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Smart hockey stick

To improve engagement and fun for para hockey players

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Abstract

This bachelor thesis presents the development and evaluation of a smart hockey stick designed to enhance engagement and fun for para hockey players. The study employed a user centered design approach involving the coach of the para hockey team throughout this project. The objectives of the user study were to assess the impact of the smart stick on engagement, fun, disengagement, and discomfort, as well as to identify potential improvements and future directions for the device. The user study involved participants using both the smart hockey stick and their regular stick during three training exercises. Behavioral observations were recorded, a smileyometer questionnaire was utilized to measure participants' perceived fun and ease of use and an interview has been held with the coach.

The results indicated a significant increase in fun when using the smart stick compared to the regular stick. Engagement and disengagement scores showed a trend towards improvement with the smart stick, although the differences were not statistically significant. Discomfort scores increased when using the smart stick, aligning with the hypothesis that adjusting to the new technology could cause initial discomfort.

The study findings and feedback from the coach suggested that the smart hockey stick has the potential to empower individuals of all abilities and enhance their enjoyment and participation in sports. However, further research, including long-term studies and wider-scale testing with diverse user groups, is necessary to validate and expand upon these findings.

Acknowledgement

I would like to express my sincere gratitude to Marjolein Purmer, the coach of para hockey team Hengelo, for her invaluable time and insights throughout this project. Her expertise was instrumental in shaping the development of the smart hockey stick. I would also like to extend my heartfelt appreciation to the para hockey players for their enthusiasm and active participation. Their feedback and joyous engagement not only enhanced their experience but also fueled my own passion and motivation throughout this project.

I am deeply grateful to Champika Epa Ranasinghe for her unwavering support, invaluable advice, and continuous guidance, keeping me focused and reminding me of the essential aspects of project management beyond my areas of expertise. I would also like to acknowledge Dees Postma for his critical observations, thought-provoking questions, and the given guidance during module 6, which laid the foundation for this project.

Special thanks go to the members of JUMA, the collaborative group involved in creating the initial prototype. Their contributions, support, and encouragement played a significant role in the progress and success of this project.

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Chapter 1 - Introduction

People with Intellectual impairments participate around 20% less in sports than their typically developing peers (Chien et al., 2017), even though partaking in physical activity has shown to improve both physical and mental wellbeing. Moreover, empirical evidence substantiates that engagement in sports enhances social skills and cognitive function, two attributes of particular significance for individuals with Intellectual Impairments (Yang et al., 2022).

Para hockey or in Dutch “G – hockey” is a form of field hockey for player who are intellectually impaired.

The user group are eleven para hockey players of “HC Twente G-hockey team”. These players have difficulty with keeping their attention to the games, them having difficulty understanding the assignment given by the coach, struggling with certain techniques, and finding it difficult to interact with other players on the field resulting in a lower engagement and decreased fun. Field observations and interviews with the coach also revealed that. The coach struggles with instructing the para hockey players and finds that she often must visually and physically show techniques for these players to understand them. The goal of this thesis is to explore a creative technological solution that can be used as a tool to improve the engagement and fun of para hockey players and that assists the coach with training them.

During a second-year bachelor project a smart hockey stick was created to combat these problems (see Fig 1). This stick consists of an accelerometer sensor to determine when the ball is hit and an LED strip to indicate different states associated with the amount of hits. This initial version of the stick showed a very good potential and was well received by the coach. However, it had limitations such as big size, low robustness, and limited functionalities. In addition, the smart hockey stick was not tested with actual para hockey players.

Fig 1: Initial prototype.

The main goals of this research are to develop an improved version of the smart hockey stick for use during training sessions and to evaluate its effectiveness with the target users. The research aims to address the following research questions:

- RQ 1. How can we improve the first version of the smart hockey stick to improve engagement and fun for para hockey players?
- RQ 2. How can the coach be supported in training para hockey players?

The paper is structured into chapters, starting with background research exploring related studies. The methods and techniques chapter outlines the used methods and techniques used throughout the research. Followed by an ideation chapter with requirements for the different stakeholders. The next chapter is the design chapter which provides an alternative prototype and insights in the used sensor. The specification chapter highlights the final prototype that has been used in the user study. How this user study has been conducted and its findings can be found in the evaluation and results chapter. The paper concludes with a conclusion and discussion chapter.

Chapter 2 - Background Research

This chapter discusses intellectual impairment means. It explores the challenges faced by individuals with intellectual impairments in cognitive functions and their lower participation in sports. The potential benefits of sports for people with intellectual impairments are also discussed, along with the use of technology in sports and the need for sports technology tailored to individuals with cognitive challenges.

Understanding intellectual impairment

Intellectual impairment has had a variety of names and multiple definitions in the past, still often being termed intellectual disability. In earlier literature, individuals with intellectual impairments were often referred to using various labels such as mental retardation, mental deficiency, feebleminded, idiot, imbecile, and moron (Luckasson, 2016). Within this research however, intellectual impairment is used instead of intellectual disability to emphasize the potential and capabilities of individuals with intellectual impairments, rather than focusing solely on their disability and limitations. This shift in terminology reflects a broader societal shift towards adopting more inclusive and person-centered language that promotes empowerment and emphasizes the strengths and abilities of individuals with intellectual impairments.

Trying to find a clear definition of intellectual impairment is much more difficult nowadays than it was in the past. In the past, identifying if a person had intellectual impairments was solely based on IQ (Luckasson, 2016; Pyeritz & Korf, 2013). Nowadays there is more variation on how to define intellectual impairment. "*Individuals with intellectual disabilities have an IQ lower than 70 and have difficulties with day-to-day practical and social skills*" (Bérubé & Kramer, 2014, p.371). Later in this article the idea is introduced that epigenetic regulation is an important mechanism in defining intellectual impairments. Luckasson (2016) also states that biomedical factors, such as chromosomal disorders can serve as a fourth domain for identifying Intellectual disabilities. Even though this is true for people with severe to profound intellectual impairments, three quarters of people with intellectual impairments have a mild form where the underlying specific ethology is less likely to be identified (Patel et al., 2020). Multiple sources (des Portes, 2020; Luckasson, 2016; Pyeritz & Korf, 2013) look at the American Association on Intellectual and Developmental Disability (AAIDD) for a definition. It is apparent that the definition given by the AAIDD also changes over time based on how it is described in Pyeritz and Korf (2013) in comparison with how it is stated at the time of writing (April 2023). The definition on the website as of April 2023 is stated as:
"*Intellectual disability is a condition characterized by significant limitations in both intellectual functioning and adaptive behavior that originates before the age of 22.*" (American Association on Intellectual and Developmental Disabilities, 2023)

Challenges

People with intellectual impairments face a wide range of challenges depending on the severity of their intellectual impairments. Most research regarding intellectual impairments at some point stresses the highly individualistic characteristics of intellectual impairments. Because of the individual needs and capabilities, intervention technology must be created with the option to be personalized and fitted to any specific person (Lopresti et al., 2008). One of the common struggles for people with intellectual impairments, is regarding processing and integrating sensory information like spatial processing, auditory processing, motor processing, language processing and understanding of social cues (Kielhofner, 1997, as cited in Lopresti et al., 2008).

This knowledge combined with the definition of intellectual impairments reveals that individuals struggle with many of the cognitive functions. Some examples of cognitive tasks that people with intellectual impairments commonly struggle with and are important within this project are: memory difficulties (Hall et al., 2011). This can include short-term memory deficits, difficulty with remembering new information, or difficulty with retaining and recalling information over time. People with cognitive disabilities may have challenges with attention and concentration (McDermott et al., 2022), which can affect their ability to focus on tasks and not get distracted. Language and communication (Patel et al., 2020). This can include difficulty with expressive language (verbal or written), receptive language (understanding spoken or written language), and pragmatic language (social use of language). Processing speed refers to the ability to process information quickly and efficiently. It can also impact their ability to respond to tasks in a timely manner.

Sports' Impact on Quality of Life in People with Intellectual Impairments

Sport has a wide range of health benefits. Some specifically regarding people with intellectual impairments. Aitchison et al. (2022) suggests that the physical and mental health benefits are the same regardless of which group they belong to, children and adolescents, adults, or elite athletes. However most notable is how it is argued that sport challenges the stereotypes. “*Sport allowed individuals to challenge the stereotypical restraints and expectations placed on those with a disability, whilst also in some cases breaking one's self-imposed restrictions*”(Aitchison et al., 2022). Diaz et al. (2019) acknowledges that sport has the tendency to improve one's own body image and argues that sport also improves peer relations, self-efficacy, and self-competence. Varahra et al. (2022) adds community integration and psychological well-being to this list based on evidence from 16 studies. Physical activity appears to have a positive effect on mental health including psychological and cognitive function (Aitchison et al., 2022; Van Schrojenstein Lantman-De Valk, 2005; Yang et al., 2022). In addition, McDermott et al. (2022) reports that physical activity has positive effects on body composition, strength, fitness, and sleep patterns. These findings collectively emphasize the potential benefits of physical activity and sports in enhancing the health and well-being of all individuals, and especially those with intellectual impairments.

People with intellectual impairment partake around 20% less in sports than their typically developing peers (Chien et al., 2017). This has its reasons. Barriers to sports participation include physical abilities such as medical conditions, physical limitations, and communication difficulties(McDermott et al., 2022). Students also had difficulty with developing gross motor skills resulting in being less likely to engage in sports. Other barriers include high initial costs to participate in adaptive sport, lack of access often due to limited transportation options, fatigue, lack of motivation and lack of knowledge of opportunities(Diaz et al., 2019). With motivation being especially important because this is one of the most cited facilitators to participate in sports (Aitchison et al., 2022; Diaz et al., 2019). These personal challenges for the individual are often not considered in existing physical activity interventions (McDermott et al., 2022).

State of the art

The use of technology in sports has significantly increased over the past few years. Recently, in the FIFA World Cup 2022, the first sensor technology integrated into a soccer ball by KINEXON was introduced to the international scene. This ball can track its location on the centimeter exact, 100 times per second (Kinexon, 2023). There are many smart implementations currently in use like the camera tracking systems from Second Spectrum, (2023) and Pixellot, (2023). These are developments of smart sports equipment that aim to improve fairness and enhance the viewer's experience of the game. Assistive technology in sport is also growing enabling more and more players with an impairment to participate in sports they normally could not play. A few examples are wheelchairs for racing, basketball or rugby, monoski or sit ski but also prosthetics for running and even rock climbing. Within this project however the aim is to design sports technology to be used to aid sport instead of enable sport, it is to help individuals with the cognitive challenges they encounter. In doing research no other product could be found specifically targeting hockey in combination with intellectual disabilities.

Related Technologies

The technology proposed by in this research belongs to the domain of smart technologies. These technologies are characterized by their ability to collect and analyze data which they can use to respond or adapt to changing conditions. These smart technologies are playing a significant role in numerous fields, with this research hopefully soon also the field of para hockey. Smart technologies work by utilizing sensors, used for gathering data about their surroundings. This data is then processed and analyzed to derive meaningful insights and trigger appropriate responses. Actuators, on the other hand, enable smart technologies to perform physical actions based on the processed information, thus influencing their environment.

Smart technology and data physicalizations are interconnected through the process of transforming digital data into tangible or physical representations. Smart technologies, with their sensing and actuation capabilities, can capture and analyze data from various sources. This data can then be transformed into physical forms or representations, known as data physicalizations, to convey information, insights, or patterns in a more tangible and accessible manner.

The smart hockey stick is a form of such data physicalization. An overall strength of the smart hockey stick is the use of visual feedback, vision being the dominant sense followed by hearing and touch. Allows for multisensory feedback instead of only using audio for feedback as predominantly used currently. The stick physicalizes the number of hits and the angle at which the stick is held using the number of LEDs and different LED colors. However, utilizing light in physicalizations is not uncommon. An example of this is the EmoClock by Peeters and Ranasinghe (2023) Also a Creative Technology project perfectly showcasing how users can interact with real time data which is presented to the user in a clear and understandable way. The smart stick strives for this same goal.

Ranasinghe and Degbelo (2023) talk about several variable types with each a list of options. The types are: Physical variables, visual variables, haptic variables, sonic variables, olfactory variables, gustatory variables, and dynamic variables which are all at the designer’s disposal when creating a data physicalization. The smart stick utilizes multiple of these options. Many of the visual and dynamic variables are used. Not using the other options has been an intentional choice to limit overstimulating the users as indicated by the parents; both sonic and olfactory variables can easily do this as indicated by their parents.

Chapter 3 - Methods and Techniques

The main methodological approach used throughout this project is the user centered design process. This was essential due to the very specific needs of this target group. The coach has been involved throughout this iterative process to guide and direct the product for both her needs and the needs of the para hockey player.

In this chapter all the different methods and techniques used will be explained (see Fig 2). First the findings of the user studies that were conducted before this thesis will be summarized and their results and findings will be reevaluated.

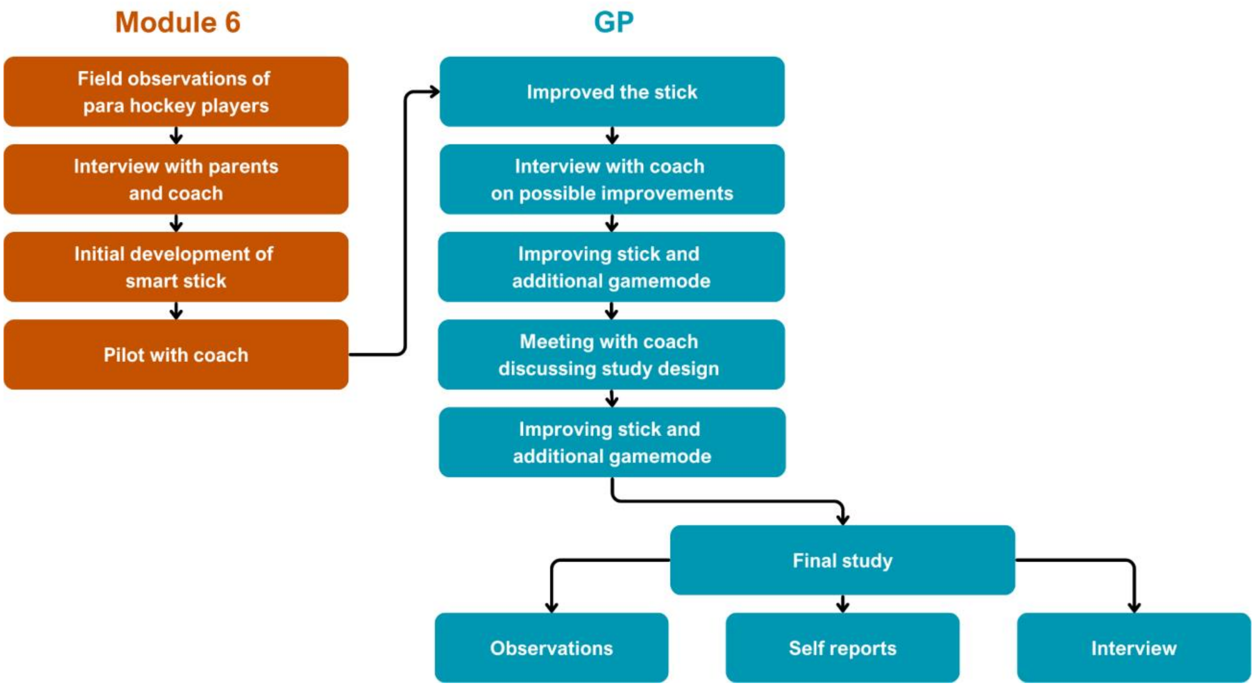

Fig 2: Methodology throughout module 6 and the graduation project.

Interviews and field observations

These initial field observations functioned as a baseline and control study. During these field observations and the interviews conducted with para hockey players, their guardians and coach, it was observed that the para hockey players demonstrated a close social connection with each other on the field, deriving joy from their social interactions. This was confirmed by both guardians and coach in interviews. However, despite their close bond, the para hockey players sometimes faced challenges expressing their feelings and thoughts. This lack of effective communication occasionally resulted in friction between players, which expressed itself in diminished strategic communication during hockey matches and subsequently impacting team performance.

Furthermore, during a practice match, it was observed that some players were inattentive and not actively participating, which was not due to lack of motivation or skill, but rather related to their attention levels. The coach had to verbally instruct them to start participating again, and this cycle of instruction and loss of awareness repeated for different players throughout the practice match. Additionally, it was noted that the para hockey players had varying skill levels due to differences in severity of their intellectual impairments and experience in hockey. However, all of them were placed in the same team as there were limited participants in proximity to the hockey club. The disparity in skill levels was evident during training, necessitating a training approach that is broad and applicable to a wide range of skill levels.

This initial research addressed the problem of keeping the players engaged. The highly individualized needs of each player due to varying skill levels and severity of intellectual impairments further stressed the need for technology to be tailored to each user.

Pilot with coach.

Due to covid it was not possible to do user testing with the para hockey players, therefore the product is tested with the coach. While using the prototype the coach answered questions of her experience indicating the prototype was intuitive to use, will in her opinion not be too distraction to the players, it will hinder the player in performing regular hockey tasks due to the large volume the prototype occupies, she indicated that for the Para hockey players maintaining focus on the displayed colors was definitely much simpler than counting, she was unsure if the prototype as is was fit for all players in all skill levels because there is such a big difference in muscle power and hockey skill.

Concerns were raised in both miniaturizing and attaching electronics to the stick without hindering the user in performing regular hockey exercises. And again, the individualized needs of the players were pointed out and that there is a big difference in muscle strength that should be considered when determining when a ball is hit or not.

Interview with coach

At the onset of this project an online meeting with the coach was arranged with the goal of revealing her insights and possible challenges on the previous prototype and to show her the possible game modes that have been thought of so far. The interview with the coach began with proposing an initial design of the user interface including the placement of a usb-port, buttons, and a power switch. After which different functionalities and game modes were discussed. The coach was given the opportunity to propose her own ideas of possible game modes, this was done by using a simplified version of the draw-write-tell method where the coach was provided with an empty version of the format used as can be seen in Fig 4. The coach could now explain what additional important game modes could be. She explained that a way of guiding instructions of a backhand block would be a valuable addition to the existing game modes since this is a very complicated technique which the players have difficulty with understanding. After this the conversation continued regarding her specific requirements for the prototype. Main findings were that the stick should not be in the way of playing, the stick should last the whole practice being one hour, and she wanted to be the only person that is able to change the game mode. Curiosity was raised about a possible app to change game modes of all the sticks synchronically and wirelessly. This is interesting to consider for future research but outside the scope of this project and will be further discussed in Chapter 8 Limitations and future work.

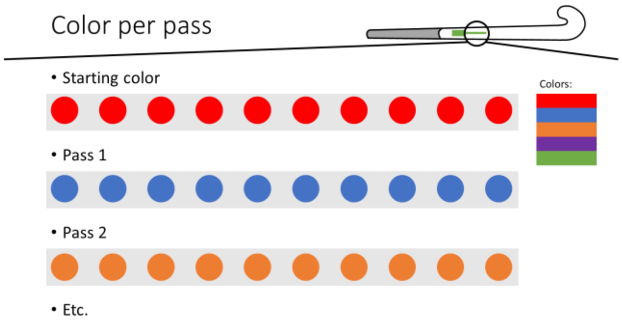

Fig 4: Visualization of game mode.

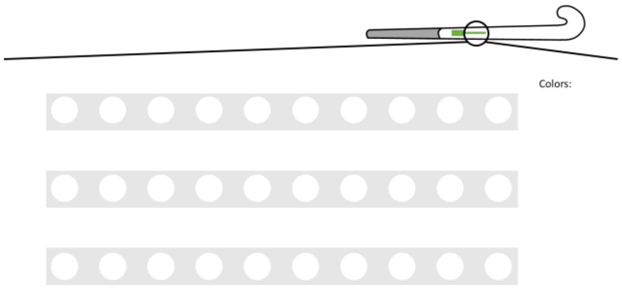

Fig 3: Empty sheet for visualizing game mode

Discussing study design

During the development of the study design the insights of the coach were asked. In collaboration it was decided on which type of study would be conducted and what the best way of executing user testing was. During this last meeting before evaluating the product also behavioral cues were identified by the coach. More on this final study design can be found in Chapter 6 - Evaluation and results.

Chapter 4 – Ideation

In this chapter, the ideation process for the development of the smart hockey stick will be explained. User characteristics are defined after which the reasoning for a to the given problems will be explained. A list of requirements will be made and organized. After which possible game modes are shown.

User characteristics

The para hockey players

The target user group of this research are the g-hockey team in Hengelo, the para hockey players from this team have an age ranging from 14 to 45 years old. All these players are intellectually impaired, which impact their cognitive abilities and everyday functioning.

The para hockey players have difficulties with memory, attention, concentration, and language. Memory difficulties may include short-term memory deficits, difficulty with retaining and recalling information. Difficulty with memory results in the players forgetting what exercise they were performing and how certain techniques must be performed. Attention and concentration issues can affect their ability to focus on tasks and avoid distractions. During trainings players are easily distracted. This can be seen in the form of looking into the distance but also going to the sideline and talk with their parents. Language and communication impairments are usually seen in difficulty processing verbal cues and how much better visual and physical feedback works.

The para hockey coach

During a training often three coaches are present. These coaches have a crucial role in supporting and guiding the para hockey players. A coach for the para hockey team must adapt trainings to accommodate the cognitive abilities of the players. This consists of not only using verbal guidance they should also show players techniques. In some cases, even physically guide them to let them feel how certain techniques are performed. However, the coach's role extends beyond technical aspects of the game.
The coach must remind the players of what exercise they are doing, and where players are in certain exercises. Due to low attention of the players the coach often must bring the players attention back to the game, usually multiple times throughout each exercise. The coach also must motivate the players and has the goal to always create a fun and engaging atmosphere during each training.

Solution design

In the pursuit of a comprehensive solution benefiting both the players and the coach, numerous considerations have been examined. These considerations encompass a diverse range of sensory modalities, including sight, sound, smell, taste, and touch.

Initially, the concept involved implementing a vest equipped with LEDs to facilitate communication among teammates, indicating readiness to receive the ball. Concurrently, the exploration of additional electronic components on the stick aimed to gather data on players' ball-hitting techniques. To ensure a seamless integration without the need for wires connecting the stick to a possible vest, the decision was made to incorporate LEDs onto the stick itself and thus to create only a so-called smart hockey stick.

The use of colors as the communication medium stemmed from the coach's input, advocating its potential positive impact. Moreover, a critical factor was the players' aversion to physical touch, leading to the presumption that haptic feedback was not a viable option. As for the senses of smell and taste, their electronic stimulation proved to be particularly challenging, especially within the context of a dynamic hockey training session. Similarly, sound was deliberately omitted to prevent overstimulating the players, as the coach's vocal guidance during training sessions was already prominent. Introducing additional auditory cues from the smart hockey stick was anticipated to cause more confusion and overstimulation rather than provide benefits.

Requirements

After defining the users' characteristics and reviewing the findings of conducted user research in the methods and techniques chapter, requirements can be listed for the two types of users, the players, and the coach. After which these requirements can be ranked on prioritized using the MoSCoW method.

Player's requirements:

1. The implementations on the stick should not obstruct the user's gameplay.
2. The user interface should be easy to understand.
3. The different game modes should feel intuitive, and the users know what is asked of them.
4. The smart hockey stick should be safe to use and not pose any risk of harm to the para hockey players or others on the field.
5. It should be adaptive to the user's relative strength.

Coach requirements:

6. The electronics should be able to be attached to everyone's own stick.
7. The electronics should not cause damage to the stick.
8. The buttons interface is only accessible to the coach, not to the players.
9. At all times it should be clear in what game mode the stick is in.
10. The sticks should be controlled in synchronization.
11. It should help visualize techniques.

Other requirements:

12. The technology on the stick should stay within the dimensions of 40x100x10mm.
13. The additions made to a regular stick should weigh less than 20g.
14. The use of the stick should increase engagement while not causing more distraction.
15. The LEDs should emit enough light for easy identification of intent, without posing any harm to the eyes.
16. The stick can actively be used for at least 1h without the need of being recharged.
17. The stick is automatically calibrated to each specific user.
18. All LEDs are individually addressable to show clear visualizations of tasks to the user.
19. The stick should not break within normal use, being a para hockey training session.
20. The stick should track data (e.g., training duration, number of strikes, maximum strike speed) for post training analysis.

The MoSCoW method (Agile Business Consortium Limited, 2014) devices requirements in four categories. All 18. mentioned requirements can be placed in one of these four categories.
Requirements 4, 7, 8, 12, 15, 18 and19 are categorized as **must have**, these requirements are essential requirements for functioning and safety of the product. It cannot be used when these requirements are not met.
Requirements 1, 2, 3, 6, 11, 13, 14 and 16 are categorized as **should have**, these requirements are important requirements however without meeting these requirements the solution is still viable.
Requirements 5, 9, 17 are categorized as **could have**, these requirements are desired but less important.
Requirements 10 and 20 are categorized as **will not have,** these requirements clarify what aspects will not be pursued and help manage expectations.

Each of the requirements were placed in each category as followed.

- Requirements 1, 2 and 3 are categorized as should have, because these are all important requirements regarding the ease of use of the product however are not essential and the product can still be usable and deployable without meeting these requirements.
- Requirement 4 was categorized as must have, because this is directly associated to the safety of the user.
- Requirements 5, 9 and 17 are all categorized as could have because, these are not important for the stick to function however are still nice additions to the stick.
- Requirement 6 was categorized as should have because, this allows for more and easier use within a training but does not affect the functioning of the product itself.
- Requirement 7 is categorized as must have because, this is regarding damaging the players property which cannot be allowed to happen and is therefore essential.
- Requirement 8 is categorized as must have because, otherwise players would interact with this button themselves making the product unusable for the coach.
- Requirements 10 and 20 are categorized as will not have because, even though these are interesting additions to the smart hockey stick they will be very time consuming while not being essential for creating and testing the smart hockey stick.
- Requirement 11 is categorized as should have because during the testing of the initial prototype this feature was discussed and classified as an important feature to add.

- Requirements 13 and 14 are categorized as should have because, both these requirements are desirable but not essential to the functioning of the stick.
- Requirements 12 and 15 are categorized as must have because, both size and safety are essential for the stick to be used. If these requirements are not met the stick cannot be tested.
- Requirement 16 is categorized as should have, because this being able to use the stick for a full training is not an absolute crucial part of the smart stick but would still be extremely inconvenient if this requirement is not met.
- Requirement 17 is categorized as could have because, this feature has work around like manually calibrating however it is a nice feature to have.
- Requirements 18 and 19 are categorized as must have because, the addressable LEDs give this stick the functionalities that it has and without this it could not be used in the same or even a similar way. These LEDs are crucial for its functioning. And when the stick cannot be used within a normal training then the product is unfit to test, making this a crucial requirement.

Possible game modes

Name: One color one pass (See Fig 5)
Description: When selecting this game mode, the stick will start off at the first color, when the player passes the ball the stick changes to the second color. When the ball is passed again the entire stick changes to the third color. When the player passes the ball when the stick is the fifth color the stick then turns into the first color again. This process can repeat indefinitely.
This game mode can be used in a variety of games, like pass to each other till everyone's stick is the same color. Or pass till the stick is the same color again.
This game mode makes abstract concepts like numbers/counting easier to comprehend by associating an amount to a number support the players memory. The LEDs also grab the players attention towards there stick keeping them engaged throughout the exercise.
Focus: Memory and attention.

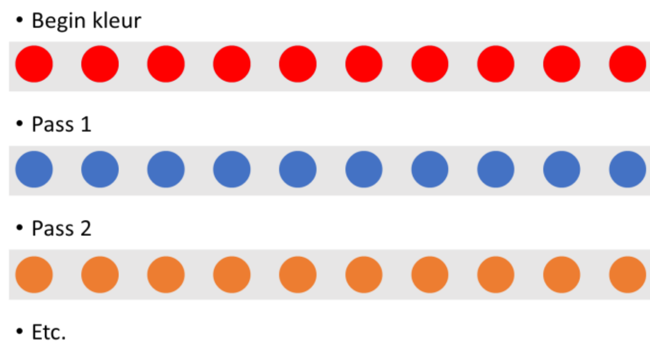

Fig 5: One color one pass.

Name: Count per pass (See Fig 6)
Description: initially the entire stick is black. When the player passes LED 1/10 turns the first color, second pass LED 1/10 and 2/10 turn the first color till 10/10 on the 10th pass. On the eleventh pass LED 1/10 Turn the second color while all other LEDs stay the first color. After five full color cycles the 51st pass turns LED 1/10 again in the first color.
This game mode can be used in a variety of games, like ten passes to the other side. Or when players are

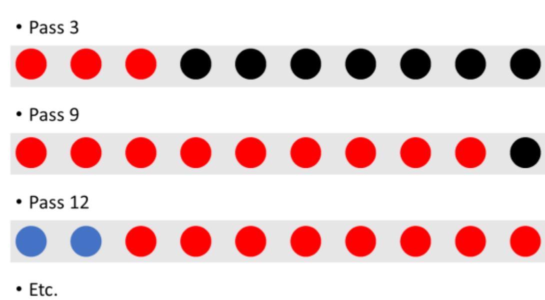

Fig 6: Count per pass.

practicing on their own this game mode can help them keep track of the number of passes, so the players do not have to memorize themselves. By making data (like to number of passes) visible can also motivate the players as they have clear goals e.g., fill the stick with one color.
Focus: Memory, motivation.

Name: Random color (See Fig 7)
Description: Every time the user hits the ball all LEDS turn briefly off after which they turn in one of three colors. All LEDs are the same color.
This game mode can be used in a variety of games like an example is: each color represents a passing technique or a passing direction that the player must follow. This game made can bring a competitive element to otherwise less competitive exercises. And players must directly respond to their stick causing them to have more attention towards the exercise.
Focus: Motivation and attention.

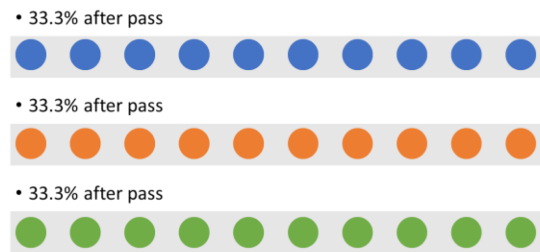

Fig 7: Random color with 33.3% a certain color each hit.

Name: Tilt angle (See Fig 8)
Description: When the stick is fully upright all LEDs are color one, when the stick is lowered into a horizontal position all LEDs turn off but one red LED indicating if the angle is too small or too big. If the stick is flat on the ground with the rounded side facing up the angle is 0 degree, and the red LED is all the way at the front of the stick. If the angle between the stick and the ground is 120 degrees, the red LED is all the way at the back. If the angle is just right (between 70 and 45 degrees) the entire stick lights up green.
This game mode is used to learn players how to block a hockey ball. This game mode functions as a visual guidance to verbal instructions given by the coach. The LEDs give continuous instant feedback on the angle with the ground of the hockey stick that keeps the player engaged.
Focus: Technique and attention.

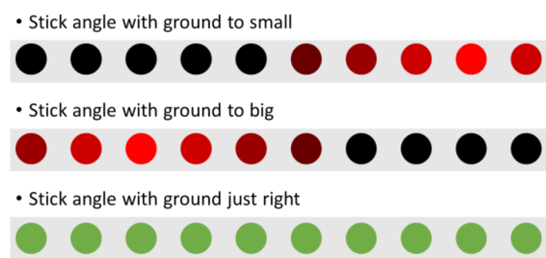

Fig 8: Tilt angle.

Chapter 5 - Specification and realization

the specification and realization chapter will first dive into some specifications of the most important sensor that has been used in this project and how this sensor can be used to determine a hit after which some of working of the software is explained. This chapter finally shows the realization of two different prototypes and the rationale behind the choses that have been made.

MPU6050:

Throughout different prototypes mentioned in this report, but also previous iterations of the smart hockey stick rely on one single MPU6050 that consists of a three-axis gyroscope, three-axis accelerometer, and a Digital Motion Processor (DMP) for its data. Additionally, the MPU6050 has an integrated temperature sensor but these functionalities will not be used in this project (LastMinuteEngineers, 2023).

The accelerometer measures acceleration in m/s^2 . It works by utilizing newton's second law ($F = ma$), to do this, it utilizes MEMS (Micro-Electro-Mechanical System) this means that inside the chip there are moving micro-machined parts. Inside the MPU6050 there is a structure situated on a silicon wafer Fig 9. The structure is supported by polysilicon springs, enabling it to bend or deflect when subjected to acceleration along the X, Y, and/or Z axes.

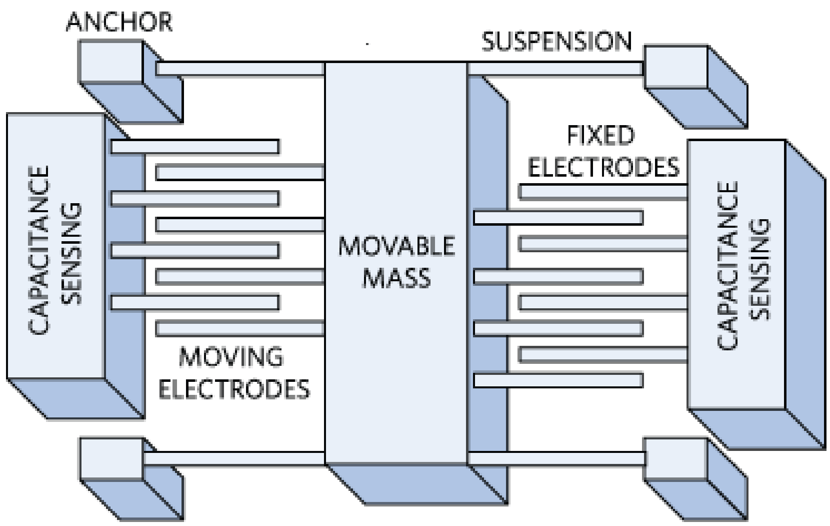

Fig 9: mechanical model of an actual accelerometer (Dadafshar, 2014)***.***

When deflection occurs, the capacitance between fixed plates and plates connected to the suspended structure alters. This change in capacitance is directly proportional to the acceleration experienced along the specific axis. The sensor interprets this change in capacitance and converts it into an analog output voltage which will be converted back to acceleration in m/s^2 (LastMinuteEngineers, 2023).

In the different prototypes in this research the orientation of the MPU6050 has remained the same, the orientation can be seen in Fig 10.

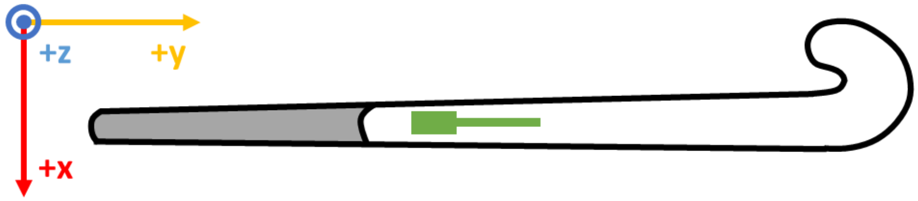

Fig 10: MPU6050 orientation on stick.

Apart from considering acceleration and angular velocity some other variables have been investigated that originate from one of these two initial variables.

Through the process of integrating acceleration (a) over time (t), velocity ($v = \int a\, dt$) can be obtained, and further integrating velocity yields displacement ($x = \int v\, dt$) of an object. Taking the derivative of acceleration with respect to time allows the calculation of "jerk," representing the rate of change of acceleration ($j = \frac{d}{dt} a$).

Determining a hit

To infer a strike using the data coming from the MPU6050 the acceleration data has been analyzed from a hockey player who performed the following techniques: static dribbling, dynamic dribbling, push, sweep, and strike. During these techniques a lo fi prototype of the smart hockey stick was used which consisted of only the microcontroller (Wemos LOLIN 32 lite) and the gyroscope and accelerometer (MPU6050).

Fig 11: Acceleration in X, Y and Z direction during field hockey strike.

The data revealed that during techniques used for passing (push, sweep and strike) there was a drop in the acceleration in the Y axis. The other axes also showed a peak or valley in this case. These other axes however also showed peaks or valleys during other techniques (e.g., dribbling and running) as can be seen in Fig 11 between 3 and 5.5 seconds. When further investigating this phenomenon, it became apparent that relying solely on the acceleration of the Y axis was also non-ideal due to certain movements unrelated to passing (e.g., pulling the ball towards the player) resulted in huge spikes in the Y axis.

Using the rate at which the velocity changes as measure for calculating the hits has been considered but did not prove to be reliable enough. It was eventually decided that a hit is detected when a peak of the total acceleration is detected, obtained by taking the root of the summed squire acceleration components. Together with a valley in acceleration in the y axis. In Fig 12 we see these peaks in total acceleration but a lack of valleys in y acceleration. In Fig 13 it is visible that peaks in total acceleration and valleys in y acceleration are both present when the stick is being hit at 1.1, 4.8 and 9.5 seconds.

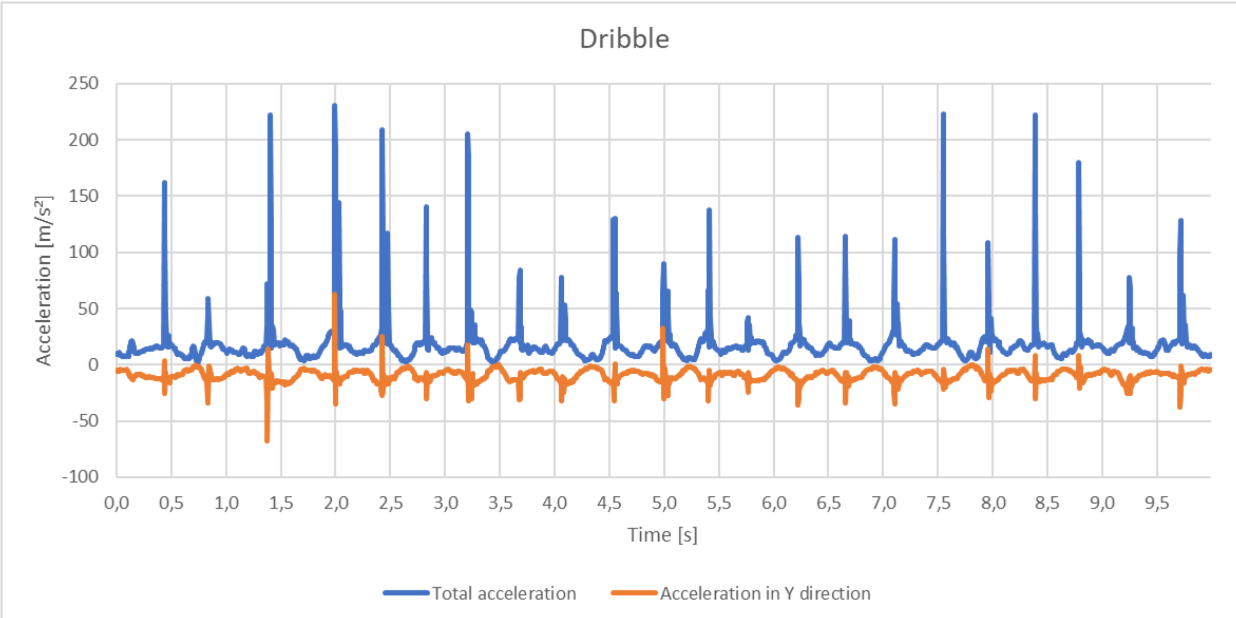

Fig 12: Total acceleration and acceleration in Y direction during field hockey dribble.

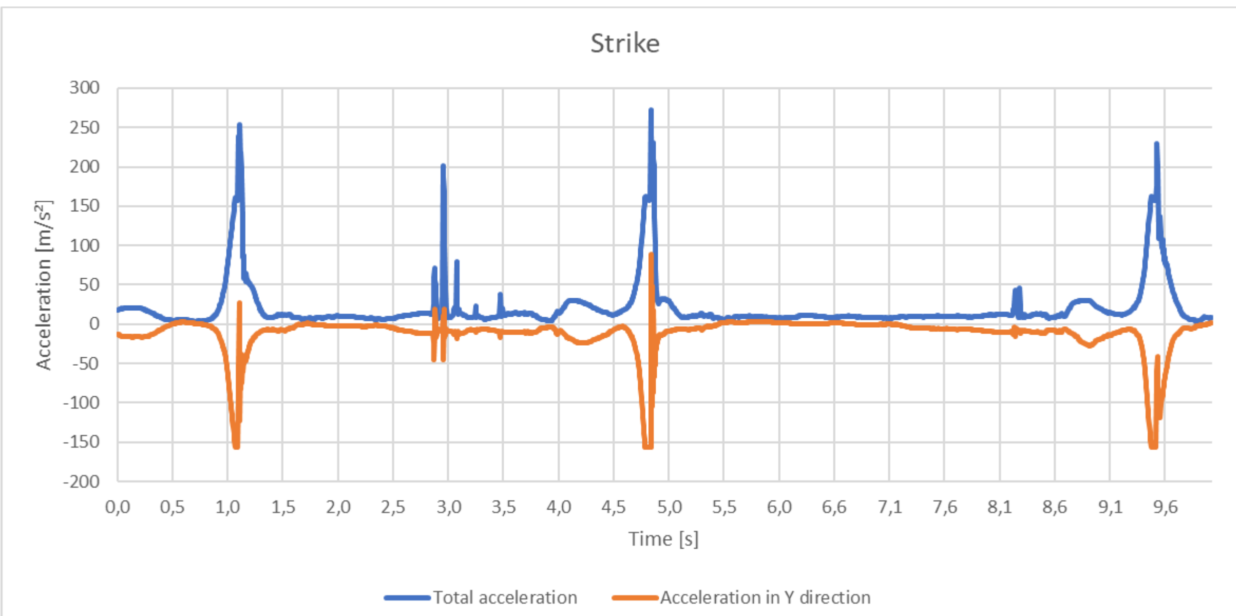

Fig 13: Total acceleration and acceleration in Y direction during field hockey strike.

A lower sampling frequency results in lower peaks and valleys in the signal. The sample frequency is also used for integrating, differentiating, and applying filters. Therefore, it is important to determine and set the sample frequency. Within this project the sample frequency has been set to 200Hz. Trial and error proved that this was still a reliable and achievable frequency while being a relatively high frequency to show a larger range in peak and valley heights.

After testing, detection of the minimum acceleration in the Y axis and detecting the maximum magnitude of the normal Force is usually around 15 measurements apart. With a 200Hz sampling frequency this is 75ms apart.

Stick functioning and software

The smart hockey stick uses five distinct game modes and a calibration state, outlined in the flowchart presented in Fig 14. The user can progress through these game modes using the press of a button. A detailed explanation of each game mode and the calibration state will follow in this chapter. Additionally, the term "array of colors" will refer to the following five colors: red, green, blue, yellow, and purple, in sequential order. The use of these colors has been deliberately selected due to their ability to offer distinct contrast from one another within the array.
The code that has been used on in this final prototype can be found in Appendix D: Code.

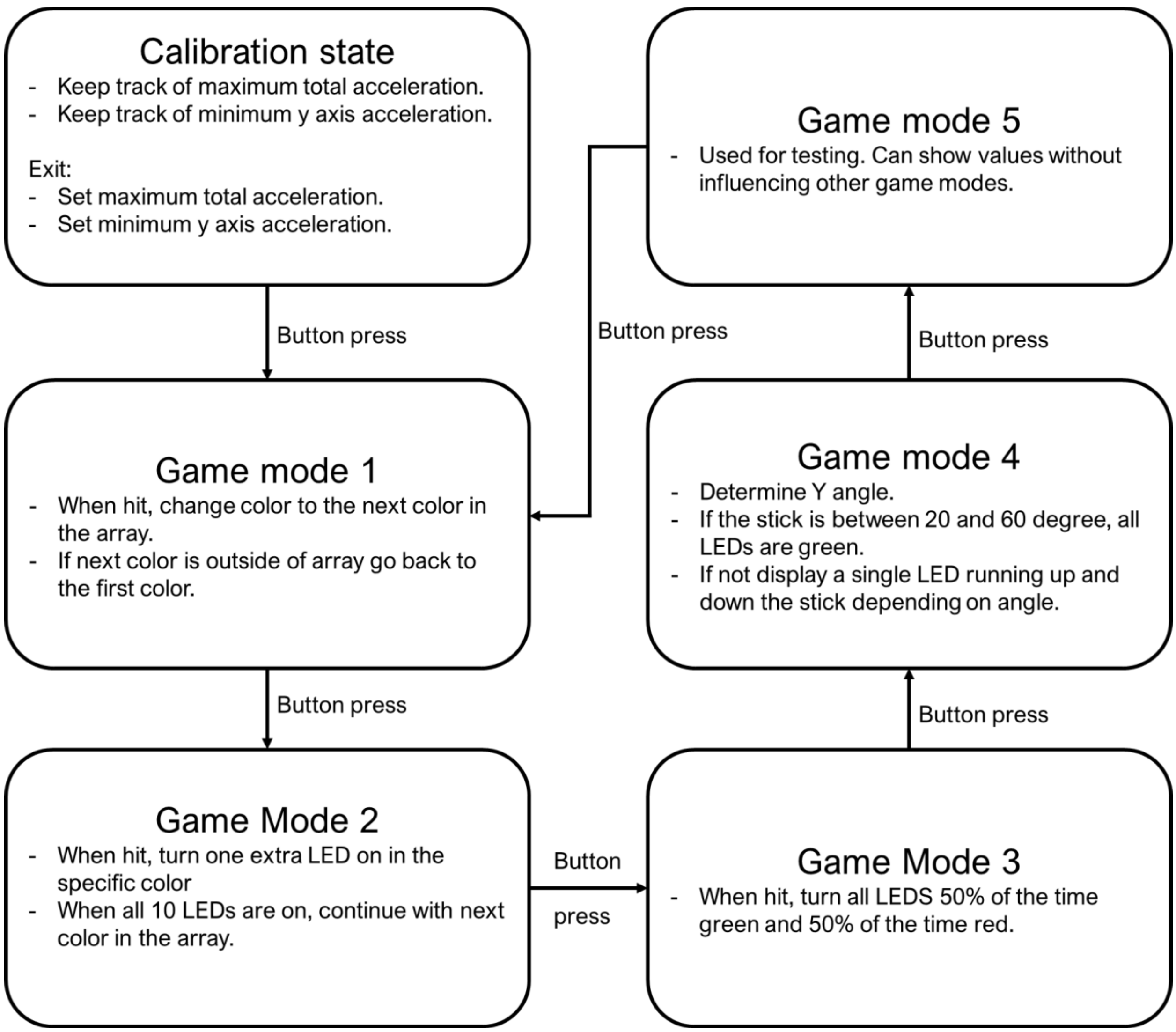

Fig 14: Flowchart of different game modes.

Calibration state

When the stick is turned on it automatically starts in the calibration state. In this state, the stick keeps track of two values: Maximum total acceleration obtained by taking the square root of the summed square accelerations.

$$Total\ acceleration\ = \sqrt{accelerationX^2 + AccelerationY^2 + accelerationZ^2}$$

and minimum acceleration in the y direction both utilizing the data given by the MPU6050. These two values serve as reference points for each player's strength and are used in subsequent game modes (one, two, and three) to detect when a hit is performed.

Hit detection by the smart hockey stick

During game modes one, two, and three, the smart hockey stick runs at a loop frequency of 200Hz thus receiving accelerometer data 200 times per second. To determine if a player has made a hit, two conditions need to be met. Firstly, if the current normal force exceeds 0.8 times the maximum normal force recorded during calibration, the first condition is satisfied. Secondly, if the current acceleration in the y direction falls below 0.8 times the minimum acceleration recorded during calibration, the second condition is met. If both conditions are simultaneously fulfilled within a time frame of 0.15 seconds (30 loops), the smart hockey stick registers the movement as a hit.

Following the successful registration of a hit, the smart hockey stick implements a brief period in which it does not register any hits for 0.5 second duration (100 loops). This intentional delay is designed to prevent the stick from identifying repeated hits stemming from the same movement, such as a push or sweep.

Switching between game modes

When the button is pressed, the game mode progresses by one. When game mode five is reached and the button is pressed it will be reset to game mode one. The calibration state is registered as game mode zero and will therefore not be entered after initializing. Each time the button is pressed the smart stick will also visualize in which game mode it is in by showing the corresponding number of LEDs in white at the top of the stick. These white LEDs turn off again after one second.

Game mode 1

In this game mode the stick checks if the user hits the ball. When this happens all LEDs on the stick progress one step in the array of colors. As an example, the stick is red (first color in the array) after the player hits the ball the entire stick changes to green (second color in the array) When the stick is purple, the fifth color of the array and is being hit it changes back to red, the first color of the array. This continues indefinitely. See fig 15.

Fig 15: Game mode 1, color per pass.

Game mode 2

During game mode two the stick shows an extra LED each hit. On the first hit the stick shows one single red LED. On the second hit it shows two red LEDs. After the stick is full of a single color the stick continues counting with the next color. In fig 23 on the left we can see the stick after fifteen hits and in Fig 16 on the right after 16 hits.

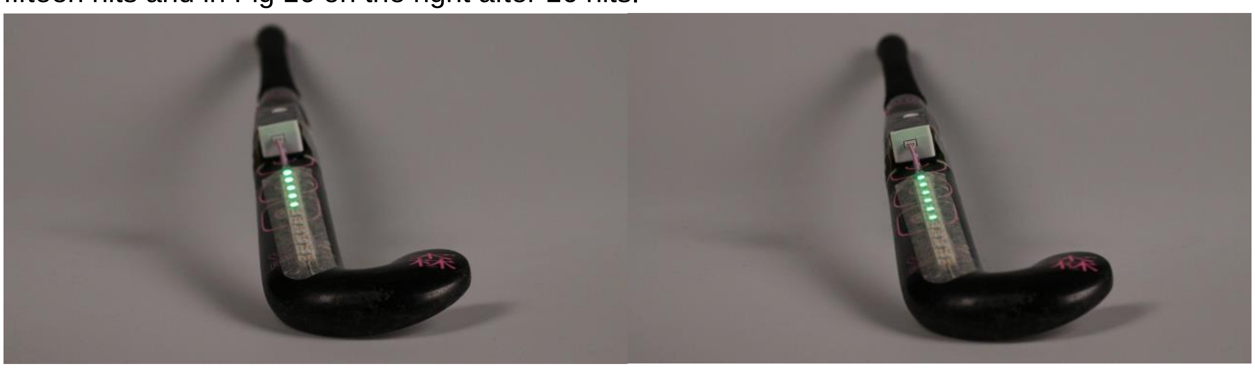

Fig 16: Game mode 2, LED per pass.

Game mode 3

Game mode three has each hit a 50/50 percent chance to show red or green (see Fig 17).

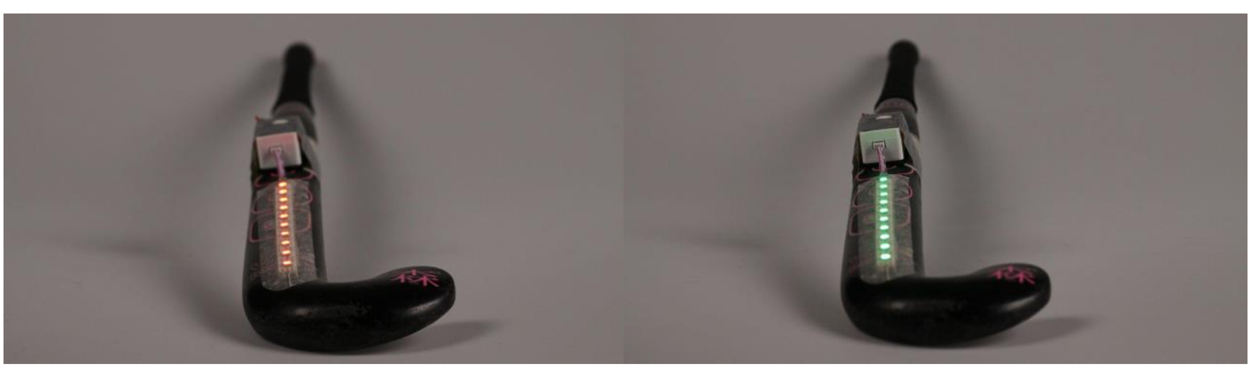

Fig 17: Game mode 3, Red or green 50/50.

Game mode 4

During game mode four the sticks calculate the angle that the y axis makes with the ground. The preferred angle is between 20 and 60 degrees as discussed with the coach. When the stick is held at this angle the entire stick displays green as can be seen in the middle of Fig 19. The further the stick is moves away from this angle the stick shows a single red LED moving away from the middle of the stick. When the stick is tilted passed 0 degrees the red LED fully has moved fully up the stick, when the stick is tilted passed 115 degrees the red LED is all the way at the bottom of the stick. These angles visualized in Fig 18 are calculated by the stick using the following equation:

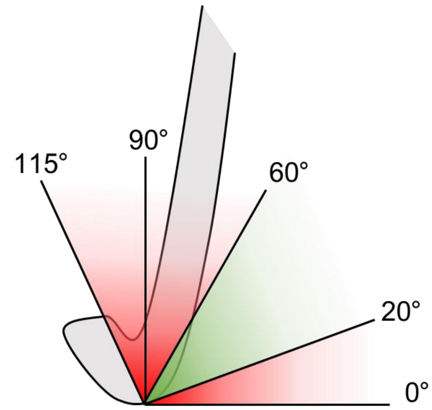

Fig 18: Stick angle.

$$angleY = atan2(-accelX, accelZ) * 180/\pi$$

In addition a moving average filter is used during angle calculation this is explained in [Data processing](#).

Fig 19: Game mode 4, correct block.

Game mode 5

Game mode five is used for testing. In game mode five values like acceleration in various axes can be displayed without influencing the other game modes. So called serial printing often has a huge influence on loop frequency which affects the multiple filters that have been used.

Data processing

The smart stick receives acceleration and angular velocity in the three different axes from the MPU6050. The Adafruit MPU6050 library (Herrada, 2023) is used to extract these values. This library requires the programmer to specify the range for the sensor. The range has been chosen to be 0 to 16 g (gravitational force) for the accelerometer which is the biggest possible range that could be chosen. A larger range will make sure that the signal does not clip. Testing showed that when using a smaller range, the signal did clip and thus parts of the signal was lost. This library also allows for directly applying a low pass filter using a function "*setFilterBandwidth*". A low pass filter of 5 Hz has been chosen to reduce high frequency noise like stick vibrations.

In game mode four where the sticks tilt is calculated, in addition to the low pass filter a moving average filter is used. This filter uses the following formula. $angleY_{filtered} = \frac{angleY_{old} \cdot n + angleY_{new}}{n+1}$ When the code is executed each loop the $angleY_{new}$ is calculated using the acceleration data as stated in Game mode 4. This stick angle is added to n times the $angleY_{old}$, this value is then divided by n plus one. Each time the codes gets executed the $angleY_{filtered}$ becomes the new $angleY_{old}$. After testing, n is chosen to be 50. Such a moving average filter makes that $angleY_{filtered}$ is very similar to $angleY_{new}$ but with reduced random noise and slower transitions from high to low angles resulting in a smooth animation during game mode four which is much easier to follow and adjust to for the players.

Hardware

Two different prototypes that have been created are shown in this subchapter. The second prototype is used during evaluation and user testing.

Prototype 1 - PCB

One of the iterations of the smart hockey stick is the PCB prototype. In this iteration the focus has been on reproducibility and miniaturization. The printed circuit board (PCB) design is made in EasyEDA. Other software has been considered like Altium and KiCAD. However, EasyEDA is chosen due to ease of use, the linked PCB manufacturer (JLCPCB) and component distributor (LCSC) which makes it very convenient for beginner PCB designers.

The first step in creating a PCB is to determine components and create a schematic. On what components to use and how to wire these components together. Inspiration has been gained from the schematic of the Wemos LOLIN D32 (Wemos, 2018), an ESP32 based board with battery charger onboard. Inspiration was also taken from Carl Bugeja's LED ping pong ball (Bugeja, 2023). A list of components has been created (see Appendix B: Information on PCB parts) and these are grouped and connected in a schematic as can be seen in Fig 20.

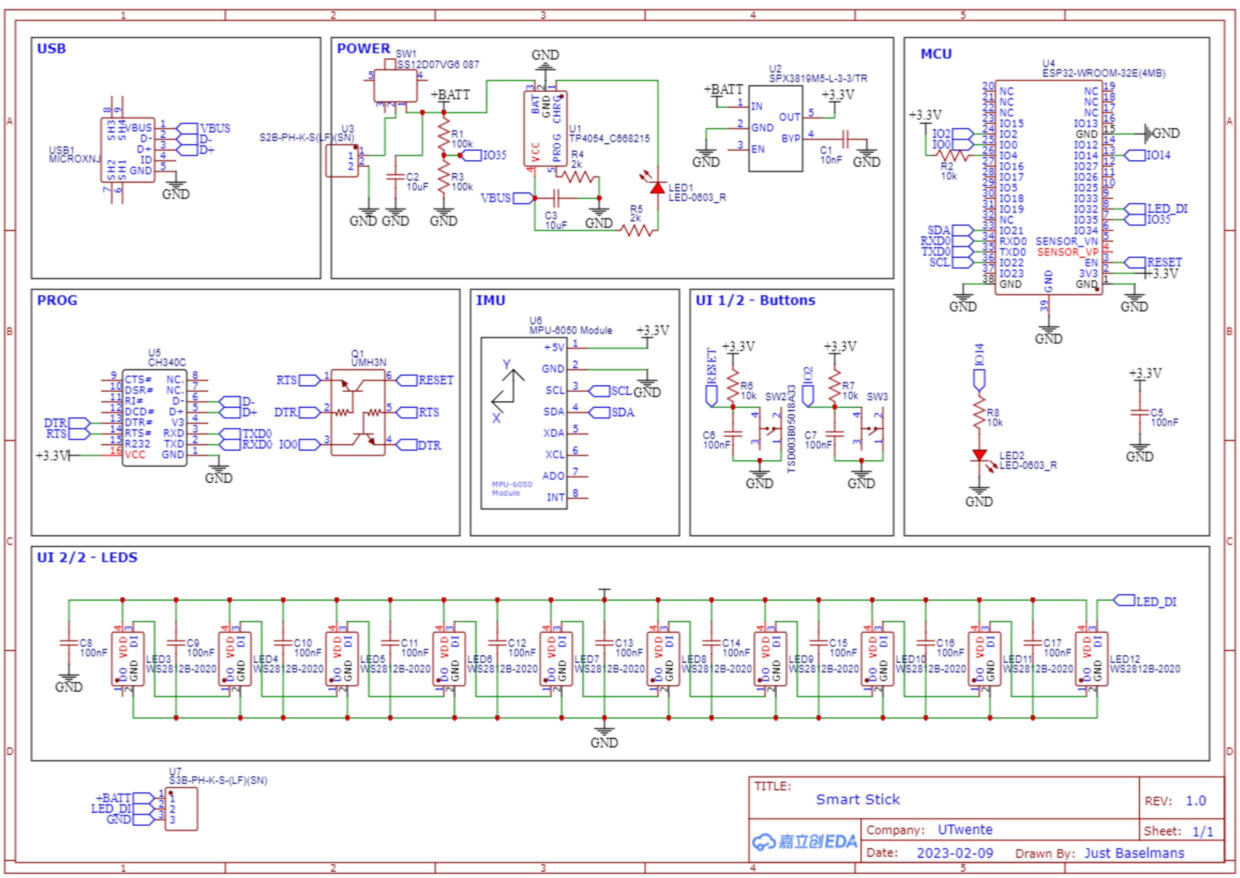

Fig 20: PCB schematic of smart hockey stick

To ensure that the PCB is as flat as possible, all components available in multiple packages have been chosen to be surface mount devices (SMD). And all SMDs are assembled on one side of the board. The preferred package size of passive components is 0603, this means the components are approximately 0.6 mm by 0.3 mm. This size of component can still be soldered by hand.
The PCB prototype consists of two separate PCBs, the mini LED strip (see Fig 22) and the main board (see Fig 21). These two PCBs can be connected using a JST PH-3 connector. This makes it possible to also connect different LED strips that use a three-wire interface.

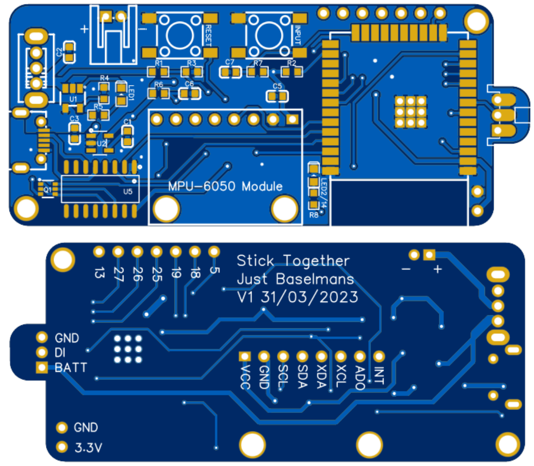

Fig 21: Main PCB scale 1:1, top side above, bottom side below.

Together with the supervision of electrical technician H. Waaijer; this prototype has been built with attention for placement of each component, clearance, wire thickness, mount ability, and pad sizes.

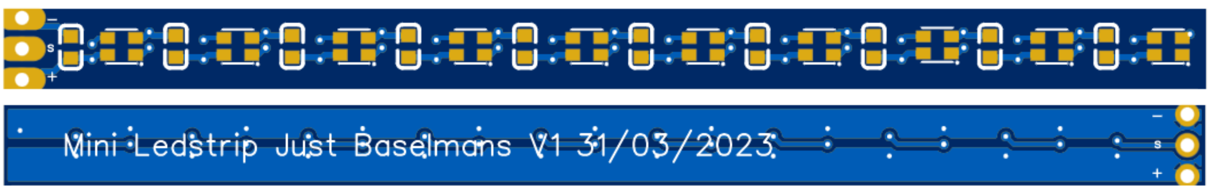

Fig 22: Mini LED strip scale 2:1, top side above bottom side below.

However, this design has not been used during user testing due to it not being functional in time. When programming the device was identified however was not able to be programmed. The following error message was displayed:
“A fatal error occurred: Timed out waiting for packed header”.

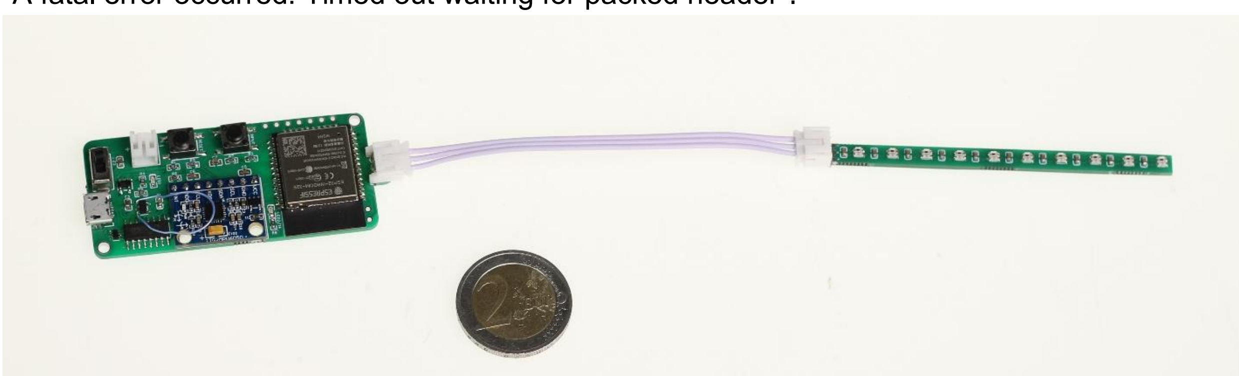

Fig 23: Physical PCB prototype.

Prototype 2 – LOLIN 32

Because the PCB prototype based on a LOLIN 32 board did not function in time a new prototype has been created around the LOLIN 32 lite directly. This prototype focused on creating a number of these devices within a short time span. This was due to the need for devices to start user testing.

Next to the LOLIN 32 lite board several components have been used. The smart hockey stick consists of the following components. The number corresponds to where the components are placed in the assembly as can be seen in Fig 24 and 25.

1. LED strip: A ten LED WS2812b LED strip is used to give visual cues to the user based on the given data by the MPU6050.
2. MPU6050: This IMU (inertial measurements unit) consists of a three-axis MEMS accelerometer and a three-axis MEMS gyroscope in one chip, used to measure acceleration and angular velocity of the stick. More information on the MPU6050 can be found in Chapter 5 MPU6050:.
3. Button: The button is used to change the functionality of the stick by cycling through game modes.
4. LiPo battery: An 350mAh battery with battery protection and recharge capabilities used to supply the smart stick from energy.
5. LOLIN 32 lite: The LOLIN 32 lite is an ESP32 based microcontroller with both Wi-Fi and Bluetooth capabilities and built in LiPo charging circuit. The LOLIN 32 lite processes data and makes all decisions regarding the other electronic components.
6. Snap-fit case: The electronics are encased in a snap fit case for easy access in case something malfunctions. The case allows for Charging port, power plug, button and led strip access. It also acts as an extra barrier to protect the electronics.
7. Charging port: The charging port is always accessible for the user to recharge the battery.
8. Power plug: The power plug connects the battery to the device and also acts as an on/off switch.
9. Prototype board: Used to connect components to the microcontroller and creating a sloth for the battery.

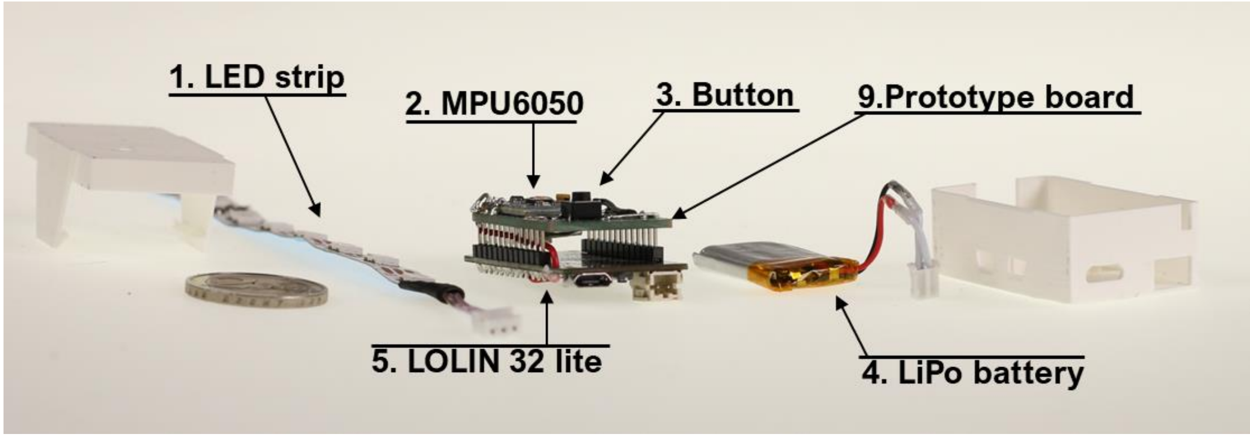

Fig 24: Internal components of the smart hockey stick.

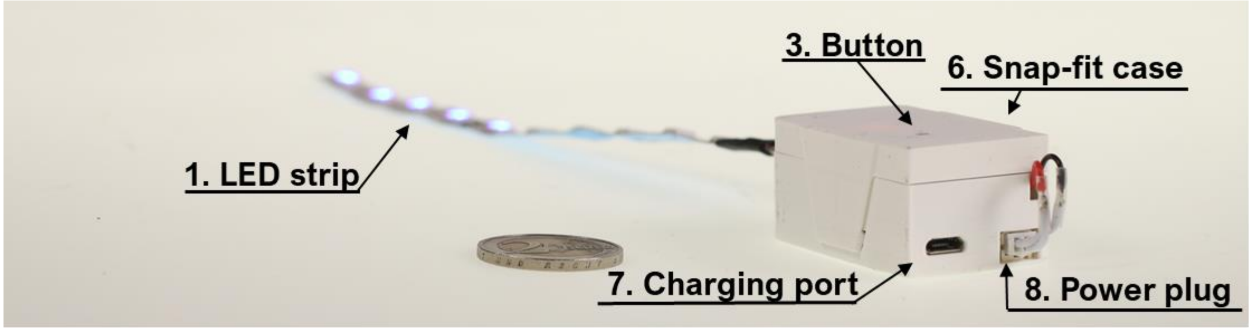

Fig 25: Assembled smart hockey stick.

Components one, two and three are wired via component nine to be connected to the microcontroller (component five). The connections made to nine are hidden to only show all in and outputs of the microcontroller itself. This can be seen in Fig 26.

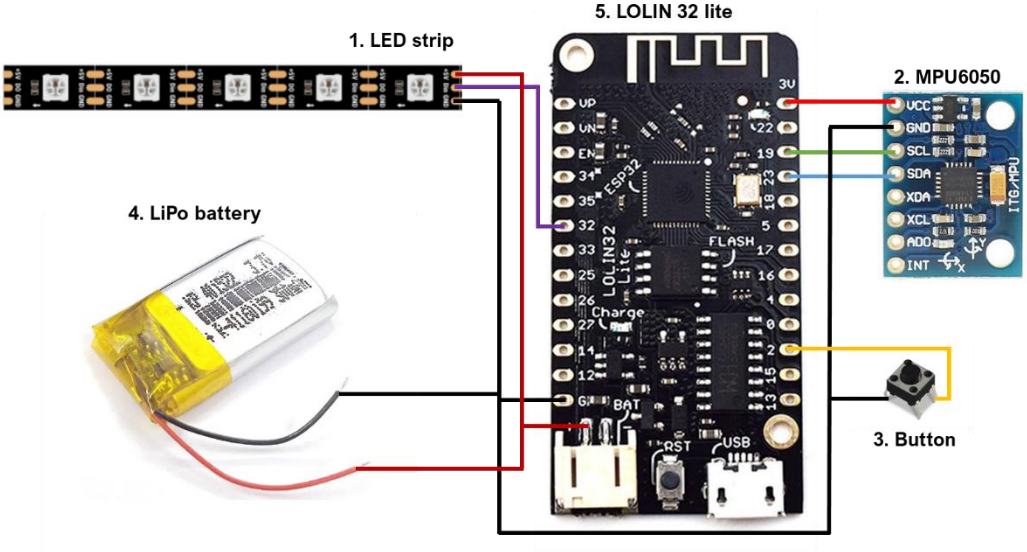

Fig 26: Connections made to the microcontroller.

The product is attached to the stick using a thin layer of neoprene which is placed between the 3D printed casing and the stick, after placing this masking tape is used to secure the device to the stick. Separately the masking tape is also used to secure the LED strip to the stick. Duct tape is used as a final layer sturdy layer over the masking tape. The duct tape is only placed over the masking tape to ensure no residue is left on the stick after removing the device.

This prototype has been used for testing and further evaluation. During the following chapters this prototype will be mentioned as, the smart hockey stick or the smart hockey stick device.

Chapter 6 - Evaluation and results

A user study was conducted with the following evaluations goals:

- Goal A. To what extent does the smart hockey stick enhance engagement and enjoyment among para hockey players?
- Goal B. To what extent can the smart hockey stick help the coach to train the para hockey players?
- Goal C. What are shortcomings and possible improvements for the smart hockey stick?

This section summarizes the details of the user study.

Variables

The dependent variables of the user study are engagement and fun. To obtain a complete picture their counterparts, disengagement, and discomfort, will also be examined. The independent variables are the tasks which will be explained more in depth later. And the stick type (normal stick versus smart stick).

Study design

An in-the-wild study has been conducted to see how the smart stick would be adopted in a natural training environment. Due to the limited number and highly individualistic nature of participants a within-subject repeated measures design has been chosen. This is a design where each participant undergoes multiple conditions with the same order of presentation for all participants.

Participants

In this user study, a total of five participants took part, with four participants involved at a time. After exercise one, one of the four participants was replaced by a player who was more severely intellectually impaired. This was due to a fair distribution of the two groups on the field. Beginner group participating in the user research and the advanced group participating in a regular practice. Two of the five participants went home directly after the training, because of this they were not able to participate in filling in the smileyometer. The other three participants did. All participants are members of the para hockey team, more on this user group can be found in Chapter 4 The para hockey players. To maintain anonymity in the report, fictional names will be assigned to each participant. The following names will be used to refer to the participants: James, William, Maria, Suzan, and Linda.

Exercises

During the user study three different exercises were performed. Each exercize was first performed with the users own normal hockey stick for five minutes. After these five minutes the players would change sticks to the smart hockey stick and perform the same exersice for again five minutes. When using the smart hockey stick, each of the exercises used a different game mode, more information on these game modes can be found in Chapter 5 Stick functioning and software.

- Exercise one, normal stick, correct block:
    - Players make pairs and stand 10m distance apart.
    - Player two lowers the stick in blocking position and says "Yes" when they are ready to receive the ball.
    - Player one pushes the ball towards player two, who will stop the ball.
    - This goes back and forth.
- Exercise one, smart stick, game mode four, correct block:
    - Players make pairs and stand ten-meter distance apart.
    - Player two lowers the stick in blocking position.
    - When the stick of player two becomes green (indicating the stick is held at the right angle) they yell "Yes" to player one.
    - Player one, pushes the ball towards player two, who will stop the ball.
- Exercise two, normal stick, passing around:
    - All players stand in a circle.
    - The exercise is that all players should pass the ball only once.
    - If all the players have passed the ball once and no player has passed it twice the task is performed successfully.
- Exercise two, smart stick, game mode one, passing around:
    - All players stand in a circle.
    - Everyone starts with their stick being red.
    - Player one, passes the ball to player two with a red stick. The stick from player one will become green.
    - Player two, does the same to player three with a red stick. The stick from player two will become green.
    - This repeats until all players have a green stick.
- Exercise three normal stick, quickest to ten:
    - Players make pairs.
    - Player one of the pair stands ten meters from player two of the pair. The coach recommended this distance.
    - Players pass to each other until they pass ten times.
    - When the players completed ten passes, they sit down.
- Exercise three, smart stick, game mode two, quickest to ten:
    - Players make pairs.
    - Player one of the pair stands ten meters from player two of the pair. The coach recommended this distance.
    - All players start with a red stick. And push to each other until their stick is fully blue (20 passes).
    - The players with a blue stick sit down

Procedure

The study was conducted during a regular training session of the para hockey team. The total duration of these training sessions is 60 min of which in this case 20 minutes will be used for a brief introduction, their regular warm up and at the end of the training a short match. This leaves 40 minutes for the study itself in which the participants will partake in the user research each exercise first using their own normal stick after which they will perform the same task using the smart hockey stick. Each task with each stick variation will be played for five minutes.

During the tasks three observers made both quantitative and qualitative observations. After the study the players were asked to fill in a smileyometer to indicate their perceived level of fun and to show their stick preference. And an interview was conducted with the coach about her experiences with the smart hockey stick.

Hypothesis

Based on previous tests with previous prototypes a few reasonable expectations can be formulated:

- H1: The introduction of the smart hockey stick will result in an increase in observed levels of fun and engagement and decreased level of disengagement among para-hockey players. Because of the fun and engaging nature of LEDs and the effects observed during previous tests with the smart hockey stick.
- H2: The smart stick might cause an increase in observed discomfort because players may have difficulty familiarizing and adjusting to the new technology. It is likely that this will cause confusion and frustration during these initial tests.
- H3: Overall, the smart hockey stick is anticipated to be viewed as a beneficial tool by both players and the coach, enhancing para-hockey training sessions.
- H4: Shortcomings and improvements for the smart hockey stick will be found both regarding software and hardware.

No hypothesis will be made on the possible improvements of the stick.

Apparatus

The study has been done during a normal training of the para hockey team therefore some of the necessary equipment and materials were already accounted for like the playing facility and normal hockey sticks owned by the players themselves. Additional materials needed were the five smart hockey sticks, data collection materials i.e. pens, blank paper, printed observation sheets, printed smileyometers, audio recorder. The observation sheets can be found in Appendix C: Empty observation sheet. The smileyometer can be found in appendix Appendix A: Smileyometer results.

Observations

There were three different observers to count certain behavioral cues. Multiple observers were used to increase objectivity. The observations were done by filling in an observation sheet (see Appendix C: Empty observation sheet). This observation sheet consists of the observer's name, what game is being played, a list of behavioral cues, a space for additional notes and multiple lines to add additional behavioral cues during the study.

During the observations, each observer took note of behavioral and verbal cues related to engagement and fun. The observation sheet (as can be seen found in Appendix C: Empty observation sheet) contained a list of behavioral cues related to engagement disengagement, fun and discomfort obtained by literature, interviews, and observations as well as an interview with the coach, conducted during the study design phase. In addition, the observers were instructed to record any cues that were not provided in the list in the empty spaces on the observation sheet. The list of behavioral cues that show engagement (E) / disengagement (DE), fun (F) or discomfort (D) is a combination of behavioral cues defined by different sources:

- Behavioral cues identified by literature (Read et al., 2009).
    - Laughter (F)
    - Exhibiting increased energy (F)
    - positive vocalization (F)
    - Negative vocalization (NF)
    - Concentration signs e.g., fingers in mouth, tongue out (E&F)
    - signs of boredom e.g., ear playing, fiddling (DE)
    - Frowns (NF)
- Behavioral cues identified doing interviews and field observations as described in chapter 3.
    - Laughter (F)
    - Negative vocalization (NF)
    - Looking into the distance (DE)
- Behavioral cues identified when discussing the study design with the coach as mentioned in chapter 3.
    - Cheering (F)
    - Quietness (E)
    - Off topic questions (DE)
    - Walking off (DE)
    - Throwing with stick (NF)
- Additional behavioral cues from intuition
    - Responding positively to questions e.g., nodding (E)
    - Using gestures to demonstrate understanding (E)
    - Ask on topic questions (E)
    - Ask off topic questions (DE)
    - Looking away into the distance (DE)

Some of the above behavioral cues were combined due to their similar nature. In table 2. All collected observations from the user study can be seen. The first row shows the exercise and stick type "N" refers to normal stick and "S" to smart stick, the number corresponding to which exercise they performed. In the second row the three observers can be identified using their unique letter.

Stick type and exercise	N1			S1			N2			S2			N3			S3		
Observer	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
laughter	0	1	1	2	2	2	1	1	1	0	0	3	2	3	4	4	5	5
positive vocalization	1	2	2	0	1	3	0	0	1	0	2	3	3	1	4	2	3	4
increased energy	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	3
concentration signs	4	3	1	2	4	4	1	4	2	1	2	1	1	2	2	0	3	1
demonstrating understanding	2	0	1	2	1	1	1	0	0	2	0	1	2	3	0	0	2	1
ask on topic questions	0	1	0	2	1	0	0	0	0	2	0	0	0	0	0	2	0	0
ask of topic questions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
signs of boredom	2	0	0	0	0	0	1	1	1	0	2	2	0	0	0	1	0	0
looking into the distance	1	2	2	1	0	1	0	1	1	1	0	0	0	0	1	1	0	1
walking off	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
negative vocalization	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	2	0	0
frowning	0	0	0	0	0	1	1	0	1	1	1	1	0	0	0	1	0	2
throwing with stick	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2: List of behavioral cues and resulting observations.

Each behavioral cue corresponds to one of the four behavioral categories. Green for engagement, blue for fun, red for disengagement and orange for discomfort. Throughout this section of the report these colors will be used for these same categories. When all behavioral cues from each observer are summed up a number can be found for each exercise and behavioral category. This gives a first overview of how the observed engagement, disengagement, fun and discomfort changed with each exercise and stick type (see Fig 27).

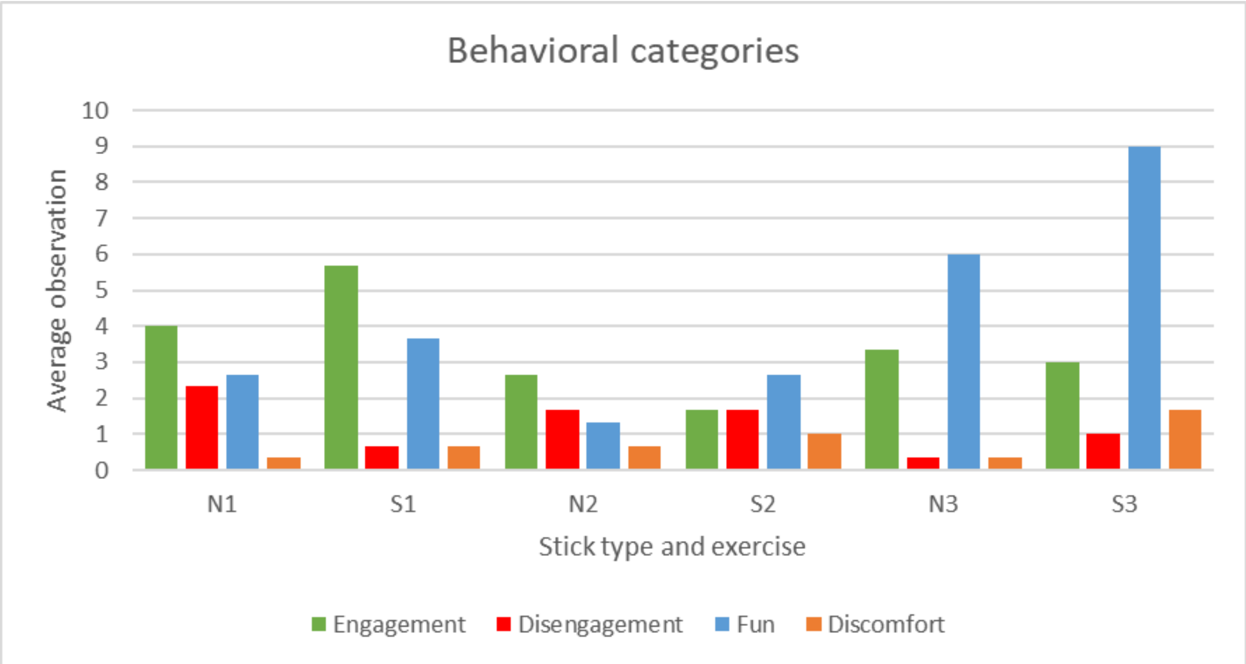

Fig 27: Behavioral categories per exercise and stick type.

Most conclusions regarding the made observations will use the average observed values. This means that the observations from the observers are added up and divided by the number of observers. This is done to reduce the observer bias and increase reliability of the data. For the paired sample t-test each observer's results are considered on their own instead of using an average. This has been done so a larger sample size can be used, additionally it gives the varied perspectives of the observers which may include interesting nuances and variations that show up in the presented boxplots and would otherwise be lost. However, these insights could lead to an observer bias.

The paired samples t-test has been conducted to compare the mean scores of each of these behavioral categories between the normal field hockey stick and the smart field hockey stick. This analysis will determine if there are statistically significant differences in fun, engagement, disengagement, and discomfort when participants used the different stick types.

Engagement and disengagement

The hypothesis testing conducted for engagement and disengagement scores yielded non-significant results based on the paired-sample t-tests.

For engagement, the null hypothesis (H0) stated that the mean difference between observed engagement when using a normal stick and observed engagement when using a smart hockey stick is 0. The alternative hypothesis (H1) proposed that the mean engagement score is greater when using a smart hockey stick compared to a normal stick. However, the results indicated a non-significant difference between the normal stick (M = 3.3, SD = 1.5) and the smart stick (M = 3.9, SD = 1.8), with a t-value of 1, and a p-value of .183. Therefore, there is insufficient evidence to reject the null hypothesis, suggesting no statistically significant difference in engagement scores between the smart hockey stick and the normal hockey stick among para-hockey players.

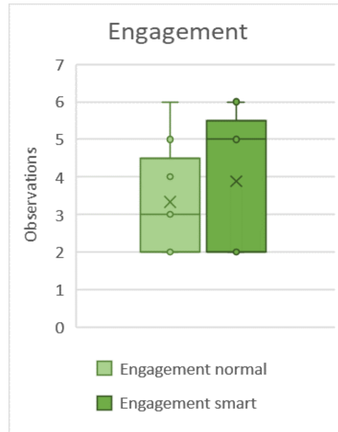

Fig 28: Plot engagement.

Similarly, for disengagement, the null hypothesis (H0) stated that the mean difference between observed disengagement when using a normal stick and observed disengagement when using a smart hockey stick is 0. The alternative hypothesis (H1) proposed that the mean disengagement score is smaller when using a smart hockey stick compared to a normal stick. The results revealed a non-significant difference between the normal stick (M = 1.4, SD = 1) and the smart stick (M = 1.1, SD = 0.8), with a t-value of 0.8 and a p-value of .219. Hence, there is insufficient evidence to reject the null hypothesis, indicating no statistically significant difference in disengagement scores between the smart hockey stick and the normal hockey stick among para-hockey players.

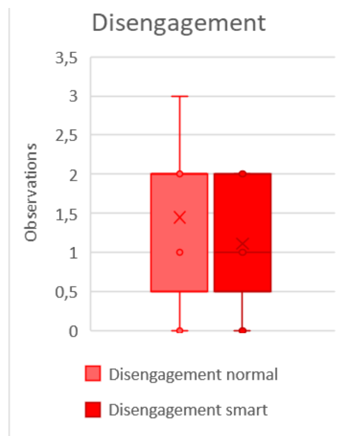

Fig 29: Plot disengagement.

Although the paired sample t-tests did not demonstrate statistical significance for both engagement and disengagement, it is worth noting that the data exhibited trends and patterns that can be considered and further explored.

By examining the combined boxplots of engagement and disengagement it becomes evident that there is a notable increase in average engagement and a slight decrease in disengagement when using the smart hockey stick compared to the normal stick (see Fig 30). Additionally, the boxplot comparison suggests that the number of disengagement behaviors is considerably lower than the number of engagement behaviors across exercises regardless of stick type.

When looking at the different exercises the average observed engagement increases for exercise one and two and decreases for exercise three when using the smart stick compared to the normal stick. Similarly, the disengagement clearly decreased during exercise one after which it stayed the same during exercise two and increased during exercise three as can be seen in Fig 31.

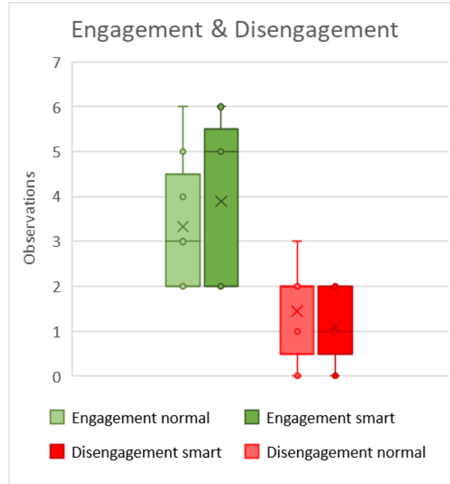

Fig 30: Combined boxplot visualizing engagement and disengagement.

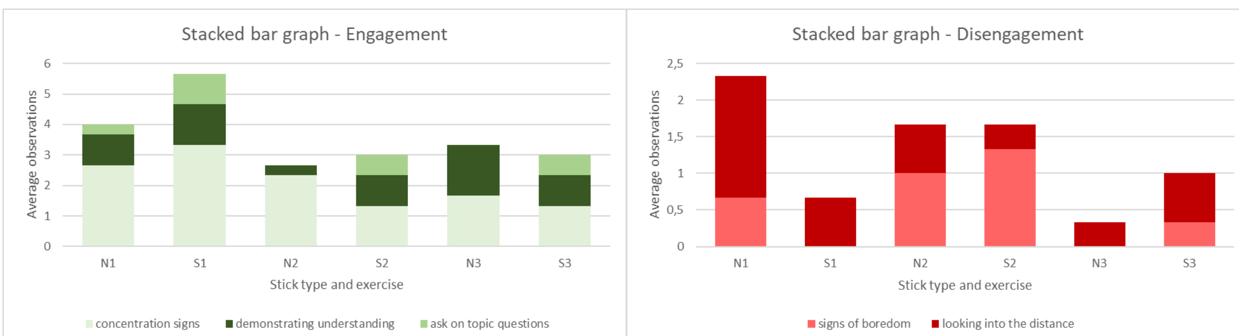

Fig 31: Behavioral comprising engagement and disengagement.

Fun and discomfort

The hypothesis testing conducted for fun and discomfort scores yielded a significant result for fun and non-significant result for discomfort based on the paired-sample t-tests.

Following the same method as with engagement and disengagement, the null hypothesis (H0) stated that the mean difference between observed fun when using a normal stick and observed fun when using a smart hockey stick is 0. The alternative hypothesis (H1) proposed that the mean fun score is greater when using a smart hockey stick compared to a normal stick. Results of the paired-t test indicated that there is a significant large difference between normal stick (M = 3.3 ,SD = 2.6) and smart stick (M = 5.1 ,SD = 3.7), t(8) = 3.2, p = .006. This means there is sufficient evidence to reject the null hypothesis, meaning there is a statistically significant difference increase in fun when using the smart hockey stick compared to the normal hockey stick among para-hockey players.

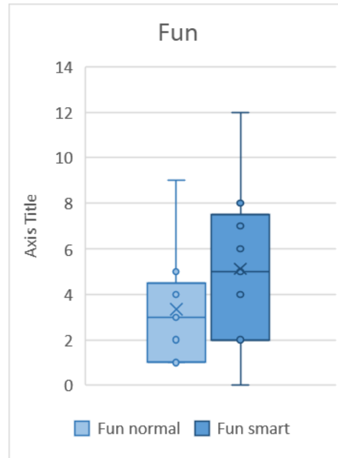

Fig 32: Plot fun.

For discomfort, the null hypothesis (H0) stated that the mean difference between observed discomfort when using a normal stick and observed discomfort when using a smart hockey stick is 0. The alternative hypothesis (H1) proposed that the mean discomfort score is smaller when using a smart hockey stick compared to a normal stick. The results indicated that there is a non-significant difference between Before (M = 0.4 ,SD = 0.5) and After (M = 1.1 ,SD = 0.9), t(8) = 2.3, p = .975. There is on average even a slight increase in discomfort. However, there is both no significant increase and decrease therefore, there is insufficient evidence to reject the null hypothesis, indicating no statistically significant difference in disengagement scores between the smart hockey stick and the normal hockey stick among para-hockey players.

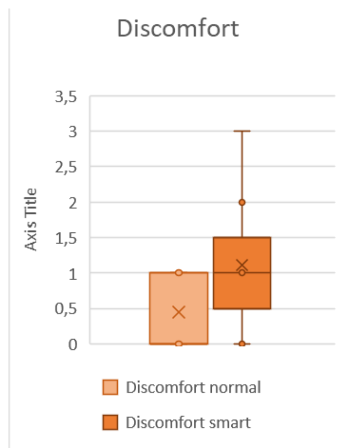

Fig 33: Plot discomfort.

The increase in fun is the only statistically significant different in behaviors that can be drawn from the observations. This huge increase in fun can also be seen when looking at Fig 34. Something that is noticeable is that discomfort also increased when looking the smart hockey stick. This is in line with the stated hypothesis two (H2) and likely due to the players struggling to familiarize and adjusting to the new technology.

Fig 34: Combined boxplot visualizing fun and discomfort.

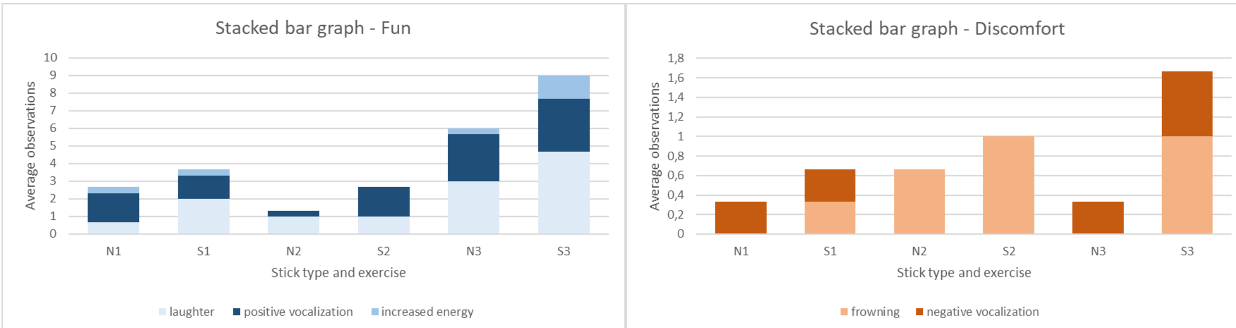

Fig 35: Behavioral comprising fun and discomfort.

Other observations

Besides the tallied observations on the specific behaviors many other observations were made during and besides the user study.
During the user study players were often exploring their sticks. This was identified and written down by all three of the observers during some part of the user study. The players were seen tapping their stick on the ground, swinging the stick, and making dance-like movements with the stick all to see what influence this had on the lights. This is often accompanied by laughter and enthusiastic communication with their teammates, with players frequently laughing and yelling during these interactions.

Players who were not part of the user study were also interested in the prototype and approached the stick before and after training. When the functionalities of the stick were shown and explained one of the players noted how this would be helpful for novice hockey players.

During exercise three where players were asked to pass the ball ten times. Maria and Suzan counted to ten themselves while the coach counted for James and William. Maria and Suzan were counting out loud while using the normal stick, and when they changed to the smart stick they did not bother to count, and they fully trusted the smart stick to do the counting for them. This further highlight that parts of their cognition was now free for other tasks. The coach also noted that it was quite hard to count while passing and that it was very nice that the LEDs could take over this task.

Smileyometer

The questionnaire used in the study consisted of five questions that employed a 1-5 Likert scale. When employing the Likert scale, considerations brought up by Hartley and Maclean (2006) were considered in the form of providing clarification of the questions and making use of pictorial representations of response alternatives inspired by the Smileyometer from O'Brien et al. (2018)

After the training the participants were asked to rate the level of fun, they experienced for both the smart stick and the regular stick, with 1 indicating "not at all fun" and 5 indicating "very fun". Similarly, participants were asked to rate the perceived level of ease associated with each stick, with 1 representing "very difficult" and 5 representing "very easy".
Given the limited amount of data, drawing broad conclusions, and identifying significant patterns may be challenging. However, analyzing the provided answers does offer valuable insights. For instance, all three participants expressed a preference for the smart stick. Also, when rating the ease of use and fun factor, they consistently reported that the smart stick was equally or more enjoyable and easier to use compared to their regular sticks. These findings can be found in Appendix A: Smileyometer results. And are summarized in table 3 below.

Participants	1	2	3
I liked the assignments with the normal stick. (1 - 5 Likert)	5	4	5
I found the assignments with the normal stick easy. (1 - 5 Likert)	4	4	5
I liked the assignments with the Smart stick. (1 - 5 Likert)	5	6	5
I found the assignments with the smart stick easy. (1 - 5 Likert)	5	5	5
which stick do I like better? (normal / smart)	smart	smart	smart

Table 3: Smileyometer results.

Previous studies (Hartley, S. L, p.824) have shown that people with intellectual impairments have the tendency to select the most positive response, this was also noted during deployment of the smileyometer. However, the participants indicated in their verbal response that they still had a genuine preference. As participant three reacted to the question regarding their perceived level of fun when using their normal hockey stick, "It was very fun." and to the same question regarding the smart hockey stick "Very, very, really, very fun! Really amazing!".
Participant two responded regarding liking the assignments with the smart hockey stick that they were even more fun than very fun. This response was incorporated into the results by dedicating a six.

These findings show that at least for these three individuals they would choose the smart hockey stick above their normally used hockey stick. In addition, it seems for people with intellectual impairments that the smileyometer had a positive influence on both response rate and understandability of the questions.

Interview

Following the training session, a conversation was conducted with the coach to collect qualitative data. A list of topics was prepared before the interview, however the objective of this interview was to engage in an open discussion regarding her insights and experiences with the smart hockey stick, as well as her observations regarding any behavioral changes among the participants. The interview took place immediately after the practice session and was recorded - with the coach's consent - using a mobile phone. The interview was initially conducted in Dutch and subsequently transcribed using Sonix. The transcription was later translated into English utilizing ChatGPT, with both processes being manually edited by a native Dutch speaker. Some statements have been modified to add necessary background information and to make it more readable. The entire translated transcription can be found in appendix a. Timestamps have been added to each quote so the quotes can easily be found in the full transcription. It is possible that different quotes stem from the same time stamp due to the conversation being cut into smaller pieces to highlight only the relevant information within each section.

Engagement and disengagement

During the first exercise, the players had to orient their stick in the right position after which they had to stop the ball. When using the smart stick William posture improved a lot while focusing on the LED lights of the smart stick and had a lot less of a convex back compared to when he was using the normal hockey stick.
Marjolein: [00:00:29] "You could see, for example, during the stopping exercise, how they immediately started looking at the lights. What caught my attention was that with the normal stick William stood up very stretched out whereas he did this less when he was focusing on the lights of the smart stick. At the same time, I also noticed that those lights can be quite distracting."

William was not the only player that was really focused during this first exercise. Multiple players focused so much on his stick that he forgot to stop the ball. This was written down by two of the observers and the coach also commended this during the interview. The lights kept the players engaged to the extent where they were only focusing on the lights and not on the given exercise anymore.
Marjolein: [00:06:46] "I found it really nice to see during the stopping exercise, especially with the beginner hockey players. It was nice to see how they would look at it like, "Oh yes, it's green. That means I have my stick in the right position." And actually, it would be even better if they paid slightly less attention to the green light. Because at one point, you could see that they were focused on the light, and the ball passed them."

The coach pointed out a positive change in engagement, it was not usual that all players participated the entire practice and often people dropped out halfway through.
Marjolein: [00:03:15] "It was a small group, so that also plays a role of course. But ultimately, they all participated in the entire training session, and you could see their enthusiasm during the passing exercises. So, in the end, nobody walked away or dropped out."

Fun and discomfort

The coach commented on the behavior of William and how these differed from how William participated during a normal practice.

Marjolein: [00:01:24] "Lights just work. You know, I happened to discuss this with William' father. William can really stand by the boards doing nothing for the entire training session. And now he participated in the whole training, and I said, "Yes, lights. They are really motivating and fun." It is really true."

While observing it was hard to interpret the emotions of James. Marjolein pointed out that also James had fun and that this could be seen since he was very eager to switch to the smart stick again.

Marjolein: [00:03:15] "When they had to switch sticks, they put their current stick aside to pick up the other one. I was a bit worried about the stick switch because I thought, "Oh, everyone will want to keep their own stick, and nobody will want the other one." Well, that went perfectly fine too. So, you could see that they were very, well, engaged but also excited to play with the smart stick."

Even when the smart stick was laid down to play with the smart hockey stick the players were observed to still watch the smart stick and occasionally look back to the smart stick, this was not observed the other way around while they were playing with the smart stick regarding their normal stick.

During the third exercise, which involved completing ten consecutive passes, the competitive nature of the players became evident. Specifically, Marjolein made a comment about the potential effectiveness of a function such as counting, expressing how beneficial it could be, not only for para hockey players but for individuals in general.

Marjolein: [00:03:15] "Of course, exercises like passing ten times in a row just work. It taps into their enthusiasm, and it is a very fun exercise overall. And I noticed that when I had to count with William and James who have more trouble with counting that you do get easily distracted. So when the stick visualizes that, yes, it works quite nicely."

Problems and potential improvements

A problem that became apparent was the confusion that arose with interpreting the colors. This group of participants tested a previous product made by a different student at the University of Twente that used colored LEDs in a bracelet that gave feedback. Because of this, players often asked if the color of their stick had a meaning, like if they were doing good or bad.
Marjolein: [00:01:24] "You could hear him all the time, like, "It's green now, did I do it right?" They associate the lights of the smart stick with whether they did something correct. This is of course because of those wristbands we tested, because when he did something well during those tests, he received a different light. So, he asked about that now, but that's not how it works with the smart stick."

This became especially evident with the colors red and green which are generally associated with good and bad. Within game mode four used in the stopping exercise, red and green were also utilized this way which worked well according to the coach.
Marjolein: [00:02:26] "But with the stopping, that was perfect. It starts with red saying something was still wrong and when it changed to green it meant the stick was held correct."

Something that also came up during the conversation with the coach was that the calibration could still be improved.
Marjolein: [00:04:36] "Because if I have a small downside, it was probably related to the calibration as you mentioned. Especially with the second exercise where they had to play in circles and move to the next color. Yes, there was such a difference in what each participant had that it was almost impossible to reach a consensus on the correct color somehow."

Another potential improvement that was talked about is size and robustness. The coach had the following to say about the current prototype:

Marjolein: [00:10:07] "I do think it's usable yet outside of the beginner group. I'm just concerned that if you become a better hockey player, it might break quickly. It might eventually break because the intensity increases. However, I do already think it can be used during regular training."

A big problem with previous prototypes was the weight. The coach commented that this was not a big issue with the current prototype.

Marjolein: [00:16:56] "Now the weight is definitely not an issue. And the sticks don't break easily with this target group."

The biggest concern that the coach still had were revolving the attach and detachability of the stick. She had a hard time handing out the smart sticks because these were only available in certain sizes. She had to give the right stick to the right participant while giving the training which required a lot of thinking from her.

Marjolein: [00:10:55] "Yes, you know, because the way the smart stick now works it requires a lot of thinking because each specific size stick has to be given to an individual that can use that size stick. The ideal scenario would be that it's easy to remove from one stick and attach it to another

… If you want to use it effectively in a training session, I think that's essential. Yes, and something that I think might be difficult to solve. It was sometimes a bit hard to see but maybe that was because It's sunny today. so maybe that also affects the visibility of the lights."

Later during the interview, she once more confirmed this and added the following.

Marjolein: [00:16:11] "I would be really thrilled if it could detach from those sticks. That's probably my biggest concern… It would be nice if you have something like a start button. So it doesn't start counting before the exercise starts. And thus, one group is not already halfway through the exercise while another group has not even started yet."

As a last remark the coach suggested a new game mode. This game mode would motivate players to hit the ball as hard as they can and also show them how hard they are hitting.
Marjolein: [00:18:20] "can you also have something where the harder you hit, the more lights come on? I think that would be really fun, like when you say, "Now hit it as hard as you can," because if I ask them that now sometimes, they hit the ball and I am sure this is not the hardest they can hit. If you could also have something like a thermometer or something that shows how hard they are actually hitting, then it would be better visible for both me and the players when they are really hitting as hard as they can."

Here is a small overview of the identified problems from the interview with the coach:

- There was confusion regarding LED color meaning, especially red and green.
- LEDS were not always visible during sunny days.
- Coach had difficulties remembering the order of colors.
- Coach had difficulties remembering what functions belonged to what game mode.
- Calibration should be more reliable.
- Concerns regarding durability of the smart stick device.
- Should be easily attachable and detachable from the stick.
- Need for a start button.
- Additional game mode visualizing hit strength/speed.

Each of these points will be addressed in the discussion chapter.

Conclusion

The results of the user study overall were very positive and provided valuable insights into the effects of the smart hockey stick on engagement, fun, disengagement, and discomfort among para-hockey players when using a smart stick compared to their normal stick. While the paired-sample t-tests did not yield statistically significant differences for engagement, disengagement and discomfort the data exhibited positive trends and patterns.

When the difference in engagement, disengagement, fun and discomfort over the different exercises is visualized (see Fig 36) which can be obtained by subtracting the observed normal stick value from the observed smart stick value. This can nicely visualize findings.

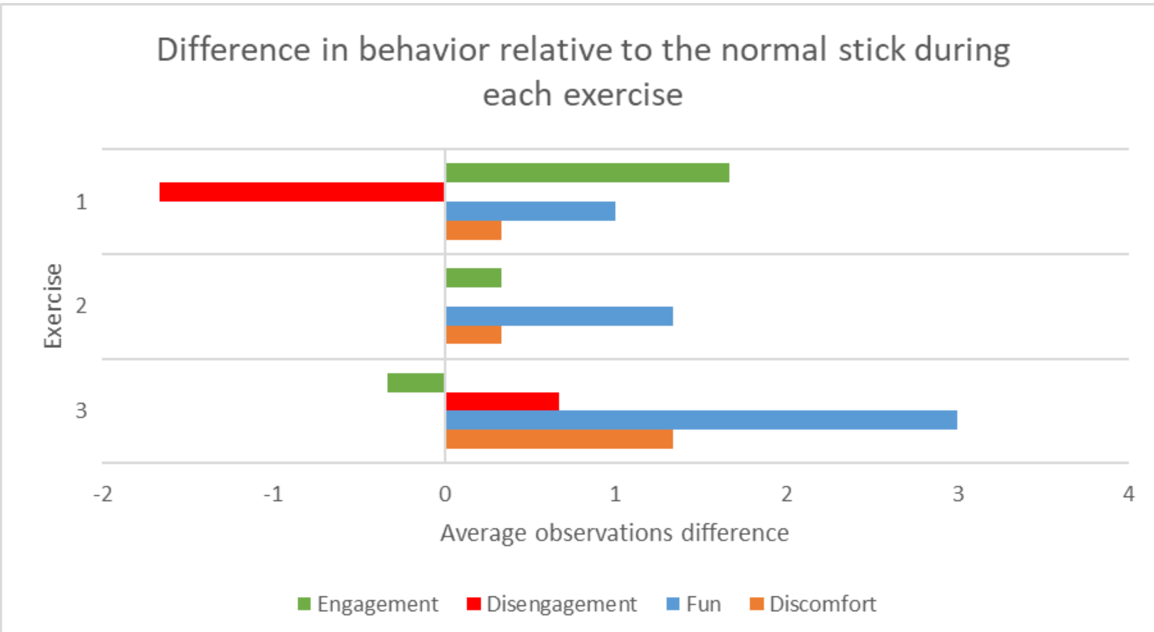

Fig 36: Differences in behavior relative to the normal stick, each exercise.

Something that can be noted is that the discomfort increased over all exercises when using the smart stick. This was also expected as explained in H2. It is also clear to see why the only significant difference between normal and smart stick is fun. This is the only behavior category that consistently scored an increase of one observation over the exercises. Additionally, the engagement decreases over the different exercises and disengagement increases over the exercises. This may look like it is due to the players getting used to the stick however this is likely due to how well the stick performed during the different exercises.

When looking at the interview it is more likely that these differences are due to how well the stick functioned and how well the game modes were designed for each exercise. Exercises two and three used both red and green in the array of colors without any additional meaning to it which caused confusion and therefore an increase in observed discomfort.

During the first exercise green meant that the stick was at the right position and red meant wrong position which were interpreted as very clear instructions. This explains the relatively low disengagement and discomfort scores during this exercise (see Fig 36).

The second exercise players were asked to pass in circles to progress through the colors, during this exercise there was a large increase in fun, small increase in discomfort and engagement and no change in disengagement. During this exercise it was harder for the coach to guide the participants because she did not know the order in which the colors came by heart. Also, this was the first exercise in which the sticks had to be calibrated for each player. This resulted in two sticks having a rather low threshold for detecting a hit. Therefore, the players could not fulfill the exercise as anticipated however this did not impede on the amount of fun they experienced as indicated by the players and the coach.

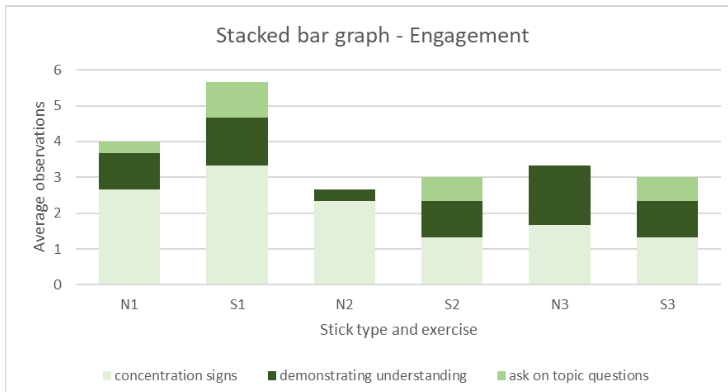

Fig 37: Behavioral cues for engagement.

Exercise three was a small game where players had to pass to each other ten times. Here a very large increase in fun was observed, also an increase in disengagement and discomfort was observed and a decrease in engagement (Fig 37). We can see that the decrease in engagement is mostly due to a decrease in demonstrating understanding. It is not fully clear why this is, it could have to do with the reason that counting is rather difficult during these types of exercises as mentioned during the interview even the coach struggled with this in addition people with intellectual impairments are known to struggle with the entire concept of numbers. Which may cause the decrease in understanding, but this is mostly speculative.

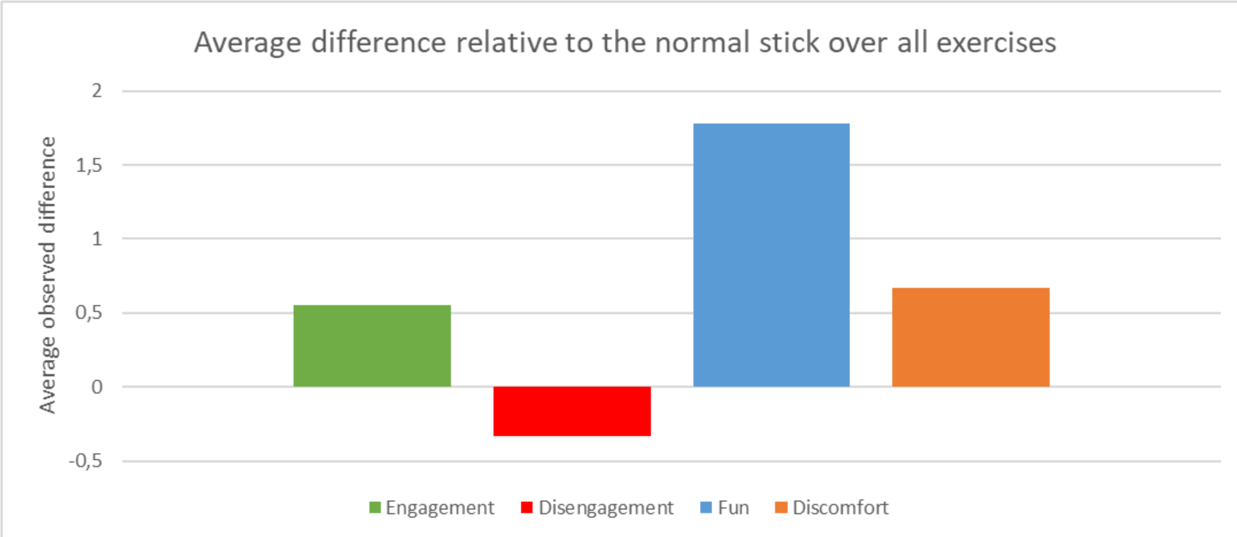

Fig 38: Differences in behavior relative to the normal stick, average overall.

Overall, the results of this user study support the hypothesis that fun, and engagement increased while disengagement decreased (H1). This was especially the case during exercise one however when taking an average of all exercises this is still the case (see Fig 38).

The increase in discomfort has been observed in all exercises as talked about (H2).
Additionally, all players preferred the smart hockey stick above the normal hockey stick and the coach agreed that this current version could already be used as tool to supplement parts of the trainings all in alignment of the third hypotheses (H3).
Also, shortcomings and improvements for the smart stick have been found regarding both software and hardware (H4). These will be further discussed in Chapter 7 - Discussion.

Chapter 7 - Discussion

So far, the results suggest that the smart hockey stick can indeed improve engagement and fun for para hockey players and that the smart hockey stick works well as a tool for the coach to be used during para hockey trainings. This chapter will look back at the research questions, reflect on the evaluation, discuss uncertainties in the results, and look at future improvements of the smart hockey stick.

Research questions

RQ 1. How can we improve the first version of the smart hockey stick to improve engagement and fun for para hockey players?
Regarding RQ 1 The ideation revealed that by adding functionalities that fit the coaches' requirements and make the stick be able to be used during practices was what was missing from the previous iteration of the smart hockey stick. The new prototype demonstrated the potential in enhancing engagement and fun for para hockey players. The coach commented that in her experience the players had an increase in attention and motivation when using a smart hockey stick compared to the normal stick for each of the exercise. Also, when taking the average over all the different exercises, the observations resulted in an increase in engagement and decrease in disengagement when the smart stick was used.
All players indicated that they preferred the smart stick over their normal stick and that the exercises with the smart stick were as much or more fun than the exercises with the normal stick. This increase in fun was also observed in every single exercise.

RQ 2. How can the coach be supported in training para hockey players?
Concerning RQ 2, the smart hockey stick has proven to be a beneficial tool for the coach during training sessions. The clear visual feedback from the smart stick in combination with the verbal cues from the coach had a huge positive effect on players technique and attention during the exercises. The stick does give support when executing exercises, the coach can link actions to stick colors which was not possible without this tool. The coach also commented that the smart stick can already be deployed in her trainings however, the coach also encountered challenges in managing the different stick sizes and the need for synchronizing all smart sticks during training.

Reflection on evaluation

The user testing yielded great results, especially considering the small sample size and the limited available time. However, novelty effects were identified which could have skewed results. This effect was also identified by the coach.

Marjolein: [00:11:48] "You could see that they were looking even more attentively. And you know, it's new, so it's interesting regardless. So, I don't know if they will look at it less attentively as they use it more frequently."

This shows the need for a long-term empirical study. Hopefully this will determine what the effect of the smart hockey stick is when used for over a longer period.

It will also be beneficial to do the study at a bigger scale possibly with users outside of the para hockey team.

Marjolein: [00:14:05] "By the way, I spoke to someone from the youth committee in my team yesterday, and they immediately said, "Oh, that could be something interesting for us as well." Just for the regular youngest youth players. I really think there is a market for it, especially for the youngest beginners. Teaching techniques, I think there's definitely a market for that."

The youngest youth encounter similar struggles as the para hockey players. These struggles include difficulty with memory, learning new techniques and remembering more complicated tasks involving multiple steps.

The observations were insightful however some adjustments could be made. Writing caused observers to miss certain behaviors because so much was happening at each moment. The ideal scenario would be if the training session could be video recorded and processed in post an alternative could be audio recording the observers and them explaining what they observe. Using one of these two methods makes it possible to observe more behaviors. And get a more complete picture of the participants response to the prototype.

The smileyometer worked exceptionally well. Players understood the questions and with little guidance of the surveyor the players were able to successfully indicate their perceived fun and ease of use of the stick. In future research perhaps more often and longer questionnaires using a smileyometer format can be used to gain more insights from the players themselves.

The interview gave great insights and has functioned as a backbone throughout the results to give context to findings. Involvement of the coach has helped this project a lot overall and to learn from her insights has been of great value. Working closely with the client is greatly recommended when such a specific task with a unique target group is given.

Result uncertainties

Throughout this study, it has been evident that individuals with intellectual impairments exhibit a wide range of differences, making it challenging to generalize results for this user group. The limited sample size used during the evaluation of the smart hockey stick further adds to the uncertainty in generalizing the findings to a broader population of para hockey players. Expanding the sample size and including a more diverse range of participants with different levels of cognitive abilities could enhance the robustness of the results.

Additionally, the learning curve associated with using the smart hockey stick was not fully considered in this study. Participants were given limited time to familiarize themselves with the device during the training session. As both players and the coach become more acquainted with the smart hockey stick over time, their experiences and responses may undergo changes, potentially influencing the outcomes.

External conditions, such as weather and other environmental factors, may have impacted the players' responses during the training session. Weather conditions could have affected the visibility of the LED lights, which are crucial for providing real-time feedback. Furthermore, individual factors, such as emotional states or personal circumstances, could have influenced players' interactions with the smart hockey stick, leading to varying responses.

The role of the coach in the training session also introduces uncertainties. The coach's interaction with the smart hockey stick and their approach to guiding the players through the exercises might have influenced the outcomes. Different coaches could potentially yield different results, highlighting the need to explore how the smart hockey stick's effectiveness might vary based on coaching styles.

Taken together, these uncertainties emphasize the importance of conducting wide-scale, long-term empirical testing of the smart hockey stick. A more extensive and diverse range of participants, extended exposure to the device, and controlled conditions can provide a more comprehensive understanding of its impact on engagement and fun for para hockey players.

Future work

A list with possible improvements and shortcomings of the smart hockey stick was a result of the Interview with the coach. Each of these points will briefly be touched upon after which some additional possibilities for the smart hockey stick will be discussed.

There was confusion regarding LED color meaning, especially red and green.
Red and green should be removed from the array of colors and only be used when indicating wrong and right.

LEDS were not always visible during sunny days.
Because the smart stick has a detachable LED strip there should be multiple options for what stick to use during certain weather. Another option would be to increase and decrease the brightness in software however with the current version it was not able to increase the brightness thus other LED options should still be considered.

Coach had difficulties remembering the order of colors and what function belonged to what game mode.
This will get better the more the smart stick is being used. However, there should also be an option for the coach to decide how the LEDs will progress in each game mode and explanation for what each game mode is. Optimally this could be done during the practice for example by using a phone application. This will make the stick even more versatile and will help the coach in remembering the color order and game mode functionalities.

Calibration should be more reliable.
Ideally the stick is not only able to detect when a ball is passed but also what specific technique is used when passing the ball. The used sensor should be able to do this with enough signal processing. Possibly a machine learning software could be used to identify the different techniques and will over time be more and more reliable.

Concerns regarding durability of the smart stick device.
Decreasing the mass will result in a lower applied force to the smart stick device. In addition, the size should be decreased, especially the height to limit impact during techniques like the backhand sweep. The best way to decrease this height is by putting all components on a PCB as the started development during this research. Also, there should be a damping material between the stick itself and the device. In this current prototype neoprene fulfilled this function. Which worked well.

Should be easily attachable and detachable from the stick.
This was one of the main points of feedback for the stick to be used during a training session. A possible solution is a neoprene sleave which can be put over a stick. Due to the durable but also flexible properties of neoprene it is expected that this is a suitable material for this.

Need for a start button.
All sticks should be able to be in sync was the requirement that the coach had. This could be done if all smart stick devices are connected to one central point like for instance an application that the coach can run on her phone. From this one place the coach is able to start and stop each stick and to change game modes and features of each individual stick or all the sticks at once giving her full control over the sticks as she desired.

Additional game mode visualizing hit strength/speed.
The coach asked for an additional game mode to visualize the strength of the hit. This could be done by taking the max total acceleration which has been set during calibration. This value times three can be set to be the absolute maximum hit strength. We assume that a player can hit three times as hard as their regular pass. The stick can map the absolute maximum hit strength to the ten LEDs to visualized with the number of LEDs that light up how hard they hit the ball. The maximum number that lights up should be shown for an extended period, so players are able to view their strength themselves.

In addition to these points of improvement an interesting addition for the smart hockey stick would be to make it easier to modify by the users (with help of their parents) and the coach. The smart stick is perfect for employing drag and drop programming (Bau et al., 2017) as both in and outputs are rather simple especially when the user can simply drag and drop actions like “if a hockey strike is observed than do …”. In addition, a centralized application to run on a mobile phone which can control several connected sticks could be beneficial and should already be possible with this current version. This is worth investigating.

Chapter 8 – Concluding remarks

The development and testing of the smart hockey stick have demonstrated its potential to enhance engagement and fun among para-hockey players. By incorporating LED lights and sensors, the smart stick provided real-time feedback during gameplay, allowing players to focus on improving their techniques. The user study with para-hockey players revealed positive feedback and a preference for the smart stick over the normal stick, indicating its promising application in inclusive sports settings. However, some limitations were identified, including confusion with LED color meanings and concerns about stick durability and calibration reliability. Future work should focus on addressing these shortcomings and conducting a wider-scale user study to assess the system's effectiveness with different user groups and sports domains. By exploring the design space and tailoring the smart hockey stick to specific training contexts, it has the potential to become a versatile and valuable tool in empowering individuals of all abilities to fully participate and experience joy on the field.

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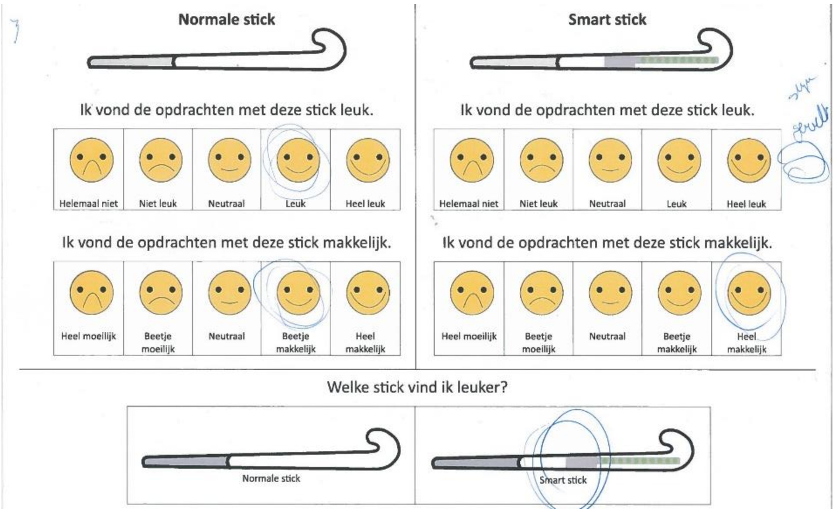
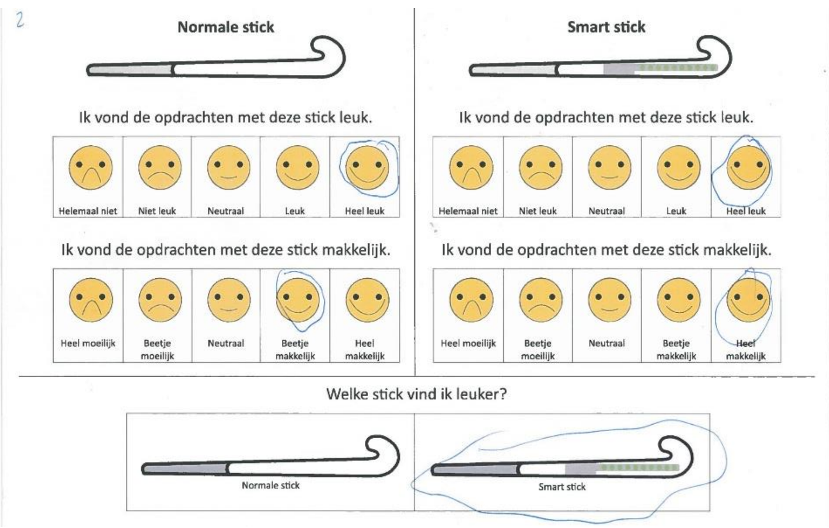
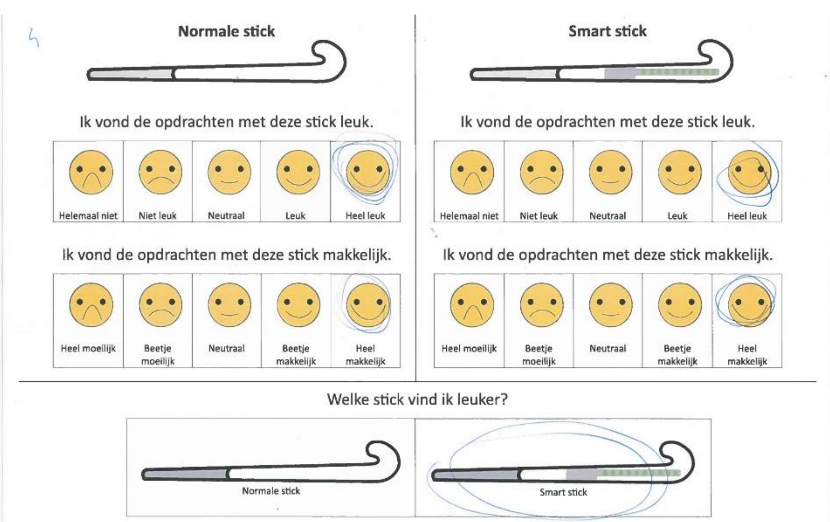
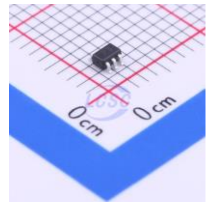
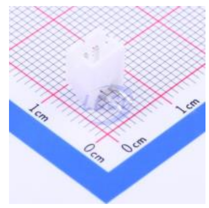
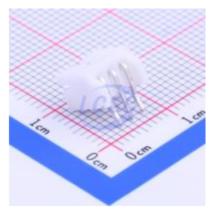
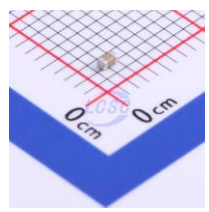
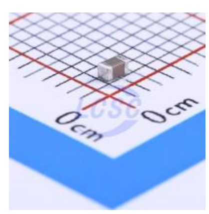
Appendix A: Smileyometer results

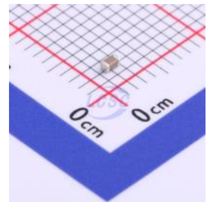
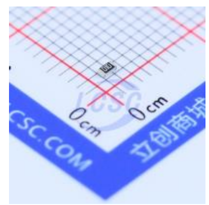
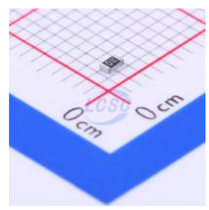
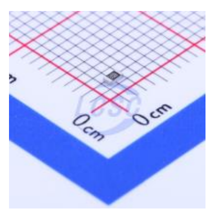


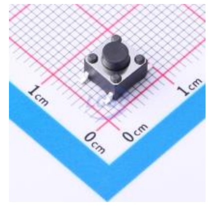
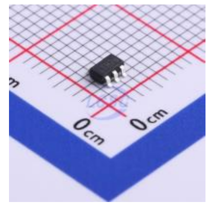
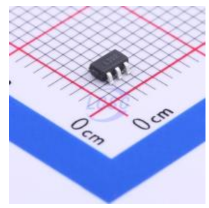
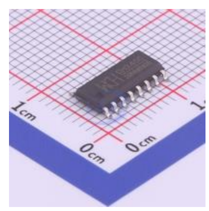
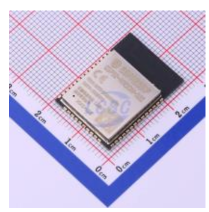
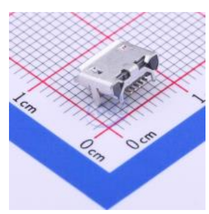


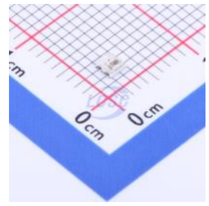


Appendix B: Information on PCB parts

Name	Description	Function	Photo	Price/piece	amount
UMH3N	2 NPN - Pre-Biased 150mW 100mA 50V SOT-363-6(SC-70-6) Digital Transistors ROHS	Auto programming of esp32		0.0446	1
S2B-PH-K-S(LF)(SN)	1x2P PH 1 2mm 2 Brass Push-Pull,P=2mm Wire To Board / Wire To Wire Connector ROHS	Battery connector		0.0263	1
S3B-PH-K-S-(LF)(SN)	1x3P PH Wire To Board / Wire To Wire Connector ROHS	LED connector		0.0332	1
10nF	50V 10nF X7R ±10% 0603 Multilayer Ceramic Capacitors MLCC - SMD/SMT ROHS	Capacitor		0.0020	1
10uF	16V 10uF X5R ±20% 0603 Multilayer Ceramic Capacitors MLCC - SMD/SMT ROHS	Capacitor		0.0162	2

100nF	50V 100nF X7R ±10% 0603 Multilayer Ceramic Capacitors MLCC - SMD/SMT ROHS	Capacitor		0.0022	13
LED-0603_R	617.5nm~633.5nm Red 60mW 0603 Light Emitting Diodes (LED) ROHS	Red indicator LED		0.0152	2
100k	100mW Thick Film Resistors ±1% 100kΩ 0603 Chip Resistor - Surface Mount ROHS	Resistor		0.0010	2
10k	100mW Thick Film Resistors ±1% 10kΩ 0603 Chip Resistor - Surface Mount ROHS	Resistor		0.0009	4
2k	00mW Thick Film Resistors ±1% 2kΩ 0603 Chip Resistor - Surface Mount ROHS	Resistor		0.0010	2
SS12D07VG6 087	Vertical plug 500mA SPDT 50V 5000次 Plugin Slide Switches ROHS	On/off switch		0.0220	1

TSD003B05018A33	50mA Brick nogging 1000000 times 12V SMD Tactile Switches ROHS	Button		0.0222	2
TP4054_C668215	SOT-23-5L Battery Management ICs ROHS	Battery charger chip		0.0344	1
SPX3819M5-L-3-3/TR	500mA 70dB Fixed 3.3V~3.3V Positive 16V SOT-23-5 Linear Voltage Regulators (LDO) ROHS	LDO		0.1478	1
CH340C	2Mbps Transceiver USB 2.0 SOP-16 USB ICs ROHS	USB to UART		0.4308	1
ESP32-WROOM-32E(4MB)	SMD,18x25.5mm WiFi Modules ROHS	IC with bluetooth and wifi		3.0967	1
MICROXNJ	1A USB 2.0 1 Surface Mount 5 Female -20℃~+85℃ Micro-B SMD USB Connectors ROHS	USB 2.0		0.0309	1

WS2812B-2020	RGB SMD,2x2mm Light Emitting Diodes (LED) ROHS	RGB individually addressable LEDs		0.0960	10
MPU6050					1
1000mAh lipo					1

All passive components (resistors and capacitors) have a 0603 package size this means the package is .06 inches in length and.03 inches in width, this is 1.55 ± 0.05 mm length by 0.85 ± 0.05 mm width. This is to ensure that all these components can be soldered by hand.

Appendix C: Empty observation sheet

Observer name:

Game played: 1 2 3 4

Behaviour	Amount	Notes
Laughter Laughing out loud		
Positive vocalization Cheering		
Increased energy Jumping, clapping, becoming livelier		
Concentration signs quietness, finger in mouth, staring		
Demonstrating understanding Nodding, giving affirming gestures		
Ask on topic questions Relevant to the main discussion		
Ask of topic questions Irrelevant to the main discussion		
Signs of boredom Fiddling, ear playing		
Looking into the distance Missing the assignment		
Walking off Away from the exercise or field		
Negative vocalization Angry screaming, vocal frustration		
Frowning Negative facial expressions		
Throwing stick		

Appendix D: Code

```
// LEDS
#include <Adafruit_NeoPixel.h>
#define PIN 32
#define NUMPIXELS 10
Adafruit_NeoPixel pixels = Adafruit_NeoPixel(NUMPIXELS, PIN, NEO_GRB + NEO_KHZ800);

uint32_t red = pixels.Color(255, 0, 0);  //Red
uint32_t green = pixels.Color(0, 255, 0);  //Green
uint32_t blue = pixels.Color(0, 0, 255);  //Blue
uint32_t yellow = pixels.Color(255, 255, 0); //Yellow
uint32_t purple = pixels.Color(255, 0, 255); //Purple
uint32_t colors[] = {red, green, blue, yellow, purple};
unsigned char totalColors = 5;
unsigned char currentColor = 0;
int x = 0;

// MPU
#include <Adafruit_MPU6050.h> //https://github.com/adafruit/Adafruit_MPU6050
#include <Adafruit_Sensor.h>
#include <Wire.h>
Adafruit_MPU6050 mpu; //SDA 21, SCL 22
sensors_event_t a, g, temp;
float normalForce, maxNForce, minAccelY;
float rotY, oRotY;
#define n 40
// OTHEr
bool pressed = true;
bool displayGameMode = false;
#include <math.h>
long randomNumber;
bool hitY = false;
bool hitN = false;
//states
#define totalModes 5
unsigned int gameMode = 100;
// timing
unsigned long waitingTime, hitDelayTimer, timerY, timerN;
unsigned long loopStartTime;
const unsigned long hitDelayTime = 500;
const unsigned long desiredLoopPeriodMicros = 5000; // 1/200Hz = 5ms
const unsigned long minLoopPeriodMicros = 5100; // Minimum 196Hz
const unsigned long maxLoopPeriodMicros = 4900; // Maximum 204Hz
```

```
void setup() {
  Serial.begin(115200);
  while (!Serial)
    delay(10); // Pause until serial console opens
  Serial.println("Adafruit MPU6050 test!");
  Wire.begin(23, 19); // set SDA 23, SCL 19
  if (!mpu.begin()) {  // Try to initialize!
    Serial.println("Failed to find MPU6050 chip");
    while (1) {
      delay(10);
    }
  }
  mpu.setAccelerometerRange(MPU6050_RANGE_16_G); //2, 4, 8, 16
  mpu.setGyroRange(MPU6050_RANGE_1000_DEG); //250, 500, 1000, 2000
  mpu.setFilterBandwidth(MPU6050_BAND_5_HZ); // 5, 10, 21, 44, 94, 184, 260 Lowpass cutoff
  // mpu.setHighPassFilter(MPU6050_HIGHPASS_0_63_HZ);

  pixels.setBrightness(25);
  pixels.begin();
  pinMode(2, INPUT_PULLUP); //IO2 input button
  delay(1000);
  loopStartTime = micros();
}

void loop() {
  unsigned long currentTime = micros();
  unsigned long elapsedTime = currentTime - loopStartTime;
  if (elapsedTime >= minLoopPeriodMicros) {
    // Run your main loop code at the desired frequency


    mpu.getEvent(&a, &g, &temp);
    normalForce = sqrt(pow(a.acceleration.x, 2) + pow(a.acceleration.y, 2) +
pow(a.acceleration.z, 2));

    /* Check if button is pressed*/
    if (digitalRead(2) == LOW && pressed == false) {
      pressed = true;
      gameMode++;
      currentColor = 0;
      displayGameMode = true;
      waitingTime = millis();
      if (gameMode > totalModes) {
        gameMode = 1;
      }
```

```
    } else if (digitalRead(2) == HIGH) {
      pressed = false;
    }
    pixels.clear();
    /* Game modes*/
    switch (gameMode) {
      case 1: // color per pass
        CheckHit(a.acceleration.y, normalForce);
        if (hitN == true && hitY == true  &&  millis() > hitDelayTimer + hitDelayTime) { //
did the stick hit after waiting?
          currentColor++;
          hitDelayTimer = millis();
        }
        if (currentColor >= totalColors) {
          currentColor = 0;
        }
        pixels.fill( colors[currentColor] , 0, NUMPIXELS);
        break;

      case 2: // count per pass
        CheckHit(a.acceleration.y, normalForce);
        if (hitN  &&  millis() > hitDelayTimer + hitDelayTime) { // did the stick hit after
waiting?
          if (x < NUMPIXELS) {
            x++;
          } else {
            currentColor = (currentColor + 1) % totalColors;
            x = 1;
          }
          hitDelayTimer = millis();
        }
        pixels.fill(colors[currentColor], 0, x); // Lavender for low to high
        break;

      case 3: // Random color
        CheckHit(a.acceleration.y, normalForce);
        if (hitN &&  millis() > hitDelayTimer + hitDelayTime) {
          hitDelayTimer = millis();
          randomNumber = random(2);
          waitingTime = millis();
        }
        pixels.fill(colors[randomNumber], 0, NUMPIXELS);
        if (millis() < waitingTime + 1000) {
          pixels.fill(pixels.Color(0, 0, 0), 0, NUMPIXELS);
        }
```

```
      break;

    case 4: // tilt angle
      rotY = (oRotY * n + (atan2(-a.acceleration.x, a.acceleration.z) * 180 / PI)) / (n +
1);
      oRotY = rotY;
      pixels.fill(pixels.Color(0, 0, 255), 0, NUMPIXELS);
      if (a.acceleration.y >= -9.5) {
        pixels.clear();
        if (20 <= rotY && rotY <= 60) {
          pixels.fill(pixels.Color(0, 255, 0), 0, NUMPIXELS);
        } else if (rotY > 115) {
          pixels.setPixelColor(9, pixels.Color(255, 0, 0));
        } else if (rotY < 0) {
          pixels.setPixelColor(0, pixels.Color(255, 0, 0));
        } else if (rotY < 20) {
          int i = map(rotY, 0, 20, 0, 4);
          pixels.setPixelColor(i, pixels.Color(255, 0, 0));
        } else if (rotY > 60) {
          int i = map(rotY, 60, 115, 5, 9);
          pixels.setPixelColor(i, pixels.Color(255, 0, 0));
        }
      }
      break;

    case 5: // backhand stop
      rotY = (oRotY * n + (atan2(-a.acceleration.x, a.acceleration.z) * 180 / PI)) / (n +
1);
      oRotY = rotY;
      pixels.fill(pixels.Color(0, 0, 255), 0, NUMPIXELS);
      if (a.acceleration.y >= -9.5) {
        pixels.clear();
        if (-75 <= rotY && rotY <= -45) {
          pixels.fill(pixels.Color(0, 255, 0), 0, NUMPIXELS);
        } else if (rotY > -10) {
          pixels.setPixelColor(9, pixels.Color(255, 0, 0));
        } else if (rotY < -100) {
          pixels.setPixelColor(0, pixels.Color(255, 0, 0));
        } else if (rotY < -75) {
          int i = map(rotY, -100, -75, 0, 4);
          pixels.setPixelColor(i, pixels.Color(255, 0, 0));
        } else if (rotY > -45) {
          int i = map(rotY, -45, -10, 5, 9);
          pixels.setPixelColor(i, pixels.Color(255, 0, 0));
        }
```

```
        }
        break;

      default: //normalForce
        pixels.fill(pixels.Color(0, 0, 255), 0, NUMPIXELS);
        if (a.acceleration.y <= minAccelY) {
          minAccelY = a.acceleration.y;
        }
        if (normalForce > maxNForce) {
          maxNForce = normalForce;
        }
        break;
    }
    if (displayGameMode) {
      pixels.fill(pixels.Color(255, 255, 255), 0, gameMode);
      if (millis() > waitingTime + 1000) {
        displayGameMode = false;
      }
    }
    pixels.show();
    unsigned long remainingTime = desiredLoopPeriodMicros - (micros() - loopStartTime);
    if (remainingTime > 0 && remainingTime <= maxLoopPeriodMicros) {
      while (micros() - loopStartTime < remainingTime) {
        // Wait until the remaining time has elapsed
      }
    }
    loopStartTime += desiredLoopPeriodMicros;
  }
}
void CheckHit(float accelY, float nForce) {
  if (accelY < 0.8 * minAccelY) {
    hitY = true;
    timerY = millis();
  } else if (millis() > timerY + 150) {
    hitY = false;
  }
  if (nForce > 0.8 * maxNForce) {
    hitN = true;
    timerN = millis();
  } else if (millis() > timerN + 150) {
    hitN = false;

  }
}
```