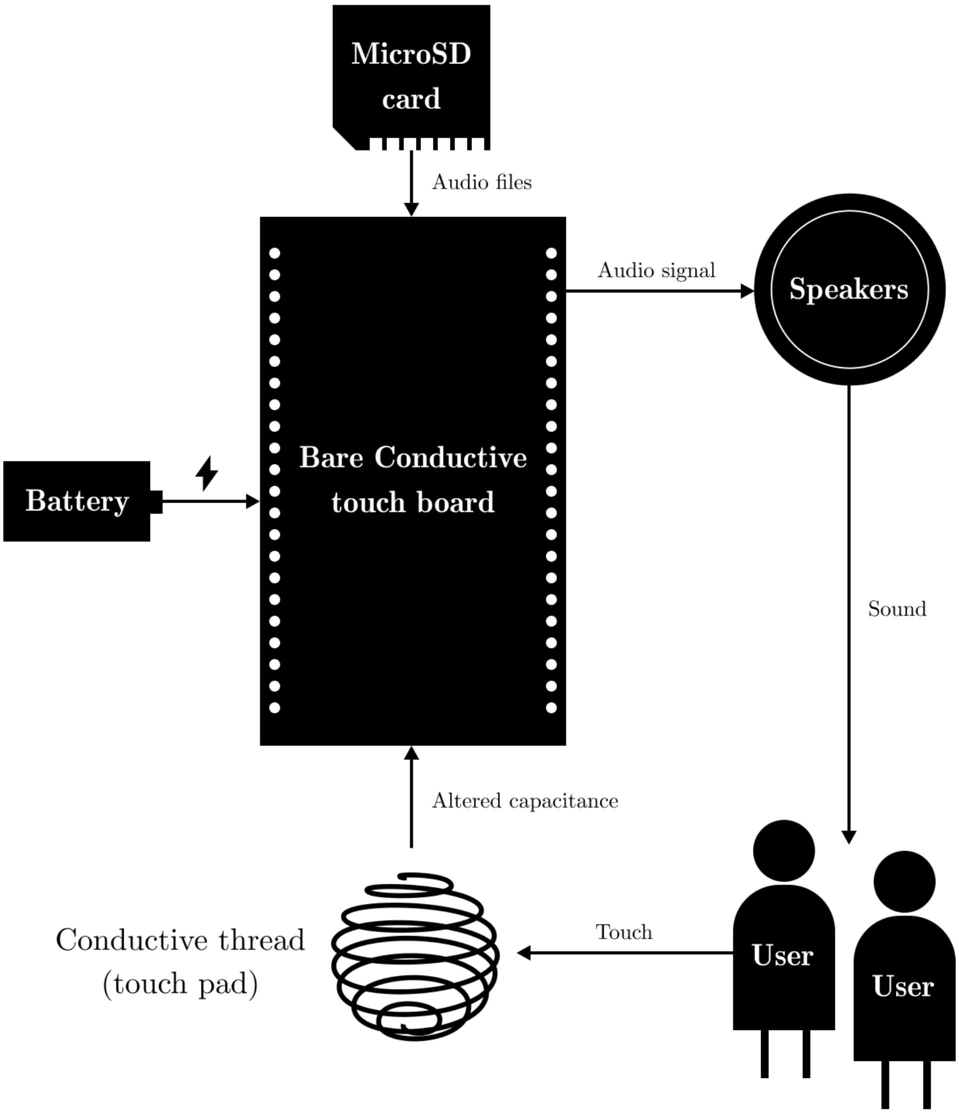

Figure 10.2: System diagram if implementing the Bare Conductive Touch Board.

10.5 Future development directions

Testing the concept in different settings

While children with blindness in ball games often benefit from a smaller group and less perceptually complex games, it could be interesting to test how the concept works in larger groups and more perceptually complex games. Although often not preferable from an inclusion perspective, complex ball games in large groups are common practice in physical education as well as in school recess. It is reasonable to test the concept in a setting that is so common.

Testing the concept with adults with blindness

This project focused on children with blindness. But adults with blindness (or severe visual impairment) would most definitely benefit from the developed concept as much as children. It is possible that the impact of the concept differs in some ways between children and adults and that could be worthwhile to investigate.

Touch sensor system

The touch sensor system that is used in the prototype works quite well in the test environments where the tests were conducted in this project; indoor, dry, clean, non-conductive floors. But it is not usable in an actual ball game setting — the system fails too often to feel useworthy and would provoke irritation after a while. The touch sensor system is easily disturbed by moisture and physical impact, and anything that is conductive, such as metal floor drains, triggers the sensor. So a valuable research direction would be towards a touch sensor system that works consistently well regardless of its environment. Conductive touch sensing is only one of many possible ways of sensing touch.

Power switch

The prototype is powered on and off by a simple slide switch. The power switching system could preferably be better adapted to the needs of children with blindness, enabling them to independently handle that part of the system's interface. One concept for this was actually tested in the first version of the prototype; implementing an accelerometer in the ball system, the sound could be switched on and off by double-tapping the ball.

Battery charging solution

A wireless electronic system like this is (most definitely) dependent on battery power. In a modern device, rechargeable batteries are the way to go. But how would the battery be charged? By cable? By inductive charging? As with the power switch, it would be reasonable to develop a battery charging solution with the aim of extending the independence of the user with blindness.

Implementation in a consumer product

In the end, the concept seems to have such potential for improving the ball game experiences for children with blindness that it should be implemented in some form in a consumer-ready product. Children with blindness all over the world could benefit from having such a ball in physical education classes, in school recess and at home. There is a long development process left to get the concept into a consumer-ready product, but this project ought to prove that it is conceivable and would be well worth the efforts.

11 Conclusion

The main aim,

> **to develop and evaluate a concept for a novel digitally enhanced audible ball system for a better ball game experience for children with blindness**

was concluded to be achieved in the project. The user tests of the final prototype showed that the developed concept is perceived as fun by children with SVI/BL and sighted children alike. Furthermore, the tests proved that the system communicates valuable non-visual information about the game that makes the users with SVI/BL feel more confident in the game. The concept was concluded to provide means for a more inclusive — and better — ball game experience for children with blindness.

The other central aim of

> **contributing with new knowledge about ball game interaction for children with blindness**

was also achieved. This thesis provides new data and knowledge about ball game interaction for children with blindness. Primarily, the findings show the great potential of equipping the ball with electronic sound and audible feedback about whether the ball is touched or not. The promising results of this study can likely inspire to more studies in this field.

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Appendix A (Observation guide for initial user study)

This appendix presents the observation guide that was used in the observations in the initial user studies.

Table A.1: Observation guide

Aspect	**Associated questions**
Ball perception	Is it in certain situations obvious that the person does not see the ball well with the help of sight? What situations? How is this expressed?
	How does the person react to the movement of the ball? When the ball is kicked, thrown, bounced, or stops?
Ball handling	What does the person do when they get the ball? What seems to determine the direction of the subsequent throw, kick or run?
Behaviour towards co-players	How does the person with blindness act in relation to the surrounding people?
Co-players' behaviour	How do the surrounding people act in relation to the person with blindness?
Physical environment	How does the person navigate on the court? Can any strategies be identified?
Miscellaneous	What else is noticeable?

Appendix B (Interview guide for initial user study)

This appendix presents the interview guide that was used in the interviews that were conducted in conjunction with the observations in the initial user study.

Table B.1: Interview guide

Area	Example questions
Exposure to ball games	*In which situations in your life do you engage in ball games?*
	Do you play with balls in your free time? Which games?
Emotional relation to ball games	*What do ball games mean to you?*
	How do you like ball games?
	What ball games are the most fun?
Difficulties in ball games	*What ball games are the easiest?*
	What is difficult in ball games?

Appendix C (WHO classification of severity of vision impairment)

Table C.1: WHO classification of severity of visual impairment

Category	Presenting distance visual acuity	
	Worse than:	**Equal to or better than:**
0 Mild or no visual impairment		6/18 3/10 (0.3) 20/70
1 Moderate visual impairment	6/18 3/10 (0.3) 20/70	6/60 1/10 (0.1) 20/200
2 Severe visual impairment	6/60 1/10 (0.1) 20/200	3/60 1/20 (0.05) 20/400
3 Blindness	3/60 1/20 (0.05) 20/400	1/60* 1/50 (0.02) 5/300 (20/1200)
4 Blindness	1/60* 1/50 (0.02) 5/300 (20/1200)	Light perception
5 Blindness	No light perception	
9	Undetermined or unspecified * or counts fingers (CF) at 1 metre.	

From World Health Organization (2015).

Appendix D (Personas)

This appendix presents the two personas that were developed and used in the ideation process.

D.1 Persona 1: Alex

Alex is a seven-year old with blindness. Alex is quite timid and introverted. During recess, Alex often stays away from the big noisy group of peers, reading a book or engaging in play with one or a few friends. Alex is not a fan of physical education. More often than not, ball games are part of the lesson, and Alex just finds it noisy, stressful, confusing and a bit frightening with all the balls flying around. Sometimes the teacher divides the class into smaller groups, and those lessons are the ones that Alex enjoys the most. With less people, sound and equipment involved, Alex has a clearer perception of what happens in the activity at hand. Alex really likes the feeling of having control.

Figure D.1: Persona 1: Alex.

D.2 Persona 2: Leslie

Leslie is an eleven years old child with blindness. They are a restless child who likes to partake in play and physical activities of all sorts. Leslie plays goalball with a local club in their free time. They often go tandem biking or swimming with their parents. Leslie is not afraid of socializing, and although the visual impairment often is an obstacle to discover and partake in social interactions and activities, Leslie takes every chance to do so. Having quite a lot of experience from ball games ever since early childhood, Leslie likes ball games, feels quite comfortable in ball games, and they are not really afraid of balls coming towards the face either. But all the sounds really make ball games difficult sometimes... There are simply too many sounds and movements at the same time.

Figure D.2: Persona 2: Leslie.

Appendix E (Discarded concepts)

This appendix presents a selection of interesting concepts that were conceived in the ideation process but discarded. After the presentation of the concepts, the possible values and implications of each concept is briefly assessed.

E.1 Discarded concepts

E.1.1 Concept A: Ball velocity reflected in its sound

An early idea was to let the emitted sound of the ball reflect the ball's changes in velocity by using an accelerometer. For example, the pitch or volume of the emitted tone could get higher with increasing velocity and lower with decreasing velocity (see Figure E.1). The idea was to let the person with blindness get more exact information about what happens with the ball, and consequently be more involved and included in the game.

E.1.2 Concept B: Noise cancelling and filtering earphones

Observing the physical education classes, it was obvious that an obstacle to perceiving the location of an audible ball was that there were too many other sounds in the environment: shouts, other bouncing balls and the sound of shoes beating against the floor. An idea to combat this

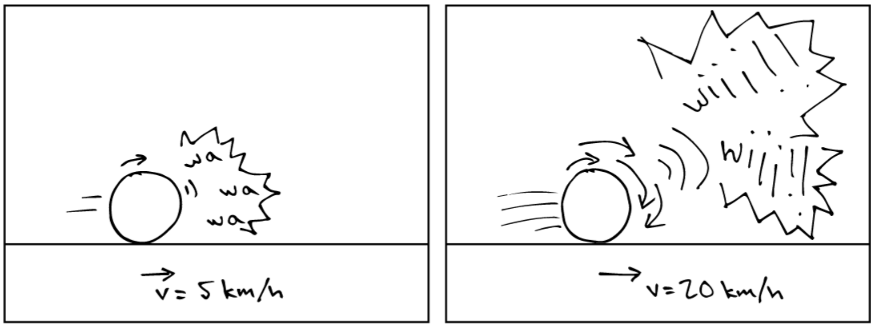

Figure E.1: Concept A: Ball velocity reflected in the pitch and volume of its sound.

was to equip the person with blindness with headphones utilizing noise-cancelling technology. By cancelling out, or rather lowering, the noises of everything except the audible ball, the ball's location could possibly be discerned more clearly (see sketches in Figure E.2. To make sure the ball's sound would not be lowered together with the other sounds, some kind of filter would have to be implemented. For example, if the ball was designed to emit sound within a few narrow frequency spectrums, all other frequencies apart from these could be filtered out by the headphones.

E.1.3 Concept C: Interconnected balls

One way that the problem was approached, was to investigate whether the level of challenge could be evened out between sighted and visually impaired children by designing a new type of game. Instead of equipping the sighted with blindfolds, or otherwise even out the game by restricting the sighted, the aspiration was to find common ground — some challenge where vision doesn't matter.

The system that was imagined included several wirelessly interconnected balls, each equipped with an electronic sound system. The game played could be something like soccer. Only one of the many balls is active

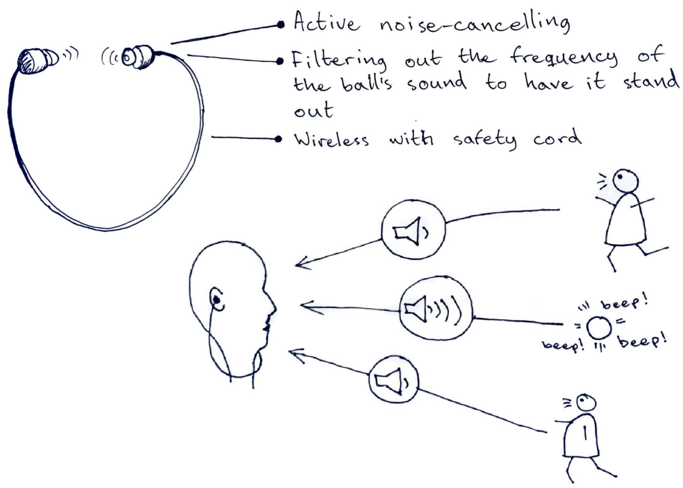

Figure E.2: Concept B: Noise cancelling and filtering earphones.

and sounding at any given moment. This ball is the only ball in play, at that moment. Every now and then, the system changes which ball is active, so the players must use their *hearing* to locate the new active ball. As the challenge is transferred from vision to hearing, the sighted and visually impaired should have a more equal chance of finding the correct ball.

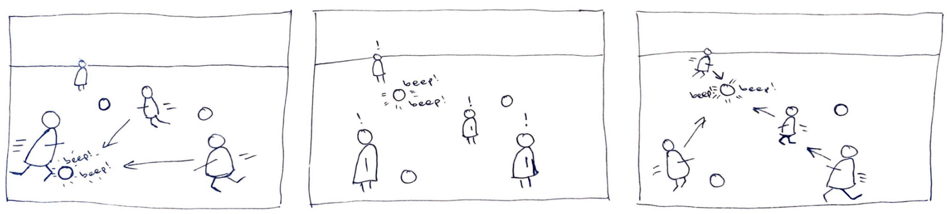

Figure E.3: Concept C: Interconnected balls.

E.1.4 Concept D: Vibrating ball

Incorporating haptic feedback in the ball was imagined as a way to improve inclusion and the user experience for a person with blindness. For example, the ball could start vibrating as the user comes close to the target, such as the basketball hoop if playing basketball, and thereby making the user aware of the closeness and the opportunity to score (see Figure E.4).

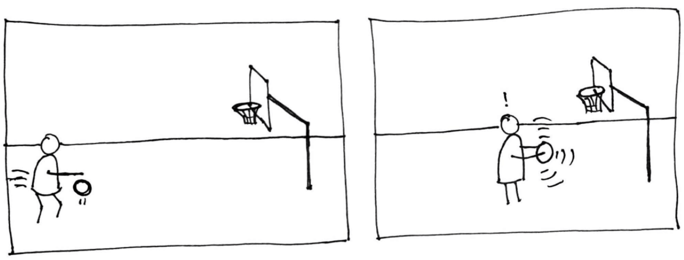

Figure E.4: Concept D: Vibrating ball. As the user approaches the target, the ball starts vibrating to communicate that the target is close.

E.1.5 Concept E: Connected wearable

Equipping the user with a wearable such as a bracelet, a smartwatch or a belt mounted device, that is wirelessly connected to the ball, could allow implementation of many interesting functions.

For example, the wearable could be made to vibrate whenever the ball is in the hands of a co-player, giving valuable information to the wearer about what is happening in the game (see Figure E.5).

If the wearable would be connected with more artifacts than the ball, or with key points in the environment, it could communicate valuable information about these as well. A wearable could for example make a sound whenever its wearer crosses the center line, as a feedback about the wearer's location on the playfield.

The wearable could also be used as a remote control, by the help of which the ball could be located (see Figure E.6). It could also be valuable for the user to have remote control functionality for changing the ball's volume or other settings, or as an additional interaction modality in some kind of game.

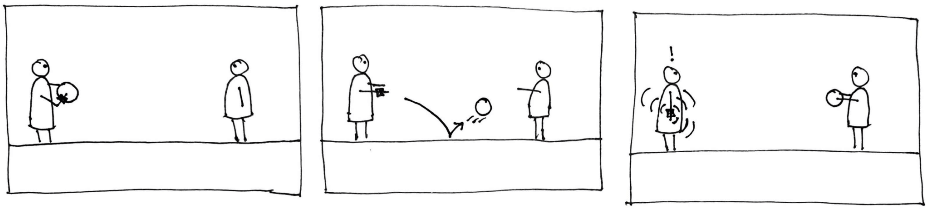

Figure E.5: Concept E: Connected bracelet. The bracelet vibrates when the ball is caught by the co-player.

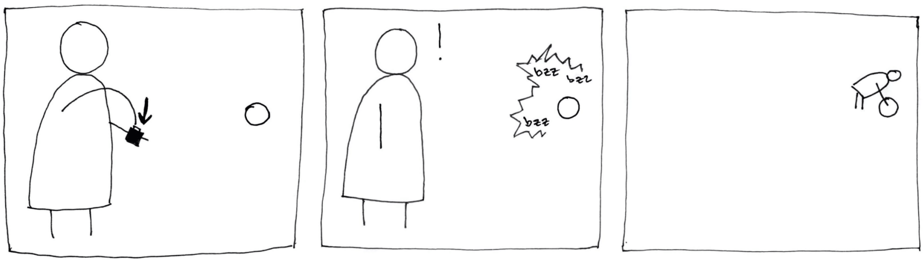

Figure E.6: Concept: Connected bracelet. When a button on the bracelet is pressed, the ball makes a sound so it can be found.

E.2 Evaluation of discarded concepts

E.2.1 Concept A (Ball velocity reflected in its sound)

Quite early in the process, the I-Ball project was encountered. In that project, the same core concept was developed — using an accelerometer to reflect the velocity in the ball's sound. When realizing that this idea had already been investigated quite thoroughly, this line of research was abandoned in favor of exploring new directions.

E.2.2 Concept B (Noise cancelling and filtering earphones)

This concept is primarily useful in a school setting such as physical education or recess play, or in other particularly noisy environments. It could be great for Alex and Leslie (see Appendix D), and maybe especially for Alex. Being more negatively affected by the loud racket of the peers, getting the relief of filtering out that noise in favor of the sound of the ball could be valuable for Alex.

E.2.3 Concept C (Interconnected balls)

Leslie, who is familiar with ball games and has a higher threshold for noise and stress, would probably enjoy this kind of game, at least more than Alex. The concept provides an opportunity for Leslie to have an advantage in ball games, having a more developed ability of sound localization than many sighted peers.

This is only a vague sketch of a vague idea. The concept raises many doubts, and would require much more careful consideration of the game design than what was proposed here to fulfill its purpose. But it was considered interesting and novel, and could be valuable for future development.

E.2.4 Concept D (Vibrating ball)

The main concern with concept D was that it only seemed to have potential for a *smaller* improvement of the inclusion aspect of ball games. As the user would probably anyway have a need for an audible beacon attached to the target as a directional guide (a common way of adapting ball games for people with blindness), the beacon would in way suffice on its own to inform about the distance to the target. The sound of a beacon would, indeed, almost certainly communicate the location more precisely compared to the vibrations of the ball. But the idea with the vibrating ball was more about making the experience of being close to the target *more intense*, *more immersive* and *more exciting* by engaging more senses in the experience.

As with concept C, Leslie would most likely be the one benefiting the most from this concept. While Alex and Leslie might both enjoy the added clarity in information about closeness to target, in some situations Alex could be better off without this functionality. In a ball game with a bigger group, the stress level would already be high for Alex, and more sensory impressions would probably only make things worse. The (sighted) group would definitely verbalize that Alex is close to the target anyways, so that information would come through clearly enough.

E.2.5 Concept E (Connected wearable)

A wearable could provide many promising opportunities for a ball game system, and is certainly an interesting future research direction. But introducing an additional aid, especially if it is visible and maybe audible to the people around, was perceived as less favorable than having a system that is contained within the ball (which was possible with the selected concept). It is slightly inconvenient to have to equip oneself with a wearable prior to engaging in ball games, and the wearable could possibly amplify the self-image, and the others' image, of *person with disability*. However, the wearable could be hidden, or in the form of an already more socially accepted wearable such as a smartwatch, and thus invalidating the arguments just mentioned. Discarding this concept was more a matter of having found an even more promising concept, and not having enough time to develop both concepts.