The University of Electro-Communications

Graduate school of Information Systems

Ph.D. thesis

DESIGNING AUGMENTED SPORTS: TEAM GAMES WITH A BALL

Student ID: 1560005

Name: REBANE Kadri

Department: Information Systems

Course: Media Information Systems

Supervisor: NOJIMA Takuya 印

Co-supervisor: HIROTA Koichi 印

Co-supervisor: HASHIYAMA Tomonori 印

Submitted: October 08, 2020

Revised: March 3rd 2021, June 30th 2021

Author declaration

I declare that this thesis is an original report of my research, has been written by me, and has not been submitted for any previous degree. The system development was done in collaborations with other augmented sports team members, and the collaborative contributions have been indicated clearly and acknowledged. Due references have been provided on all supporting literature and resources.

Parts of this work have been previously published in the sources listed under the list of publications.

Abstract

People are made for moving, but everyday activities and daily work have become much more sedentary over the last couple of decades. Getting enough physical exercise increasingly lies in the activities performed voluntarily during the person's free time. Social relationships and fun are good indicators for predicting sports participation. Team games are a great way to form social relationships and get the physical activity necessary to maintain and improve physical and mental well-being. However, team games' competitive nature can be intimidating for people less confident in their physical skills in the sport. Advances in technology and knowledge in computer game design have lots of potential for making traditional sports more exciting and easily approachable for a wider audience. This thesis gives an overview of augmentation possibilities using technology both from the game design and hardware development sides. We describe a way to augment team games with parameters known from computer games, like life points, attack power, defense power, to add more strategical depth and sophisticated game elements to emphasize teamwork and social communication between players. The theoretical overview is followed by a description of augmented dodgeball, a game designed to allow players with different skill levels to enjoy playing together. Augmented dodgeball is a game played in both the real and virtual worlds. It is played with a real ball and players, but the players' actions like

throwing the ball or getting hit by the ball also have meaning in the virtual world. The development of the prototype system's all different versions are described, and the design decisions and alterations that were tried during the process. The third part focuses on evaluating the system with a playtest in two different development stages as well as discussions, observations, and feedback from players that were obtained during playtests and public-private demonstrations of the developed system and concept

Abbreviations and definitions

ADB – Augmented Dodgeball

AR – artificial reality

Augmented sports – Augmented sports/games are a subsection of exertion games. They focus on the already known activity or exertion and enhance it with technology [34].

DB – dodgeball

Exergames – a combination of exertion and video games, including strength training, balance, and flexibility activities [31].

HMD – a head-mounted display

IBM – integrated behavior model

MTAR – missing data at random

RFID – Radio-frequency identification

RPG – Role Playing Game

SUP – stand up paddling

VR – virtual reality

Table of contents

List of publications

Journal

[1] Kadri Rebane, Yo Inoue, Ryota Shijo, David Hornmark, Sho Sakurai, Koichi Hirota, and Takuya Nojima "Augmenting team games with a ball to promote cooperative play" in Augmented Human Research Journal. Published April 7th, 2021

[2] Kadri Rebane, David Hoernmark, Ryota Shijo, Sho Sakurai, Koichi Hirota, Takuya Nojima “Developing the Thrower Detection System for Seamless Player-Ball Interaction in Augmented Dodgeball” in Transactions of the Virtual Reality Society of Japan Vol 26, No2 (p129-138), 2021. https://doi.org/10.18974/tvrsj.26.2_129

International conference paper (with review)

[1] Kadri Rebane, Takahiro Kai, Naoki Endo, Tomonari Imai, Takuya Nojima, and Yohei Yanase, "Insights of the augmented dodgeball game design and playtest," in Proceedings of Augmented Human Conference, Mar. 2017, pp. 1–10, DOI:10.1145/3041164.3041181.

[2] Kadri Rebane, Ryota Shijo, Tim Schewe, Jingyi Jiang, and Takuya Nojima "Augmented dodgeball: extended abstract" In Proceedings of the First Superhuman Sports Design Challenge: First International

Symposium on Amplifying Capabilities and Competing in Mixed Realities (SHS' 18). Association for Computing Machinery, New York, NY, USA, Article 5, 1–5, Jul 2018, DOI:https://doi.org/10.1145/3210299.3210304ers

[3] Takuya Nojima, Kadri Rebane, Ryota Shijo, Tim Schewe, Shota Azuma, Yo Inoue, Takahiro Kai, Naoki Endo, and Yohei Yanase. "Designing augmented sports: Merging physical sports and virtual world game concept." In International Conference on Human Interface and the Management of Information, pp. 403-414. Springer, Cham, 2018.

[4] Kadri Rebane, David Hörnmark, Ryota Shijo, Tim Schewe, Takuya Nojima "Augmented Dodgeball with Double Layered Balancing" In 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), pp. 1347-1348. IEEE, 2019.

Domestic conference paper (without review)

[1] 井上 暢, 四條 亮太, Kadri Rebane, 野嶋 琢也 "Augmented Dodgeball におけるプレイヤへの実時間情報伝達システムの開発" in IPSJ Interactions 2019

[2] 四條 亮太、Kadri Rebane、野嶋 琢也 "球技拡張のためのプレイヤ・ボールインタラクション検出デバイス" in the 22nd Annual Conference of the Virtual Reality Society of Japan, September 2017

[3] Kadri Rebane, Takahiro Kai, Naoki Endo, Yohei Yanase, and Takuya Nojima "Augmented Dodgeball: Gaming Experience Achieved with the Help of Technology" in the 34th Annual Conference of the Robotics Society of Japan, Yamagata, Japan. September 2016

Demos/posters/showcases

[1] Science Agora, Tokyo, Japan. November 2019. Playing Augmented Dodgeball

[2] Yomiuriland Special workshop, Kanagawa Japan August 2019. Playing Augmented Dodgeball

[3] IEEE VR Demo session, Osaka, Japan. March 2019. Poster, Demonstration of equipment.

[4] Kitahara Festival, Kitahara Rehabilitation Hospital, Hachioji, Tokyo, Japan, November 2018. Poster, Demonstration of equipment.

[5] JACI (Japan Association for Chemical Innovation), Industry-Academia Exchange in Hitotsubashi University, Tokyo, Japan. November 2018. Poster presentation

[6] Sabae Manufacturing Expo, Sabae City, Fukui, Japan. October 2018. Poster, demonstration of equipment.

[7] First Super-Human design challenge in Delft, Netherlands July 2018. Playing Augmented Dodgeball

[8] Superhuman Sports EXPO at DC EXPO June 2016, Tokyo, Japan. Playing Augmented Dodgeball

[9] UEC Tokyo open campus events. Poster, demonstration of equipment

List of figures

List of tables

1. Introduction

The fact that physical activities and sports are beneficial to a human-being is well known and proven by research [21], [28]. Being physically active reduces the risks of, for example, cardiovascular diseases, type 2 diabetes, hypertension, and obesity [37], [45]. It also has a positive effect on the muscles, joints, and bones [47]. However, the World Health Organization [54] claim that insufficient physical activity is one of the leading risk factors for death worldwide. Globally one in four adults is not active enough, and more than 80% of the world's adolescent population is insufficiently physically active. The WHO Member States have also agreed to reduce insufficient physical activity by 10% by 2025. Sedentary work is common [44]. Also, nowadays, in the USA, only about 20% of jobs require at least moderate-intensity physical activity. This number was about 50% in the early 1960s, which means that the energy expenditure during work time has lowered and correlated with overall population weight gain [5]. So, for most people, the main physical activity should be performed voluntarily by the person during their free time. As the action is voluntary, the overall rate at which the people are active is low and physical activity is a great way to maintain and increase physical and mental wellbeing. It is essential to design sports to make them more attractive for participating. This thesis introduces a design method to promote physical activity through team games and, therefore, potentially help form a habit of

being active. We use the knowledge from research carried out in the human behavior and habit domains as a reference for using novel game design elements for creating new sports games.

This thesis is organized in the following way:

The chapter background describes the phycological aspects of human motivation. It explains what kind of activities and designs have successfully created and maintained a person's attention to continue the action. The augmentation paragraph gives a theoretical overview of different methods for augmenting sports/activities and is meant to serve as a guide for designing augmented sports. The emphasis of sports design is put on team games with a ball. Then augmented dodgeball is described. Augmented dodgeball is a game developed as a case study to show how team games with a ball can be designed. The chapter discusses the design considerations both from the game design and device development side and presents three generations of devices we have used during the development. Chapter 4 concentrates on evaluating the augmented dodgeball. It consists of two playtests and presents the observations, discussion, and feedback from the players and other researchers we have obtained during numerous demonstrations and public showcases.

The contribution of this thesis is the following:

- A theoretical base of design principles for augmenting team games was formed.

- Augmented dodgeball game and system was developed (with the augmented sports team in Nojima lab)
- Evaluation of the system is provided with two playtest and through discussions and observations.

Playtest 1 used the very first generation of augmented dodgeball system and focused on the following claims:

- Introducing player roles would make the players act according to them.
- The player roles help to make collaboration during the game and therefore increases the enjoyment.
- Dodgeball will become a game of tactics.

Playtest 2 used the third generation of augmented dodgeball system and focused on the following claims:

- Augmenting team games help create social communication between players.
- Augmented team games make the playing experience more exciting.

The interview and observation part of the evaluation concentrates on the players experience and expectations. We also explain how player behaviors change when the system and game do not fulfill the expectations. Another team game augmentation based on the theoretical points and the case study results about augmented dodgeball is discussed in the discussion part.

2. Background

Being physically active is vital in every age helping with life quality and satisfaction. It is also essential to participate in the activity that corresponds to the individual's physical fitness level. Too easy practices do not develop skills, and too hard ones can result in injury. According to the flow theory by psychologist Mihalyi Csikszentmihalyi, people are most motivated and can concentrate in a state of flow. Flow state is achieved when the task at hand has a good match between the participant's perceived ability and the activity's challenge [6].

Motivation and willingness to participate in sports are associated with spending time with friends, popularity, fitness/health, social status, sports events, relaxation through sport [22]. Team games are an excellent tool for fun and social relationships, which are essential factors when deciding whether to participate in the activity [1]. Also, people are more likely to stick to the action when they do things together as it helps to make and keep the commitment and therefore serves to enforce a new habit [9].

People are by nature trying to be their best in what they do. Furthermore, according to the Self-determination theory [41], the factors that enhance their self-motivation and personality integration are competence, relatedness (being social and connected to others), and autonomy (independence,

personal achievements). So, creating an environment where these needs are satisfied will benefit people to strive for their goals.

However, in team game settings, it can be challenging to reach that kind of environment. The main reason is that it is required the presence of many people at the same place and at the same time with an objective that can be satisfied by doing team sports. Also, there is a 70% quitting rate in extracurricular sports activities among adolescents in the USA. The main reason they drop out is that the sports become unenjoyable. The main contributing parameters for enjoyment in sports are: playing as a team, being challenged, getting praised, playing time, positive attitude [46]. So, it is easy for team games to become unenjoyable if the team members have very different skill levels as the more skillful players would feel bored and the less competent players have no confidence in their skills.

Balancing or adding handicaps in a game has shown to be an effective way to improve self-esteem when done hidden. Using the conventional method of assigning levels to players, on the other hand, has led to reducing relatedness in players and lower self-esteem [11].

Computer games are played and enjoyed by many people, and the game designers and researchers have identified methods for making the games attractive to the players. For example, having player roles makes the players identify themselves with the part, act like they were the player, and contributes to the overall playing enjoyment [12]. Another enjoyment mechanism in

videogames is effectance: perception of causal influence on the game world (players feeling like their actions make a difference in the game world) [21]. While computer games are good at engaging people and providing enjoyment, they are also sedentary activities.

One way to make an activity more appealing is to gamify this. Gamification is defined as "*the practice of making activities more like games to make them more interesting or enjoyable*" [55], making physical activity more attractive by adding some game elements to it. Furthermore, it has been proven that it can be successfully applied to physical activities as well: "Our results suggest that gamification improves not only attitudes towards and enjoyment of exercise but also shapes behavior in terms of an increase in exercise activity" [9].

As a subsection of gamification, an emerging big field integrating the physical world with the digital one is exergames that are defined as "a combination of exertion and video games including strength training, balance, and flexibility activities. Exergaming is playing exergames or any other video games to promote physical activity" [34]. Another definition of exertion games is that they are a fusion of technology, play, and body [56]. A visual representation of this definition can be seen in Figure 1. These games often require specialized systems specially developed for the game and can cover a wide range of purposes, from bringing people together to specialized training and physiotherapy.

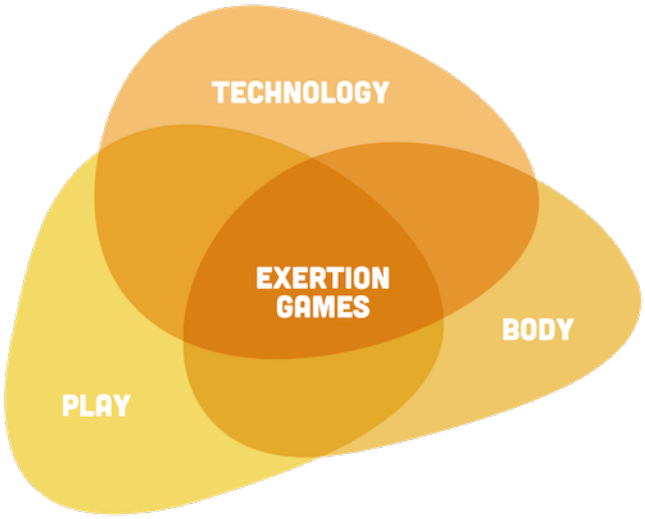

Figure 1: Visual definition of exertion games

Image source: http://exertiongameslab.org/about

Several guides help the game designers design these kinds of interfaces. [31] describes a theoretical framework on which points and movements of the human body to consider when creating an exertion interface. [16] gives more practical examples of the exergames and brings out acceptable practices when making these kinds of interfaces. [29] provides an overview of the psychological factors that people get from exercise and are an excellent guideline to consider when designing new exertion interfaces. These include an appreciation of the void, being fearful and excited at the same time, being aware of one's own body, and pleasure and humility. Some works describe how to create difficulty levels in movement-based games. Zhang et al. [50]

propose how to synthesize different levels based on poses. They use joint rotations and the center of mass as parameters for that. Xie et al. [49] describe a method to add junks of different movements to a journey-based game to achieve target exercise parameters such as intensity duration or calories burned.

Evaluation of such novel games can be tricky as there are no standards set, and each game has its different purpose—however, there some methods [26] to evaluate these kinds of interfaces.

Augmented games are a subsection of exertion games. They focus on the already known activity or exertion and enhance it with technology [31]. Jogging over a distance [28] is a system that enables people in two different geographical locations to exercise together. In addition to just comparing their results, the system allows for a real-time audio link between the users. It enables the joggers to compare their exertion by measuring heart rates and letting the exercise partners know about it. The system evaluation revealed it to provide the users with a social experience with an exercise partner in a different physical location. In the same boat [40] shows that other physical signals like facial expressions and breathing rate can also be used as an input to promote collaboration and create social experience over a distance. The augmented Climbing wall (Figure 2) [19] shows how technological advancements can be used to design more versatility and accompany different level climbers on an otherwise static climbing wall. Projection and

body tacking are used to use the same wall both for easier and advanced climbing courses and games that challenge and help develop the players' skill level of bouldering. Swim train [4] participant tracking to make an otherwise individual sort to a collaborative team effort that also considers the different levels of swimmers using stroke rate (strokes per time unit) as a measure. VR jumping and jogging game [15] that used the head-mounted display to augment in place actions proved that it is possible to increase intrinsic motivation, perceived competence, and flow with gaming technology. Li et al. [23] have proposed a system for cycling on a stationary bicycle wearing a head-mounted display to generate an exertion-aware path that satisfies the user set goals like the total work and perceived difficulty of the route.

Figure 2: Players on the augmented climbing wall

Image source: https://www.climbing.com/gear/interview-augmented-reality-climbing-games/

TAMA [35] is a ball that can change its trajectory using injected gas from a gas tank placed inside the ball. Shepherd Pass [32] is a ball-shaped quadcopter that can adjust its speed and trajectory based on the player's skill level. ACTUATE Racket [24] can change the angle of a table tennis racket's striking surface. SomaticBall [8] can make the ball stick to the player's hand using a magnetic force. These projects created active devices that can be used to introduce new game elements and handicaps between players.

However, the equipment design is closely related to the game design and cannot be easily changed or altered.

Augmenting something means making it greater in some way. In games, diminishing technology has also been used to provide unique and novel experiences. For example, D-Ball [42] uses a head-mounted display to diminish all the environment except for the markers on the ball and players. By doing this, passing the ball between players changes significantly, creating a new ball-catching game. Imaginary Reality basketball [2] uses a virtual ball that is not visible to the players. The players are only provided with some auditory feedback about the ball and should watch how other players act, to understand where is the ball.

When augmenting games by uniting the virtual and the physical world, it is essential to reflect actions and the corresponding reactions in these worlds. Moreover, a monitoring system is necessary. In projects like ShepherdPass [32], Catching the Drone [10], and Sports Support System [43], motion trackers are used to recognizing the players and ball(s), so a unique environment and setup are needed for these systems to work. For detecting the impact between the player and the ball, sensors can also be used. For example, Piezo elements have been used to calculate impact localization on table tennis rackets [3]. Gyro sensors attached to the players have been used to recognize the type of beach volleyball serve [7]. In football, pressure

sensors integrated into the shoe have been used to detect and analyze the interaction between the player's foot and the ball [51].

There are also several commercial gaming platforms where the physical input of the user controls computer games, like Nintendo Switch and its Sports Party [57], PlayStation Move controller [58], or Pokémon Go (Figure 3) [59], Harry Potter Wizards Unite [60], and HADO [61]. However, these games and platforms focus on adding motion to video games and using the screen or virtual world as a place for the player to focus, so they do not promote face-to-face interaction, collaboration, and intense action.

Figure 3: Playing Pokémon Go

Image source: https://nypost.com/2016/11/07/becoming-a-pro-pokemon-go-player-was-maybe-not-the-best-career-move/

Our project focuses on existing sports games as they have existed for a long time and are familiar to people. The rules have developed over time, making them sophisticated, well thought through, and widely accepted; they are proved to provide enjoyment and promote movement. However, as analog games, they solely focus on the physical characteristics of the players. They are not fit to be played by a group with significant differences in their physical skills.

The approach we are taking is adding video game elements to physical activities to make them more approachable, enjoyable and promote social relationships between the players in a real-world team game.

Virtual parameters and visualization techniques have been used for remote playing, training, and making solo sports have team sports elements. However, they have not been used for augmenting team sports that involve players playing together in the same physical space before. In our proposed method for augmenting team games, virtual parameters give the game designers the freedom to use computer game elements and rules in a real-world application.

This thesis gives an overview of different ways to augment sports and focuses on team games with a ball. It proposes a method to expand team games and focuses on players with varying experiences and backgrounds to enjoy being active together. In the case study, we use virtual parameters as a tool to incorporate sophisticated rules and characters for players to add tactics and teamwork to games, otherwise relying solely on physical skills. With our

developed game devices, we can also avoid cognitive overload during the game, enabling players to focus on the game.

3. Augmenting team games

According to the Cambridge dictionary, augmenting is the process of increasing the size, value, or quality of something by adding to it [62]. This project investigates how to augment team games to add value to the playing experience so that the player would feel welcome and engaged in the game. This may or may not include artificial and mixed reality technology. Our focus is on the player and its playing experience in team game settings.

This chapter gives an overview of the theoretical background of augmenting games. We focus on team games with the ball and overview how to develop such games based on existing sports, introduce different methods for augmentation, give some examples, and discuss some use scenarios for each method.

Our case study, augmented dodgeball, described in chapter four, uses digital augmentation, which allows us to create additional rules and new game elements and alter the game's focus to be more tactical. The theoretical background of our game design can be found in this paragraph.

3.1. Game design: finding the points to augment

After analyzing augmented games, we came up with a three-layer method for augmenting team sports. By analyzing each augmentation layer and deciding

on how that layer is desired in the actual game, game designers can systematically approach creating the game design (Figure 4).

Figure 4: augmentation layers for designing augmented team sports

In the game design step, the overall game purposes should be worded. Answering the following questions can help to form this layer of the game design: What is the purpose of the augmentation? What is the shortcoming of the game/sports? Identifying this allows us to know how to augment all the concepts. Is it to change the difficulty level? In what way? Who should be able to enjoy this game? Why are they not enjoying the game at the moment? Are some new gaming elements desired? Whom will they benefit?

For example, targeting the game to novice players can lead to a discussion and observations on what are the difficulties for them when playing. This step then can be used to identify the exact game mechanics that are challenging and set an overall theme of the augmentation. Targeting expert players and seeing their play would result in different results. Expert players are familiar with the game and they have confidence. Targeting expert players in the game design step would result in overviewing the from their standpoint. Identifying

some game elements that are boring or repetitive can help. At the same time, concentrating on what the expert players need to practice more can also help to set the theme for the overall game design. Targeting collaboration and inclusion between different background or skill level players would give the game design yet another direction. Identifying the problems and frustration points that can occur on the game level when very different level players play together would result a totally different game design.

The next step is to narrow the focus to the players and their experience in the game based on the overall purpose of the augmentation. The question to search the answer for is: What is the desired player response for each action in the game. What are the desired actions for each player in each situation, and how the game designer wants them to feel about the game before, during, and after it?

In player experience step, the overall direction of the game design should be continued and made more to the point based on the individual player perspective. For example, if the game direction is targeted to people who want to improve their playing skills, they should be presented with challenges in the game. Designing the challenges themselves as well as progression on how to keep it up, is the task in this design step. On the other hand, if the game design was directed to people who are looking for some fun past time activity, the focus could be to make the activity feel stress free and pleasurable. For example, walking from a perspective of a person who looks it as sports, could

be about helping them getting faster and more economic on their steps. For a person looking to getting some exercise the result could be to focus on how to activate more muscles during the activity. For a person looking to relieve some stress and leisurely spend time, adjusting to a slower tempo could be desired.

The final layer for designing augmented sports is the environment design. By analyzing where the game is taking place and which senses-ways of movements the players are using and are desired to use contributes to gaining a better understanding of which kind of physical playing environment is desired.

Again, taking into consideration the previous steps is necessary. Creating a competitive or challenging environment can be one goal that supports the overall design. In this case, changing the activity to be taken place in uneven surface or increasing some distances or playing field could help to design that. On the other hand, when designing for games for people with special needs, their skills and abilities should be taken into consideration. For example, players in wheelchairs probably would need more space for maneuvering and resizing some game props like hoops or nets could be desired.

Going through all the layers and analyzing what points of the game should and could be altered can help the game designer determine which points in the existing game can be augmented.

The next points should make the game designer consider how to implement the augmentation. When adding new rules/elements to the game, the designer must consider all the game stakeholders.

Here are the stakeholders to consider:

- Players
- Judges
- Helping/assisting staff
- Audience (spectators and observers)

Players are usually the center of attention for the game. The game should emerge them; they are busy with it, and most of their energy and attention are used on achieving the end goal of their game. When designing for the players, it is crucial to notice that their attention is limited, and information presented to them should be limited by the things they need to know according to the game design.

Judges should have a complete overview of the game and promptly do their duty in the game. It is necessary that the judges have a complete overview of the game at any point and that they understand the game and its rules to the fullest.

Helping/assisting staff are like helpers for the judges, They should have a clear overview of what is required of them, but the interface for them can be limited and not include the whole picture if it is required by the game design

The audience is also an important stakeholder to consider as the audience can produce new players to the game, increase the gaming satisfaction for the players, and promote the game. The audience can be divided into spectators (people who share the tension of the game, incorporate in some cheering) and observers (they view the game, maybe from a distance or via video, audio, or (social) media link, and have no influence at all to the players.) It is essential to notice that the audience interfaces should make the game state easily understandable and give an overview of the whole plot. The audience's interfaces can be more complex as the audience, in general, could focus on watching the game.

Not all of the games include all of them so that this list can be modified based on the existence or absence of a particular stakeholder group.

When designing the tools/technology, all these things have to be taken into consideration. Not all of the games need to include all of them so that this list can be modified based on the existence or absence of a particular stakeholder group.

3.2. Fusion of stakeholders

In sports, players are the people who have a direct influence on the outcome of the game. It is generally considered taboo to interfere with the game by any other person than the players. Spectators are the people who share the tension, and their presence can motivate players to play (ref to home and

away results in basketball, etc). According to the Colorado Rapids youth soccer club [63], spectators are expected to encourage players and not to participate (go to the field), coach, or give negative remarks. Similar codes of conduct are written to many other sports club homepages and are a common rule.

However, when we look at Gladiator fights in ancient Rome, which are a kind of early sports competition that draws many spectators, we can see that the gladiators were hired or owned by the noblemen and therefore represented them in the fight. In other words, the players represent the spectators [13].

Nowadays, sports teams have sponsors, and different countries have support systems for their athletes. Depending on these resources, some sportsmen have a better environment, equipment, and trainers to achieve more outstanding results in their respective sports. Although there are rules they need to follow during the competition to ensure a fair game, the background can have a significant influence on their achievements. So, in that sense, the background has a direct input on the outcome of the sports.

Depending on the sport, the game's outcome is decided by the judges and can depend on personal preferences. These include sports that give style points to athletes. For example, ski jumping, ballroom dancing, ice skating, gymnastics. These sports have at least some amount of the score determined by the judges on how stylish the act was. Can we say that the judge is the player? On one side, they do not win and get the prize in the competition. On

the other side, judges also have ranks and reputation. Being a successful and greatly looked-after judge is the desired outcome, just like in the early days of sports when the best player got all the respect. In that sense, we can say that there are like two different competitions taking place.

On the other hand, in entertainment, giving the audience and the judges the roles of the players (being directly responsible for the outcome of the game) is not considered taboo and is incorporated in many popular productions. These kinds of fusions have a very high popularity and are very engaging. Some examples of player/judge/audience infusion include TV shows like "Who wants to be a millionaire?[64] In this TV show, the player has to answer multiple-choice questions, and each answer, if correct, could win them some money. If the answer incorrectly, the game is over, and depending on how many correct answers they had before, they may or may not win any. The audience and the player's friends are given chances to influence and tell the player which answer to choose directly, and viewers at home can test their knowledge of the game in a more relaxed environment.

The audience is also given great power in determining the winner in many other kinds of TV shows and competitions, like The Voice [65] (TV show for singers), Got Talent [66] (a talent show where people with all kinds of skills could come and show off their talent and compete for a prize). The latter having local formats in 69 different countries proving that these kinds of shows get the attention both from the contestants and the audience.

One of the newest and most fusional player/audience/judge entertainment shows is called the Masked Singer[67], originating from Korea, but having many local versions. In that show, famous people are singing some songs, and the judges (detectives) must guess who they are by the hints they give and their singing voice/style. The audience also has a way to vote on who should reveal their identity and leave the show. In that show, the contestants play on how long they can keep their identity hidden. The detectives play on how well they can identify and guess who the contestants are, and the audience can judge the performances and play along with the detectives on the guessing game.

In team sports, baseball and American football are good examples of how to make a game that incorporates two different competitions that are separated from each other. They both have a turn where one team tries to score, and the other one stops them from scoring. And then they change their roles.

Although many team sports, like volleyball, basketball, and football, have different roles assigned to the players, they still play against each other at the same time, not changing the roles.

Augmented sports and team games have a vast spectrum, and therefore, when designing for a new game and experience, it is ok to break the taboos of traditional sports and think about stakeholders and their roles. As sports and the entertainment industry's history has shown, fusion among stakeholders and designing the play in different dimensions can result in a

very engaging experience. Furthermore, engagement should be a goal of each game.

3.3. Methods for augmentation

Most games and sports are quite simple to understand. Although performing the action right can be challenging, sports and games generally have very straightforward principles. In the running, the winner is the person who runs the fastest, and in football, the team that can hit the ball to the opposing team's gate the most. Of course, when sports evolved, the rules got stricter, starting from the limitations on which footwear to use when running and which ways of handling the ball are acceptable and which not, but the essence of the game or sports remains relatively simple. One major cause of this is that making the activity rules too difficult would result in cognitive overload for the players and slow down the game. Also, when games have complicated rules, it is easy for the players to get into arguments, and instead of playing and enjoying themselves, the situation can cause much anger and frustration, which makes the playing experience stressful and overall an adverse event.

A general understanding of sports is that the best one should win and that the most exciting game is the one that is between equally skilled players, both for the audience and the players themselves. However, this can be hard to achieve, especially when it is a more casual environment. In some games, there are systems in place to account for the differences in players' skills. For example, in golf, players are given a handicap, and as they progress, the

handicap score starts to represent their skill in the game. In team game settings, sometimes there are rules of having the same number of male and female players in a team or giving some advantage to the weaker player. For example, in dodgeball, the weaker player can get hit 2 or 3 times instead, or the stronger player can be put in a more difficult situation, like only using their nondominant hand when throwing the ball.

These alterations to the games are easy to make on the spot and relatively easy to follow. However, the downside is that they label players, which can make the weaker players feel self-conscious and not enjoy the activity as much because they feel they are not an essential part of the game, and even if some success is achieved, it will be dismissed by themselves and the fellow players because they had some advantage in the game. These kinds of alterations can never be too complex and sophisticated because they would cause too much cognitive load to the players and take the attention away from the game. Secondly, these kinds of alterations are limited by the physical world. The alteration either exists or not. For example, when a player is permitted to use only their non-dominant hand, the rule is either there or not, there is nothing in between, and the balancing cannot be done dynamically.

A field that has mastered the art of creating engaging experiences and does very well in balancing between different skill level players is the video game industry. The video game designers create visually exciting and appealing graphics, make them into a story that the player feels, they can influence, and

let the players compete on the levels that are gradually getting harder as the play and players' skill evolve. Also, players feel productive, feel that they are in charge, and thinking and trying out different strategies in-game is interesting.

Video games have also evolved and moved away from only keyboard and game controllers that only have pushbuttons. Head mount displays (HMD) can create an even more exciting world by immersing the player totally into the virtual world. Different props and computer graphics can create a virtual reality similar to the real world or create an entire fantasy world. Devices like HoloLens [68] help create mixed-reality environments that unite the physical world with the virtual world by displaying the virtual components on top of the natural surroundings (Figure 5).

Figure 5: HoloLens brings computer graphics to the natural environment

Image source: https://www.microsoft.com/en-us/hololens

Additionally, tracking systems like Vive [69] that allow capturing the user movement lead to translating the physical world movements into the virtual world. Azure Kinect DK [70] is a powerful sensor for computer vision and speech models. Moreover, commercially, some video games already have controllers that can take human movement as input. Examples of those include Nintendo Switch and its Sports Party [57], PlayStation Move[58] controller.

A smartphone is another gadget, full of high-quality sensors and many tutorials on how to create custom apps that take advantage of the sensors built into the device and the network connectivity, make them useful design tools, and most importantly, common in everybody's lives.

Computer games have done very well in engaging people in the virtual world. Development of virtualization technology, how technologically conscious people are, and the availability of various kits and sensors that are easy to use let the designers-researchers and hobbyists express and try to put the interface ideas more easily cheaply. This gives a great platform also for creating augmented games by uniting the virtual and real worlds. This way, we can use the computer game design's flexibility and complexity in a real-world setting.

Another way to augment the game is to add or restrict some physical layer or ability in the game. That includes games that are taken to some new level, for example, wheelchair basketball. It enables people in wheelchairs to enjoy a full basketball game by restricting all players to be sitting in one [71]. Or blind soccer [72]. In this game, people play the soccer game without having a visual input on where the ball is. The ball is tracked by the sound it makes. It opens up the world of sports to visually impaired people and welcomes players with good eyesight, who then blind themselves during the game.

Another example is Mucleblazer [20], which comprises a vest infused with tubes that can be filled with air. Depending on which tube is inflated, it can either make specific movements easier or restrict them. Muscleblazer is a shooting game, and when the player gets hit, their movements are being restricted to simulate getting hurt.

Figure 6: Wheelchair basketball

Image source: https://www.paralympic.org/news/summer-wheelchair-basketball

By changing the core thing on how or where people can move or which senses to use can mechanically alter the game so much that the experience of playing it changes considerably.

The third way to augment the game is to add some sense or sensation that usually is not present in the game. For example, people's sense of smell is not very highly developed. So, any game that would require relying on the smell sense is restricted to the people. On the other hand, dogs have a great sense of smell, so they can be the aids (or kinds of sensors) to aid people to follow

a game that relies on the sense of smell. An example is hunting for truffles. Simultaneously, while it is a fun activity for the dogs, the real prize (or work goal) is obtained by the person who then gets the truffle[73]. These kinds of "sensors" do not have to be living but could also be produced artificially. For example, in a game of finding a way in a maze blindfolded, a person would need some aid. It could be a guide dog, but at the same time, a device with proximity sensors would work also. So, developing and finding a sense or sensation not existing or poorly developed could contribute to augmenting an activity.

The fourth way of augmenting an activity is to change the place and/or dimension of the activity. New movements and challenges can be created by changing the environment, or a too challenging movement can be made easier. Some examples of this kind of augmentation are SUP (stand-up paddling) yoga [74]. In this activity, yoga movements are taken to a giant surfing board on the water, requiring the participants to make an extra effort to stabilize themselves. Another great example of sports taken to a different level is the Luna G ball [75] that puts the player into a horizontal position using ropes and lets them move by hopping on a vertical wall. In this position, players play catch ball.

The four ways of augmenting the activity can be used independently or combined by taking advantage of all the different changes that each way of

augmenting could bring to the experience. Table 1 summarizes the augmentation methods described in this section.

Table 1: Ways for augmentation

Augmented element	Description	Example
Uniting virtual and real worlds	Using physical movement as an input for a goal set in the virtual world	Pokémon Go [59], Augmented climbing wall [19]
Add or restrict a physical sensation/ability in the game	Changing the core thing on how or where people can move or which senses to use	Wheelchair basketball [71], blind soccer [72], Muscleblazer [20]
Add/replace a sense or sensation that usually is/is not present	Making the game about a sense that people do not have or that is not well developed, so equipment could aid the player with the missing sense or replacing one of the existing senses	Truffle hunting[73], finding a way in a maze, in the dark using some guide device

Change the place and/or dimension where the activity takes place	By changing the environment, new movements and challenges can be created, or a too challenging movement can be made easier	SUP (stand up paddling) yoga [74], Luna G ball [75]

3.3.1. Interaction with the ball

This project concentrates on team games with a ball. The ball's movement in the game is the center of attention and the source of action and excitement, so we can say that the human-ball interaction plays an important part. When we talk about augmented games and the augmentation uses virtualization technologies, we can also have the ball move in the physical world, virtual world, or have some kind of a combination of both. As the movement and/or state of the ball is a central part, the stakeholders need to know the ball's state during the game. In most ballgames, it is essential to know which player interacts with the ball at a particular moment and how also where in the field is the ball. Depending on the game design, this information is crucial to be presented to the players and the audience in some way.

When designing the player ball interaction and deciding between physical, virtual, or a mixed ball representation, the following considerations should be made:

Player safety: when the game has a physical ball, all possible trajectories of the ball should be considered when designing the augmented game's technical systems. For example, players wearing expensive and still fragile HMD systems might pose a risk to the players' health and the equipment when the device gets hit by the ball. Although the rules of the game might forbid the players to form throwing the ball in specific ways and directions, designers must accept the fact that players always will try to outsmart the rules and find ways to fulfill the game goal, so their behavior and response in the game might differ from what is expected by the designer.

Virtual world representation: when the player-ball interaction is taken to the virtual world, all stakeholders should clearly understand how the game is progressing. Virtual world representation can be different for each stakeholder group or even by each stakeholder if it fulfills the augmented game purpose. Representing the virtual world should consider the cognitive load it will demand from the stakeholders and how much information is needed by any given stakeholder at any point in time. By creating a heavy cognitive load with the virtual world representation, the game might become more strategic but will lose in tempo. On the other hand, having a fast-paced game with no virtual world representation results in the problems described previously, like the

heavy reliance on some specific physical skill, no balancing, gradual progress, etc.

Immersing the virtual and physical world: to have a game in two different dimensions, actions in the physical world should produce reactions in the virtual world and vice versa. These action/reaction pairs are expected to be logical, as designed, explained by the rules, and almost immediately. For example, when throwing the ball, the player expects it to move in the direction they threw. Having a reliable action/reaction relationship helps players gain trust in the system and the game and focus on the game. If the action/reaction system fails, the players start to doubt the system, which creates tension and arguments between players (and possibly other stakeholders) and results in a low playing satisfaction.

3.4. Technical solutions for augmentation

In this section, some technical ways of creating digital augmentation are discussed. Digital augmentation is the newest and the least investigated way of augmenting sports. In digital augmentation, the key to success is to create appropriate action-reaction interaction. Although a fast and real-time interface could be the goal of each such action-reaction pair, concepts of game design and different ideas can be tested out also without reaching the fully automatic real-time interface level. The key concepts to do that is to manage player expectations on the system as a whole and incorporate human judges and the Wizard of Oz testing method. The Wizard of oz method means that the user

is using an interface that does not exist yet. Instead, all the reactions by the system are provided by another person. This is a great way to get to know and test out user behaviors in the augmented game. The augmentation system can be divided accordingly:

- System for tracking
- System for notifications

The tracking systems are the ones that track relevant user input (action), and notification systems are the ones that display the corresponding change in the (virtual)game (reaction). Table 2 gives an overview of the augmentation systems and their purposes

Table 2: Augmentation systems and their purposes

	Tracking system	Notification system
Purposes	Tracking the state of the ball (held, bounced, etc.)	Player awareness of the game
	Which player interacts with the ball	Player awareness of his status in the game
	Ball position on the field	Audience awareness of the game
	Audience input to the game	Audience participation interface (if applicable)
	Judge/staff input tracking	Interface for judges (if applicable)
		Interface for helping staff (if applicable)

3.4.1. Tracking system

In team games with the ball, the system for tracking involves all the technical solutions considering the ball and player interactions and the state of the game. It handles all of the input from all the stakeholders mentioned above and processes the received data. The main tracking systems relevant to ball team games with the ball can be the following:

1. Tracking the state of the ball (is it held by the player, is it bounced, did it hit someone, how?)
2. Tracking which player interacts with the ball
3. Tracing if the ball is on the field (if applicable)
4. Tracing the audience input to the game (if applicable)
5. Tracking the judge/helping staff input and decision during the game

1. Tracking the state of the ball

In ball games tracking the ball is essential; it plays a key role in the outcome of the game. There are many technical solutions worth discussing in this section, and it depends on the requirements of the exact game or event. Essentially the main goal of this system would be to tell the other parts of the system the state of the ball. There are two main ways to track the state of the physical ball: computer vision and using a set of sensors applicable to the

exact need of the ball tracking in the game. The sensors category can be further divided based on which unit of the system sends out the collected data that is used to identify the state of the ball.

2. **Using computer vision**

This requires setup and calibration of the field where that it is used. It should be used in cases where the event always takes place in the same space. Also, lightning conditions should be stable to ensure accurate real-time tracking. There are many opportunities to make computer vision work. It can be done using different markers on the ball (or object to be tracked), adding filters to cameras and different light and other wave sources to the object to be tracked to make it better visible to the camera. Depending on the movement speed of the object to be tracked (ball), it might be necessary to use a high-speed camera.

Pros of using computer vision:

- One system and setup can accurately track several objects
- Good for actions where the event space is constant
- After the initial setup, the system can work reliably
- Generally, it does not require much equipment

Cons of computer vision:

- The high cost of equipment
- Not easily portable

- Long development time
- The long learning curve for beginners

An example of a system using computer vision is the bouncing star project [17]. This project uses a high-speed camera for tracking a ball equipped with infrared LEDs and a projector on top of the field to create a projection for the playing field. When the ball moves on the field, the state of the ball is tracked, and appropriate computer graphics are displayed on the field. For example, changing the color of the tiles it rolled over.

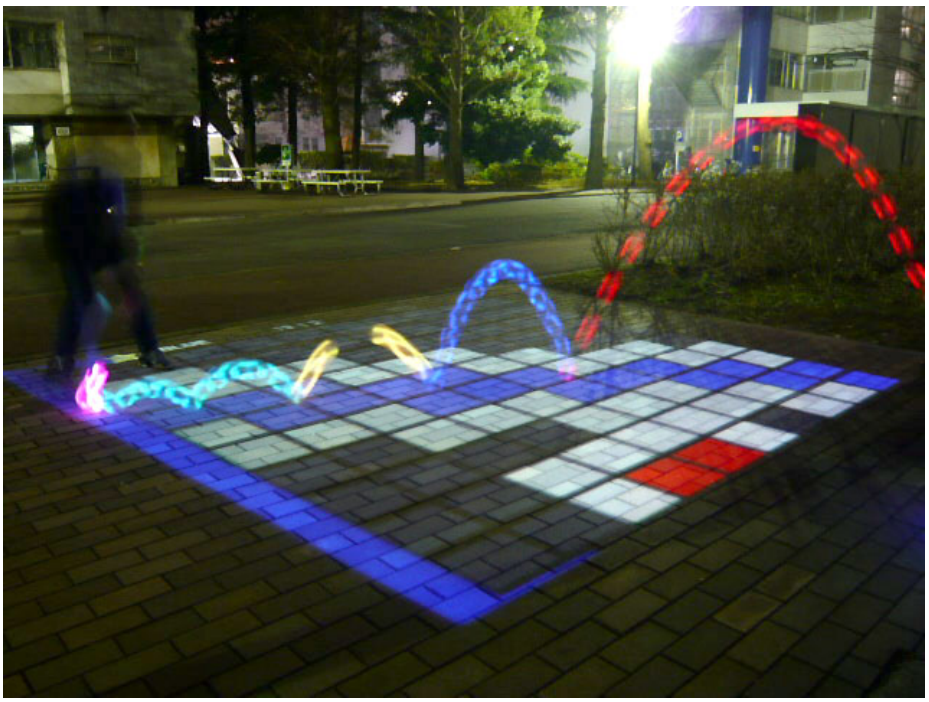

Figure 7: Playing with the bouncing star

Image source: http://www.kodama.hc.uec.ac.jp/boundingstar/index.html

3. Using sensors on the field

One way of getting to know the location and/or state of the ball is to equip the interaction space with sensors that will then locate the ball and, based on different patterns of signals, can then understand how the ball is handled.

Pros

- Using cheap sensors like microphones, for example, can be quite cost-effective
- A good solution when total automation is not necessary (user indicating a state change is an accepted solution)
- Great for tracking if the object(s) is moving in a limited or small space (for example, the ball crossing the goal line)

Cons

- Needs prior setup of the field
- Depending on the use scenario, it might not be portable
- It might require some input from the user to indicate the action
- Accuracy can be low when covering a wide area, as it is hard to create a dense enough network of sensors and different events (for example, running and bouncing the ball in case of using microphones on the floor) can produce similar sensor inputs, so it is hard to differentiate

Example of use: For timing swimming events, a sensor is placed on the pool, and the swimmer has to touch it to ensure that he/she has arrived at the point [76]. For registering marathon runners and marathon swimmers (who are wearing a sensor on them) during the track, there are special sensors or mats placed so when the sportsmen move past that, the signal is sent to the computer [77]. Lately, there are also applications tested that use Bluetooth low energy technology for the same task [39].

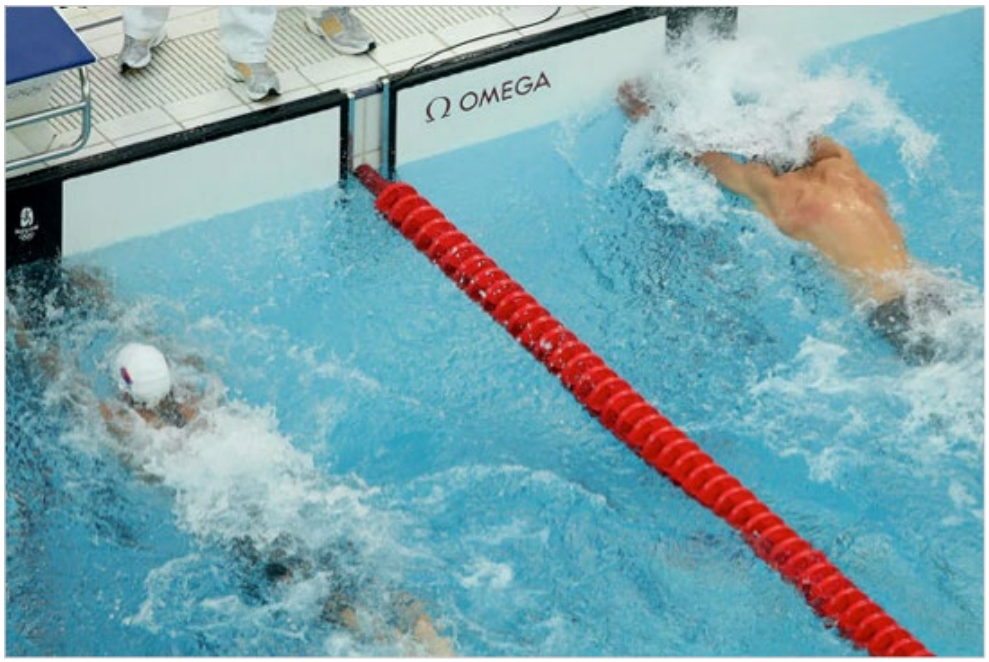

Figure 8: Pool with a touchpad to record finishing time

Image source http://technologiesinswimming.weebly.com/touch-pads.html

4. Using sensors on players

A similar approach is to have the passive part of the sensor be placed on the game prop (like a ball) and have the players who play the game wear the active sensors.

Pros:

- Portable system
- Relatively cheap developing
- Easily scalable

Cons:

- All players must be equipped
- The equipment must be safe and robust enough to be attached to the player.

Example: augmented dodgeball described in the next chapters.

Figure 9: Playing augmented dodgeball

5. Using sensors inside the ball

Implementing sensors inside the moving equipment used to create many challenges like how to protect the fragile elements and ensure their robustness as well as considerations of the weight and balance of the object they were inserted. Luckily, with the development of electronic parts, both sensors and batteries can have become very small, so these kinds of systems have become easier to implement.

Pros

- Portable
- Easy to build and experiment with (cost of prototyping materials is not high)
- Requires no on spot setup

- Easy to add different modules to the system (more sensors or change them)

Cons

- Robustness can be hard to achieve in high impact situations when prototyping
- Ensuring the robustness in high impact settings while prototyping might come from the cost of accuracy (need for cushioning)

Example system – Adidas miCoatch smart ball [78]: while not used in real gaming environments, sensors in the ball are used in training to obtain better insights of the athletes' abilities. It incorporates a six-axis accelerometer inside the ball and allows the statistics to be viewed through a smartphone app.

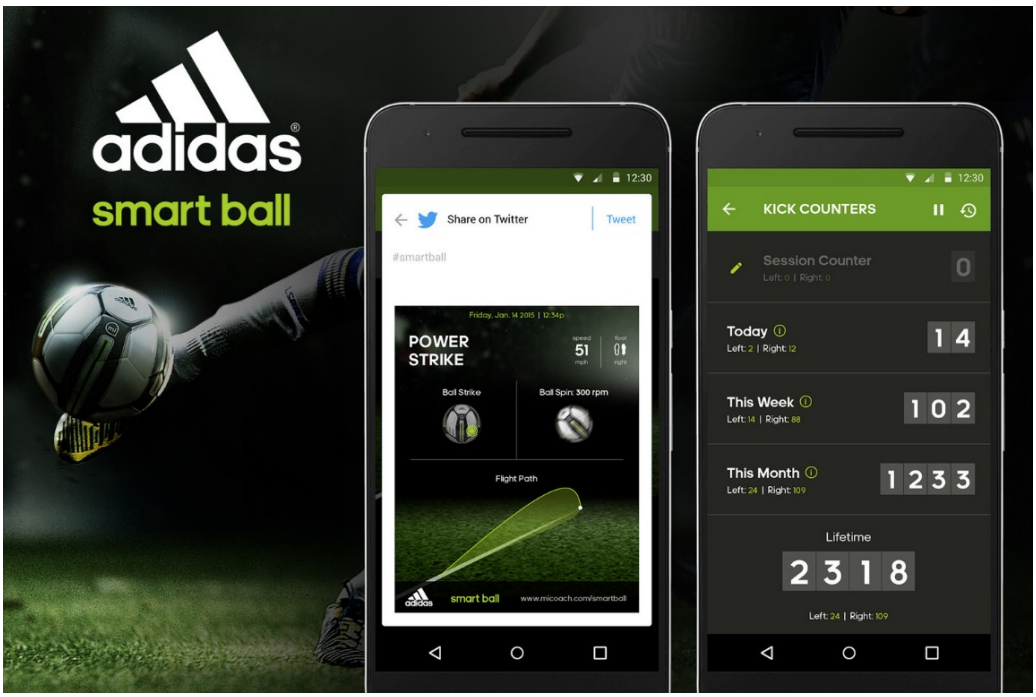

Figure 10: Adidas smart ball and its app

Image source: https://www.matthewfran.co/#/smartball/

Table 3 gives an overview of the tracking systems discussed with their pros and cons. The tracking systems can all be used separately or combined, depending on the exact requirements of the game and environment.

Table 3: Tracking system overview

Tracking system	criteria	comment
Computer vision	pros	Multiple objects can be tracked with one setup Easy to use in a decided constant place After the initial setup easy to work with Not much equipment
	cons	The high cost of equipment Not portable Long development time Long learning curb for beginners
Sensors on the field	pros	Cost-effective Good when user input might be required Accurate in small space
	cons	Needs field setup May not be portable (depends) May require user input Accuracy can be low in big areas
Sensors on players	pros	Portable Cheap developing Easily scalable
	cons	Players must be equipped Needs to be safe and robust
	pros	Portable

Sensors inside the ball		Easy to experiment with No on spot setup Easy to modularize
	cons	Robustness required already on prototype Robustness on the prototype can mean loss of accuracy or some visuals

3.4.2. Notification systems

Notification systems have a much longer background and are quite common in our everyday lives. Essentially, a notification system is a system giving information about a state of something or shows the change in a situation. A good example of notification systems are doorbells and the ringing sound of a phone. These systems let us know that there is somebody who wishes to connect with us at that moment (a change in a situation). In augmented games, the notification is handling everything connected to how to display the current state of the game to all stakeholders. It can be divided accordingly:

1. Player awareness of the status of the game and fellow players
2. Player awareness of its own status
3. Audience awareness of the status of the game
4. Audience participation interface (if applicable)
5. Interface for judges (if applicable)

6. Interface for helping staff (if applicable)

Each notification system should take into consideration that when it displays the reaction of the action, it should be timely unless hiding information until later is part of the design of the game. If the notifications of actions come at random times and/or do not correspond to the actions of what players are doing in the game when the player expects them to do that, playing satisfaction is easily lost, and players lose trust in the system, which in turn can result in an unsatisfying playing experience.

Another aspect of notification systems is that they should take into consideration the amount of cognitive power they require and the amount of cognitive power available from the player.

The third consideration point when designing notification systems is the amount of information needed by each stakeholder at each point in the game. Hiding and delaying, as well as giving different amounts of information to different stakeholders, can be part of the game design and enhance the overall playing experience.

4. Augmented dodgeball

Augmented dodgeball game serves as a case study of augmented team games with a ball. The theoretical considerations and augmentation methods described in the previous chapter are analyzed and showed how they could be put into effect to design a new team game.

Augmented dodgeball is based on the traditional dodgeball game played around the world. This paragraph introduces the dodgeball game and the concept and technical solutions for the augmented dodgeball. Also, all design considerations, hardware iterations are described and analyzed.

The main design goal of developing augmented dodgeball was to make a game that would enable people with different physical skill levels to play together and fruitfully spend time while being physically active. The design goals of the game are the following:

- Promote teamwork and collaboration inside the team during the game
- Make players feel that they are a necessary part of the team
- Take the focus of the game from physical skills to strategy

4.1. Dodgeball

Dodgeball is a well-known game around the world and is played mostly in elementary and middle schools. There are two international governing bodies for dodgeball: The World Dodgeball Association [79] and the World Dodgeball Federation (WDBF) [80] that formally govern international dodgeball sports. Aside from the official rules and regulations, dodgeball is played with varying rules on the local and amateur levels. In our project, the rules used are the common ones used in Japanese elementary and middle schools. As the main goal of this study is to make a game that is inclusive of everyone and would make people enjoy playing together with their peers regardless of the participants' physical skill level, we have adopted the general rules that are easier than the ones presented in the official rulebooks.

Dodgeball is a team game played by two opposing teams. The goal of the game is to eliminate players on the opposing team by throwing a ball at them. When a player gets hit by the ball, they are out of the game. At the beginning of the game, each team assigns one outfield player who will support their team from outside of the field. The placing of players before the game can be seen in Figure 11.

The size of the dodgeball field on official games depends on the governing organization and can vary greatly. The WDBF field size is specified as 18m x 9.1m without a neutral zone. The neutral zone is an area in the middle of the field where players are not supposed to be. In our projects and tests, we use

the field-sized 5m x 10m without any neutral zone. This field size was determined by playtests so that teams of 3-5 people could play comfortably.

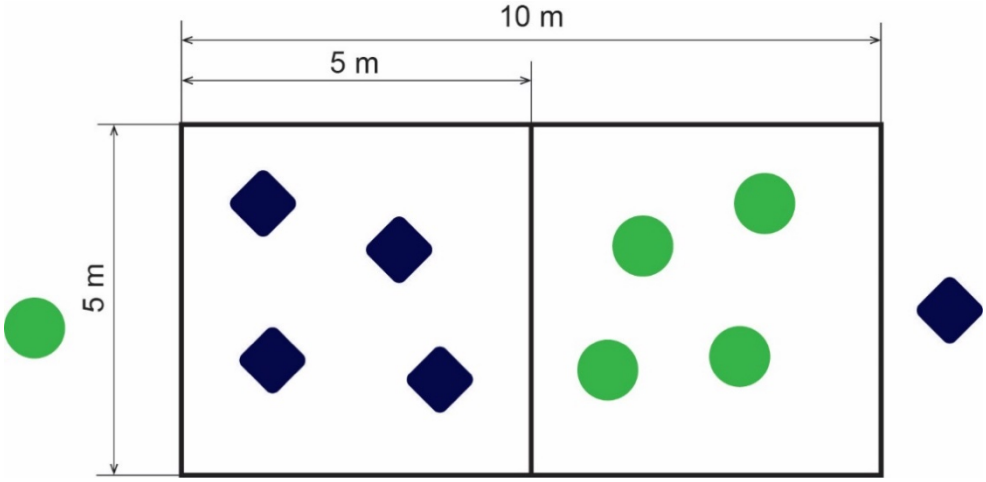

Figure 11: Positioning at the beginning of the dodgeball game

The game ends when one of the teams will have no more infield players left on the field. The winner is the team who still has players left on the field after the game finishes. There are also alterations to this rule. For example, dodgeball can also be played with a time constraint. In that case, after the dedicated game time has ended, the winner of the game is the team who has more infield players left on the field. Alternatively, during a 20-minute time frame, several matches can be played, and the winner is the team who won more matches. Also, the following rules are followed in the game:

- After getting hit by the ball, if the player who got hit or any player from the same team can catch the ball before it touches the ground, the hit is not counted

- Infield players cannot go out of their field; both of their legs must be on the field at any given time.
- The outfield player can move on the end and the sides until the centerline of the opposing team field.
- The person who starts as an outfield person can become an infield player when one player in their team has got hit and therefore can take the role of the outfield player
- After getting hit when playing an infield player, there is no chance to return to be an infield player.
- When getting hit to the head, the hit is not counted.

4.2. Augmented Dodgeball overview

Augmented dodgeball is a game based on the traditional dodgeball game. The game was chosen as a base for proof of concept of augmenting team games because it has simple rules that many people are aware of from childhood. Building on already designed games that are well known ensures that the basic concept of the game is well accepted by the people. Also, as the rules have developed over time means that they are validated by the players who have played it before to be fair and make playing fun. Additionally, as the potential players have a concept of the original game, it is easier to understand the new additions and rules.

4.2.1. Augmenting dodgeball based on the design steps

We started this project by observing the dodgeball game and identifying which parts of the game would be good to augment to create a balancing mechanism between different skill level players [33]. From the initial observations of dodgeball play, we noticed that some players act more confident during the game; they play more aggressively, attack the opposing team more, take more risks when catching the ball. On the other hand, some players concentrate on ducking from the ball rather than trying to catch it and rarely attack the opposing team by throwing the ball at them. The rest of the players fall somewhere in between. Also, it was a common thing to see the weaker players having less game time, as when they got hit, they were out of the game but could support remotely on the side. Moreover, that was also until some stronger and more aggressive players got hit, then they automatically took the active part of an outfield player, and therefore the less aggressive players were left with few opportunities to contribute to the game. Research has shown that being able to contribute to the game is an important part of the game satisfaction the players get and a good indicator if the person would like to play again in the future [46].

Taking this phenomenon as a guide, we decided to develop augmented dodgeball as a more strategic game where all participants could concentrate on doing what they felt more comfortable: attacking or ducking from the ball.

Following the three-layer augmentation model, we developed the following requirements for the augmented game:

Game design level:

What is the purpose of the augmentation? Is it to change the difficulty level? In what way? Who should be able to enjoy this game? Why are they not enjoying the game at the moment? Are the new gamine elements wanted? Whom will they benefit?

Answer: To make a game where players with different skill levels could enjoy playing together. Weaker players who are very often eliminated already at the beginning of the game do not have much game time and can feel not useful for the team. Promote team play and give all players a feeling that they are necessary and important parts of the team.

What is the shortcoming of the game in its original form that the designer is interested in approving?

Answer: Little teamwork and players is relying on their teammates during the game. There are a few star players who take the main player role and leave other players easily into the shadow.

Player experience:

How is the winner of the game decided? What are the actions that give points/decide which team is leading?

Answer: The team with players still on the field is the winner. Eliminating other team members is by throwing a ball at them

What are the qualities of the star player in the game? What is the "coolest" player in the game doing? What are all other players doing?

Answer: The star players are the ones who catch the ball and make many attacks on the opposing team. Other players might be a bit scared of the ball and tuck away from it.

Do players have different roles in the game? How do different players support each other during the game?

Answer: Dodgeball does not have any different roles between infield players. There are outfield players who can support their team from outside and pass them the ball or assist in an attack. These players (except for the beginning) are the ones who have been eliminated from infield play.

Environment design:

is the game taking place? Can we take it to some other place or dimension?

Answer: The game takes place on a field. It is probably the easiest place to play it, and adding more challenges to the game is not desired with the current design goals.

Which senses of the players are using. Can we add a different sense? What happens if we limit some of the senses?

Answer: Main sense the players are using is the eyesight. In the current setting, limiting this sense would make the game more challenging.

After going through all the design steps, we found that at the game-design level, we would like to:

- increase collaboration
- take away attention from physical movement
- increase tactical play
- On player experience level, the following changes were the most important:
- Make all players feel that they are important
- Increase playing time (for weaker players)
- On game design level:
- Find appropriate field size
-

Based on these goals, we decided to incorporate the following elements into the game:

- Add life points to players so that they can survive for a longer time in the game.
- Create player roles with different players having a different amount of attack and defense points to promote balancing and collaboration in the game
- Give players the freedom to choose their player roles, so it is a voluntary action and not labeling players based on their skills.
- For not increasing the cognitive load of the players, the point calculation is done automatically, resulting in a virtual score in the game.
-

As the augmented dodgeball has parameters that are not seen by the players and are quite difficult to calculate in the spot (parameters and their design is explained in the game parameter section), we can say that augmented dodgeball is a game taking place in two different dimensions: the physical one and the virtual one. The game takes place in the real world, with real players and a real ball. The players still try to hit other players with the ball like in traditional dodgeball, but when they get hit, they are not out of the game. Instead, they lose life points in the virtual world. The number of life points lost depends on the attack power of the player who threw the ball and the defense power of the player who got hit. The concept of augmented dodgeball can be seen in Figure 11.

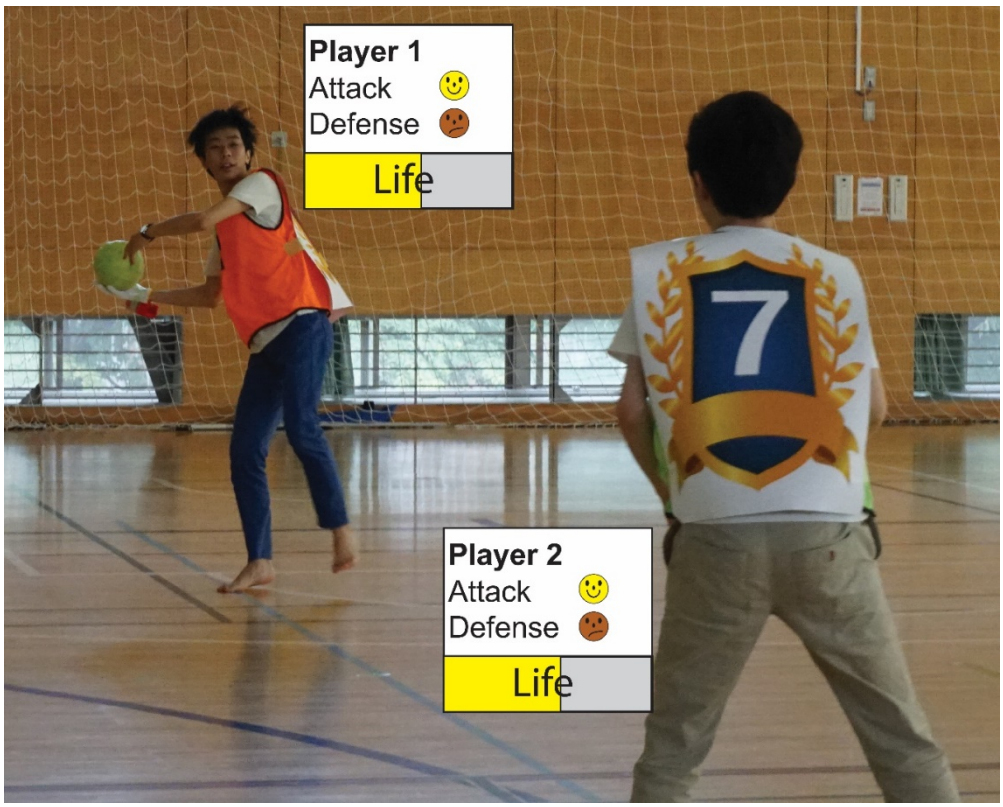

Figure 12: The concept of augmented dodgeball

To promote a more strategic game, we developed three player characters using different combinations of attack power and defense power. The attacker is a player whose attack power is high, but the defense power is low, which means that they can make the opposing team member lose many life points when hit by the ball thrown by the attacker player. On the other hand, when the attacker-type player gets hit, they also lose many life points as their defense power is weak. The defender is the opposite type to the attacker. The defender has high defense points making them more resilient to attacks. On the other hand, when they throw a ball and hit somebody from the opposing

team, they do not cause much damage to that player's life points. Balanced type lies in between the defender and attacker types meaning that their attack power, as well as their defense power, are mediocre. The reason behind developing these characters was to give the players choice between them seeing themselves as more aggressive attacker players or less aggressive defense players. The neutral type was created to add another option to players who had a hard time choosing. Also, assigning characters to the game means that the team is advised to think together and share their thoughts about the game, which makes a good basis for developing communication between players. Player types with their corresponding logos can be seen in Figure 13. The exact parameters and how they were chosen are described under the game parameters paragraph.

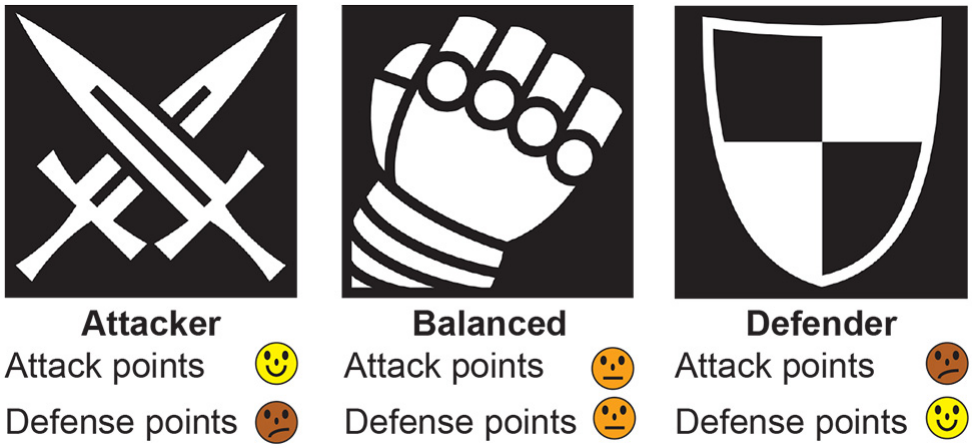

Figure 13: Player types in the augmented dodgeball game

4.2.2. Augmented dodgeball system requirements

Augmented dodgeball consists of physical and virtual layers. To realize the augmented dodgeball game, we need to know who throws the ball, who gets hit, a point management system to keep track of the course of the game, and a way to notify players as well as the audience about the state of the game also on virtual layer. The most recent overview of the system can be seen in Figure 14. It consists of a central database that is updated as the game progresses. The database provides input for the notification systems and takes data that is output from the tracking systems. The game engine is where the logic of the game is calculated, and it takes input from the database and outputs the necessary parameters to the database. Under the augmented dodgeball development versions, the system overview, as well as the hardware specifics, are described for each stage in the development.

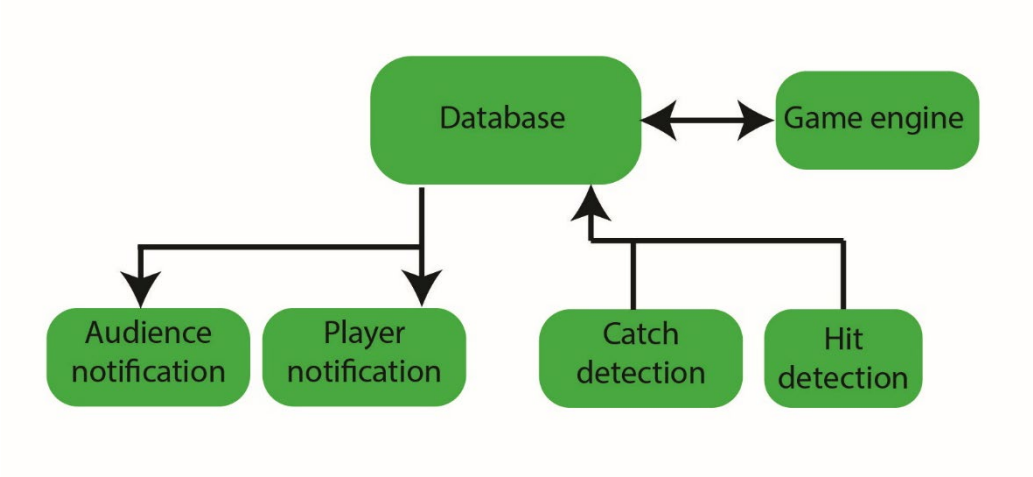

Figure 14: Augmented dodgeball system overview

4.2.3. How to play Augmented Dodgeball

In the Augmented Dodgeball game, players are divided into two teams that both have three to five players. One player from each team starts as an outfielder. The player positions at the start of the play can be seen in Figure 11. The players who are in the field can only move inside their side of the field. The field size is 5 m x 10 m, and it is divided into two equal parts. The player who is an outfielder can also move on the sides of the field until the centerline.

The purpose of the game is to eliminate all the members of the opposing team by throwing a ball at them. The hit or miss of the throw is monitored by a referee. The referee also has to insert which player got hit manually into the system. Player identification is made visible by assigning a number to each player, and that number is also printed on the shirt they wear when playing. The flow of the game can be seen in Figure 15.

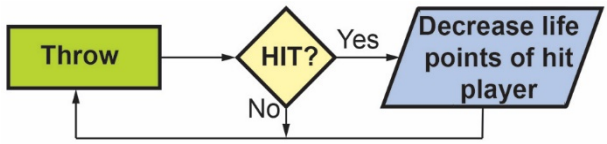

Figure 15: Augmented dodgeball game flowchart

When the player hits another player in the opposing team, that player's life points will decrease, and when they reach zero, the player is out and becomes an outfield player. When there is no hit, another throw can be made in the game. The player who started as an outfield player can become an infield player after the first player in his/her team has lost all his/her life points and

can take the position of the outfielder. When a person plays as an outfield player, their player role is automatically set as a balanced player. Only infield players have the virtual parameters that correspond to the character that they chose at the beginning of the match. All players that have lost all their life points become outfield players. The game is finished when all of the players in one team have lost all their life points.

As augmented Dodgeball takes place in the physical and virtual world in the sense that the game is played in the real world, but the points and player attack and defense powers are tracked by a computer and therefore not visible to the naked eye. As a way to keep the players and the audience aware of the state of the game, we developed a scoreboard that can be seen throughout the game by players and the audience. Figure 16 shows the placement of the scoreboard during the game. Figure 17 gives a closer view of the scoreboard. The scoreboard is divided into team A and team B. On the right, there are the player numbers and how many life points each player has left. The logo next to them represents the player type, and the white bars represent life points.

Figure 16: Players and the scoreboard

Since there are virtual parameters involved in the game, it is important to ensure that they are appropriate. For that, we used a game simulator which is described in the next chapter.

4.2.4. Game simulator

The Augmented Dodgeball virtual parameters were decided by using a game simulator to design the optimal gaming experience [18]. Our goal was to have a game length of about 15 minutes to avoid extra fatigue and keep the game interesting for the participants. We also wanted to make sure that the virtual parameters like health points at the beginning of the game, defense points, and attack points for each character type would allow a good gaming experience for all player types. In other words, one character type would not

be too strong or too weak compared to the others. For this, the traditional dodgeball game was analyzed. All different movements that players need to do in the game were recorded, and their approximate time was calculated. Also, the average hit and miss percentages were recorded and input into the simulator. Using different hit and miss ratios, we developed different player profiles. The game settings in the computer simulation environment were the following: two teams of five players with randomly selected player profiles were competing. Two of the players were defined as attackers, one balanced, and two defensive players. With each set of predetermined player parameters (health points, attack power, and defense power) 10 000 games were simulated by our system, and the average game details and amount of each team winning and losing were calculated. The best parameters were chosen by the following criteria: the average game length around 15 minutes and both teams winning around the same amount of games. In addition, the parameters which resulted in entering the plus mode (explained in the Playing Modes paragraph) were desired to be around half of the time. Based on these conditions, the parameters in

Table 4 proved to be optimal. With these parameters, the average game time by the simulator was 16:34 min; one team won 4 941 games, and the other one 5 059. The game entered plus mode 6 607 times out of 10 000.

4.2.5. Game parameters

In augmented dodgeball, there are three types of players with different virtual parameters: attack power and defense power. The attacker type of player has many attack points, but his/her defense power is weak. A balanced player's attack power and defense power are medium range, and the defender type has low attacking powers and high defense power. The number of damage points that the player loses when hit can be calculated in the following way:

$D = AP - \frac{DP}{2}$ Where:

D – Damage
AP – Attack power of the thrower
DP – defense power of the person who got hit

The new life points score is obtained when the Damage is subtracted from the old life points score of the player who got hit. In

Table 4, the parameters used in the game can be seen. The player roles marked with the “+” sign are used for the corresponding player type when they are in “+” mode, which is explained in the play mode chapter.

Table 4: Parameters used in the augmented dodgeball game

Play mode	Player role	Life points	Attack power	Defense power
	Attacker	120	140	120

Normal	Balanced	120	120	160
	Defender	120	110	180
Plus	Attacker+	120	150	150
	Balanced+	120	140	180
	Defender+	120	130	190

Only infield players can have the player type of attacker or defender. For all outfield players, their player type will change to balanced automatically. Player types can be identified by their logo on the scoreboard. The meaning of different logos can be seen in Figure 13. The emoji' represent how strong are the character's virtual powers in a non-numerical representation.

4.2.6. Playing modes

To further accommodate the idea of playing together, the game has two playing modes. One is the normal mode where all the same types of players share the same parameters (for example, an Attacker in team A has the same defense and attack points as the Attacker in team B). The second mode is the plus mode. The plus mode launches automatically when one team has established its superiority in the game. This means that one team has at least two more players on the field than the other team. In the plus mode, the attack and defense points of all the weaker team's players will increase by 10-20 points depending on their player role. The exact parameters can be seen in

Table 4. This gives a slight advantage to the weaker team's players to encourage their playing motivation. Entering the plus mode is also reflected on the scoreboard. In Figure 17, it can be seen that the logos of players 6 and 7 on the B team have changed color from green to yellow. This marks that the game is now in plus mode, and these players have increased attack and defense power.

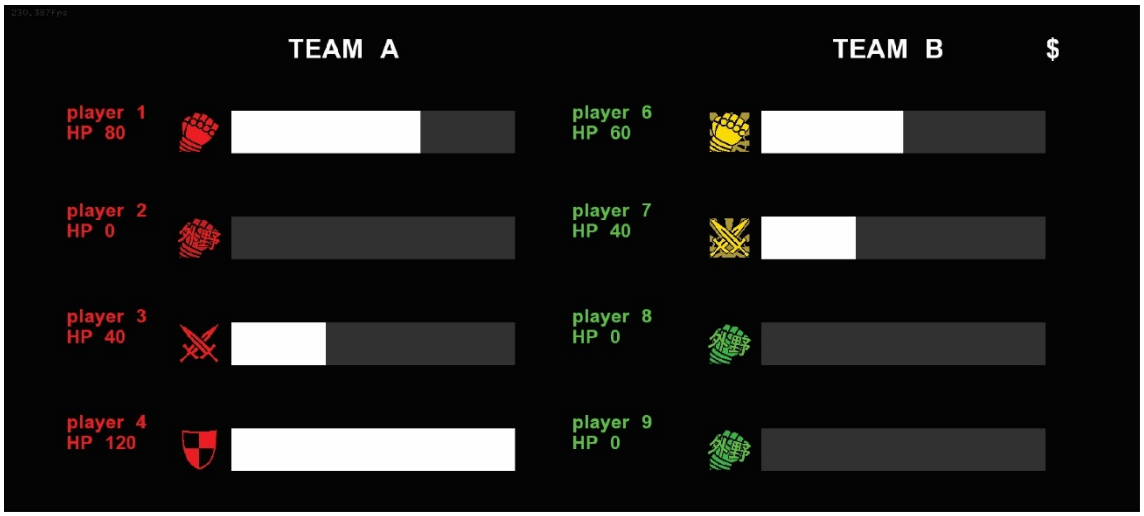

Figure 17: Augmented dodgeball scoreboard

To realize the augmented dodgeball game, we need to detect who threw the ball, was there a hit, and if yes, who was the player who was hit. Now we introduce the development of the systems used in augmented dodgeball.

4.2.7. Augmented Dodgeball 1st generation system

The first-generation augmented dodgeball system consisted of the scoreboard introduced before and a helmet and a ball system for detecting the player who is throwing the ball.

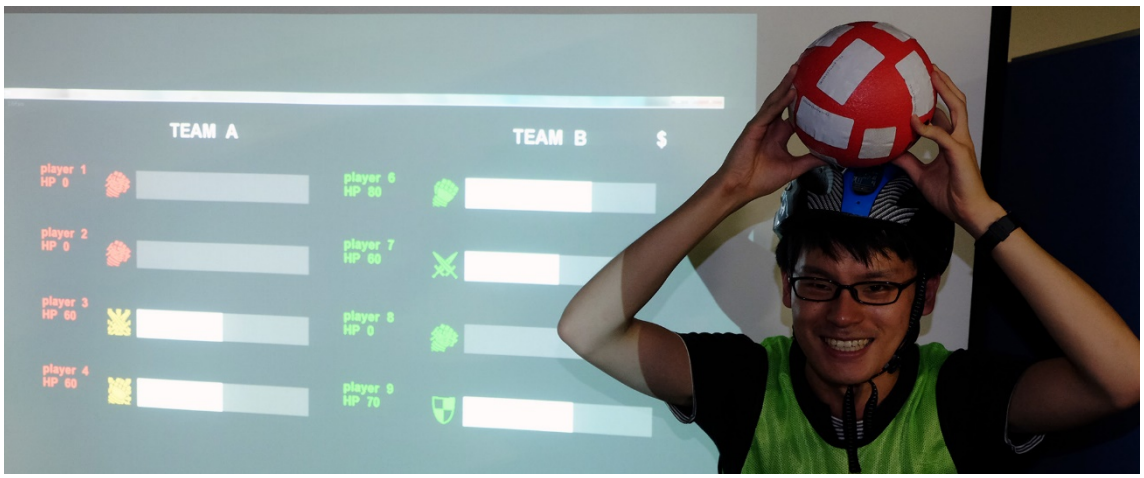

Figure 18: Player with augmented dodgeball helmet system

When using the helmet system, the player has to place the ball on the helmet to register that they hold the ball. When the ball is registered, a sound alarm lets the player know about it. When instructing the players on how to use the system, we described it as giving the ball the power to cause damage to the opposing team`s health. By adding an extra move not present in the normal dodgeball game, the game flow is slowed down so that the player would have

time to make more observations of the game and to encourage more strategic play. The average delay caused by the extra move is about 4 seconds for novice players. The players are instructed to move the ball near to the helmet until they can hear an audio signal indicating registration, so timing the registration or passing the ball without registration also becomes a tactic for the game.

The ball used in the game is a sponge ball (ϕ 160mm), and it is covered with Radio-frequency identification (RFID) tags (Figure 19). These tags enable contactless data transfer from the proximity. The type used in the system is FeliCa by Sony [81]. 14 tags are used to make the identification process easier by covering most of the surface of the ball. The tags pictured, however, were very easy to break, so later, they were replaced by tough Felica tags that are usually used for dry cleaning. Those look like buttons and are covered in plastic. They worked much more reliably on the ball that was constantly thrown around.

Figure 19: Ball with RFID tags

The helmet worn by the player (Figure 20) is equipped with a thrower registering system. The system consists of an RFID tag reader, microcontroller, wireless module, a small speaker, and a battery. The tag reader is installed in the front of the helmet to make it easier for the players to register that they have the ball. To do that, they need to raise the ball to the proximity of the reader so it can read it. This action of reading is then processed by an Arduino UNO board [82]. Each microcontroller is programmed with a unique player identification number which is sent to the PC via the wireless network. In our system, we use XBee [83] modules for wireless data transfer. The helmet is also equipped with a small speaker unit that signals the player after the RFID tag on the ball is registered. The whole system is powered with a 9V battery and mounted into the box on top of the helmet.

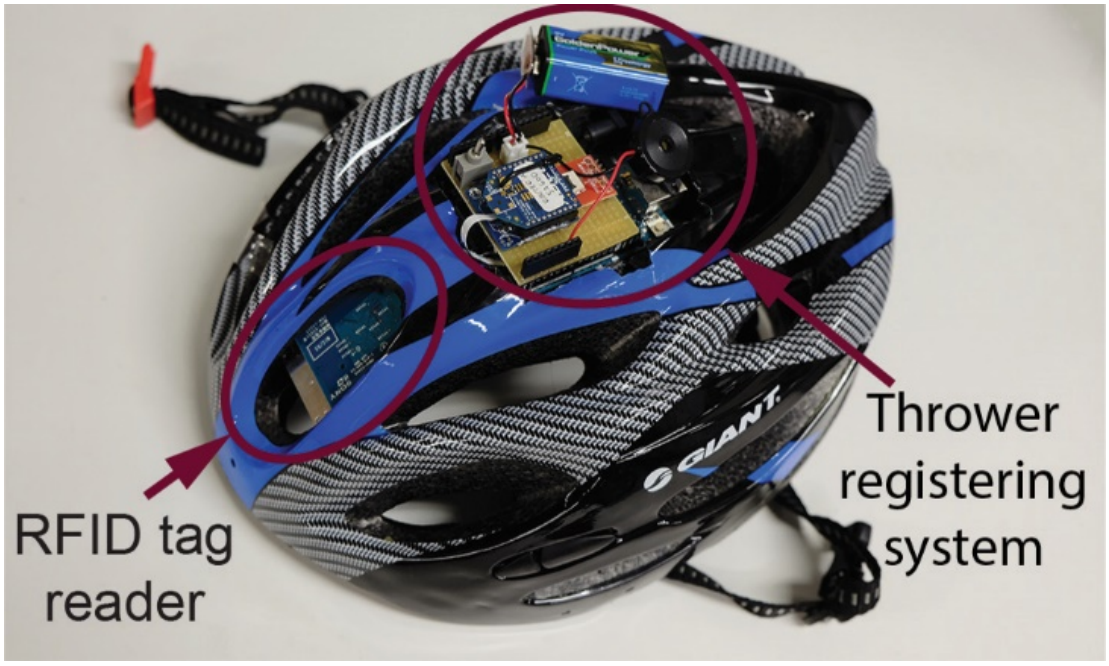

Figure 20: Helmet system for augmented dodgeball

The computer side of the system is equipped with an XBee module to receive the player identification number. This data is then directed to the Dodgeball software. Dodgeball software oversees displaying and updating the scoreboard. At this stage, the modular system with game engine database and notification and tracking systems as pictured in Figure 14 were not jet implemented. In the case of the hit, the human referee has to input the information about which player was hit to the Dodgeball software. When the hit is registered, the score table is updated.

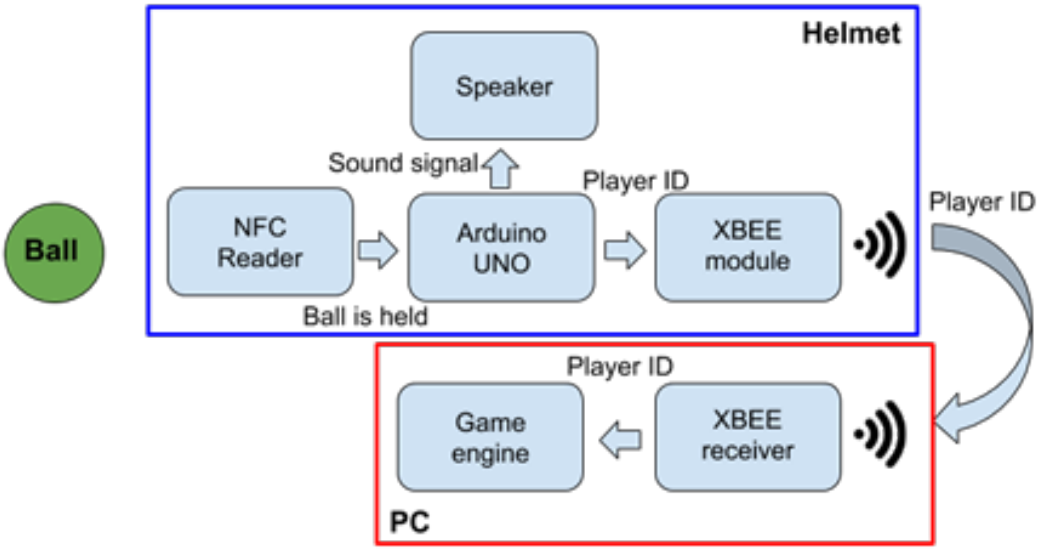

Figure 21: thrower detection device information flow

This system consisted of a fairly simple circuit and the development and building times were short. However, there were some challenges with the system:

- The ball with RFID tags was quite difficult to register as it had to be placed very precisely near to the reader. The players could not see where it was, so sometimes a fellow player would help then. Although this required more collaboration between the players, sometimes it slowed the game time too much.
- The box on top of the helmet was not secure enough when a ball was thrown on it and could easily come to lose. While the equipment, in

general, remained working, it needed to be assembled, so the game had to be stopped for that time.

- The microcontroller in use was specifically programmed with a player ID. If a person needed to change the system during the game, the new board had to be programmed, then the system could be assembled to the helmet, and only then could the player replace the system. This was time and labor-consuming

- The battery was only accessible when removing the system from the helmet, which meant that before every game, we had to check if the battery has enough power left by disassembling and then assembling the system. Same, for when the batter needed to be changed.

- The dodgeball software was not flexible about how many players can play the game. It was very hard to accommodate teams of 3 or 4 players.

- The dodgeball software code was hard to understand and was not modular, so new elements were hard to integrate.

- The second generation of the augmented dodgeball system was developed based on the hardships that came about in the first-generation devices.

4.2.8. Augmented dodgeball second generations system

The second-generation augmented dodgeball system features a major update to the software. The system is made modular and uses the structure pictured

in Figure 14. The display design was preserved for the most part, but it was updated to indicate which player is holding the ball in real-time (player with a brown ball image and a blue box around the life point bar) and also to show more clearly which player is an outfield player (players with a brown box around their life point bars) and which infield player (plain white life point bars). Figure 22 shows the updated scoreboard.

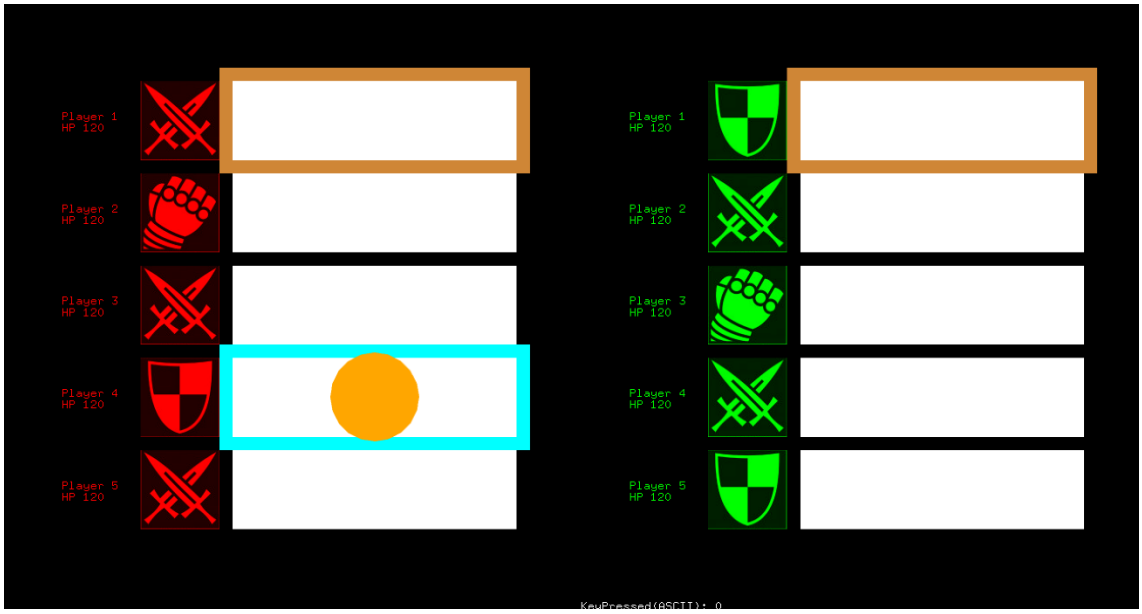

Figure 22: Updated scoreboard for augmented dodgeball

There were also major updates on the hardware side. The helmet system was replaced by a wrist warn system.

The thrower detection system is designed to be worn by the player on their hand. It requires no additional movement or settings by the player and therefore does not interfere with the natural game flow.

The thrower detection system worn by the player can be seen in Figure 23. Each player wears the system only on their dominant hand.

Figure 23: 2nd generation augmented dodgeball devices

The thrower detection system consists of a magnetic ball (Figure 23, the ball is covered for esthetical reasons and Figure 24, magnets taped on the ball, without a cover.) and a magnetic detection device (Figure 23 – devices are assembled for playing and Figure 26 – device disassembled.). In the magnetic ball, cylindrical neodymium magnets with a diameter of 10 mm, a thickness of 2 mm, and a grade of N50 are arranged on the surface dispersedly of a sponge ball having a diameter of 170 mm. The sponge ball was chosen

because it is soft, and although there are magnets on it, it is still softer than the traditional dodgeball ball and will not hurt people when they get hit by the ball.

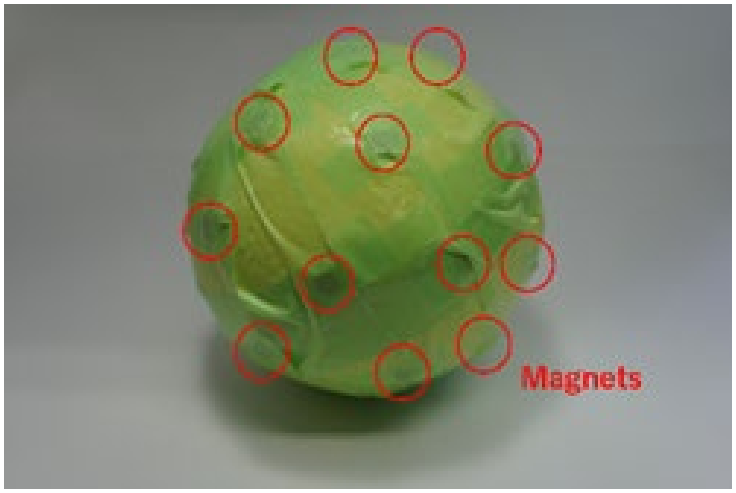

Figure 24: Augmented dodgeball ball with magnets

The magnetic detection device is composed of a Hall element and an Arduino-compatible Feather Huzzah32 board [84]. The Hall element is Allegro MicroSystems Phil Inc.'s A1324 LUA - T sensor. The resolution is 1 G in the use environment, and the range can be measured up to about ± 500 G. The sensor position is set at the tip of a little finger. This is because the little finger usually gets the smallest impact when catching the ball and therefore was thought to be the most comfortable place for the player and.

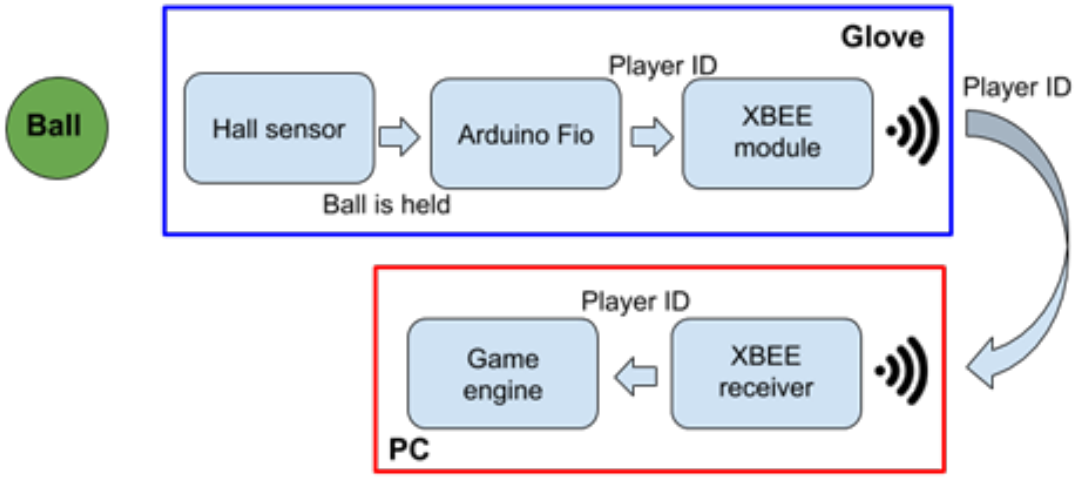

Figure 25: Information flow in Hall sensor and magnet system

Feather Huzzah32 was chosen because it features an ESP 32 chip that has a built-in wireless capability. The board is Arduino compatible, meaning that it has many tutorials and resources available for development. It also comes with a built-in LIPO battery charger and has a very compact size. The overall size of the system became 47 X 36 mm. The technical details about the earlier version of the thrower detection system and magnet placement are described in [53].

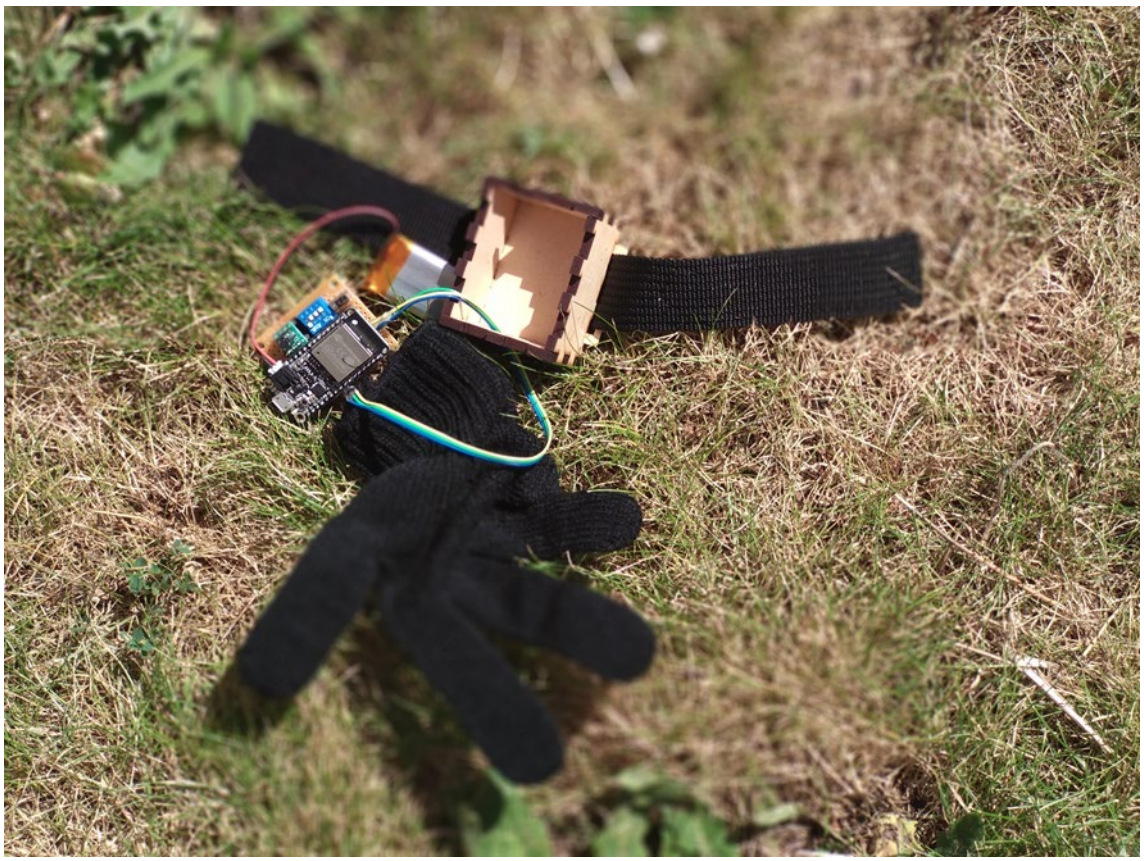

Figure 26: Catch detection device disassembled

The second generation of augmented dodgeball device also included the following features:

- Small and light
- Player ID could be set by a DIP switch placed on the device, making changing the devices fast
- The device can be charged without removing the box
- Overall, the game with the device had a faster pace, and the display was more informative for the players and audience as the state of the

ball was also displayed on it, and it was easy to distinguish the infield and outfield players. As for the referee, the interface to set up the game was made easier, and the number of players in a team could be easily changed. The players wearing the second-generation devices can be seen in Figure 27.

Figure 27: Players wearing 2nd generation augmented dodgeball devices

4.2.9. Catch and strike detection accuracy

We carried out a catch and strike detection experiment with 4 participants to prove the proposed system's concept. Striking the ball means that the player would only contact the ball momentarily until it is bounced back from their hand.

Catching means that the player holds the ball and a throwing motion occurs before the ball leaves the controllable range of the player holding it. Each of the participants had to catch and strike the ball 20 times wearing the system. For catching the ball, the system could recognize it 100% of the time for all participants. Although a small number of catch events were investigated, the system shows moderate reliability in detecting catching in this experimental condition. This was achieved by creating a tense enough magnetic field on the ball and assuring that the sensor is in the necessary proximity of the magnetic field when the ball is caught. For striking, the average detection rate was decreased to 90%. When considering playing dodgeball, rarely striking the ball by hand event happen. However, this device is essential to play augmented sports. Therefore, the detection rate should be improved[53].

To improve the accuracy of catch and strike hit detection accuracy, we focus on the deviations of the magnetic field generated by magnets on the ball. To solve this issue, we focus investigated causes that worsen the detection rates. When considering the situation of detecting striking on the reasons for failing to detect a strike, which it could have been a temporal problem: a strike is a momentary event, and the device detection speed might not have been fast enough to register the event. Alternatively, the problem could also have been positional: the participants were only instructed to strike the ball. When striking with a palm, the little finger that had the sensor attached may not have reached a value over the threshold necessary to register the event. Our playtests suggested the Hall sensor to be very sturdy for the hit caused by the ball we

used. So we decided to change the sensor's place and from the tip of the little finger to place it inside the palm. This is because of the player as the palm is the place where players usually come into contact with the ball both when holding and striking the ball.

4.2.10. Sensor evaluation

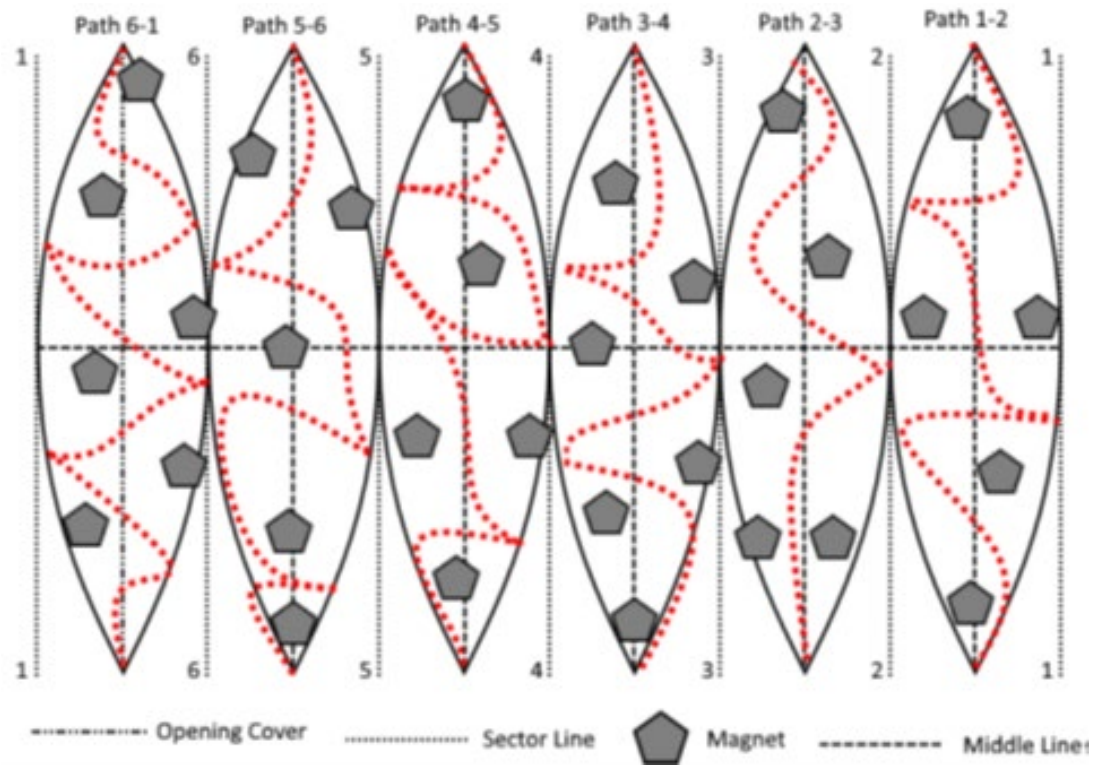

Figure 28: Ball divided into sections for testing

Then, we investigate the amplitude of the magnetic field of the ball's surface by using the hall sensor on the palm. This test is done to choose the appropriate threshold value to detect catch and strike events. We divided the ball into six segments to get the sensor readings data and ran the sensor on

the ball's surface according to the paths marked in red (Figure 28). The sensor was moved by a human hand on the trajectories and was in contact with the ball. For each path, 2000 data points were obtained. We also defined the sensor faces during the test, as seen in Figure 29. The experiments were conducted on two independent catch detection devices referred to as Specimen 1 and Specimen 2 in our experiment. The only difference between the devices' setup was that Specimen 2 had a bypass capacitor of 0,1 µF placed between the sensor's input power supply and ground. Specimen 1 did not have the bypass capacitor installed. We found no significant differences between the readings of the two different setups during our experiments.

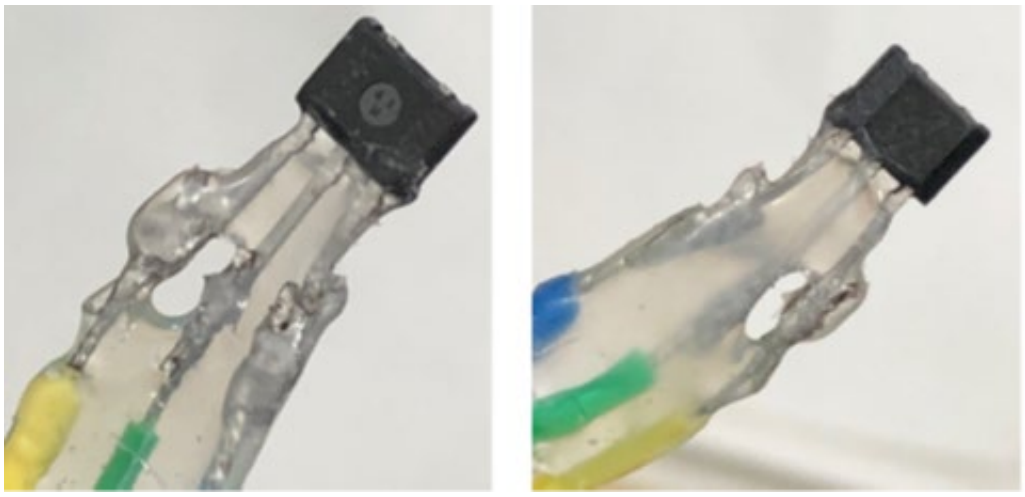

Figure 29: P-side of the sensor (left) and PF-side (right)

When moving the sensor on the ball's surface and taking readings of the Hall sensor without the Wi-Fi module enabled, we found significant differences in when the magnetic field is detected depending on which side of the sensor

faces the ball. The results can be seen in Figure 30. The percentage shows how many times of the total readings the sensor could recognize it was near to a magnet (over the threshold value). We can see that the side of which the sensor is placed on the ball matters, and when using this specific sensor, directing the P-side towards the object that we are trying to measure against gives a more reliable reading.

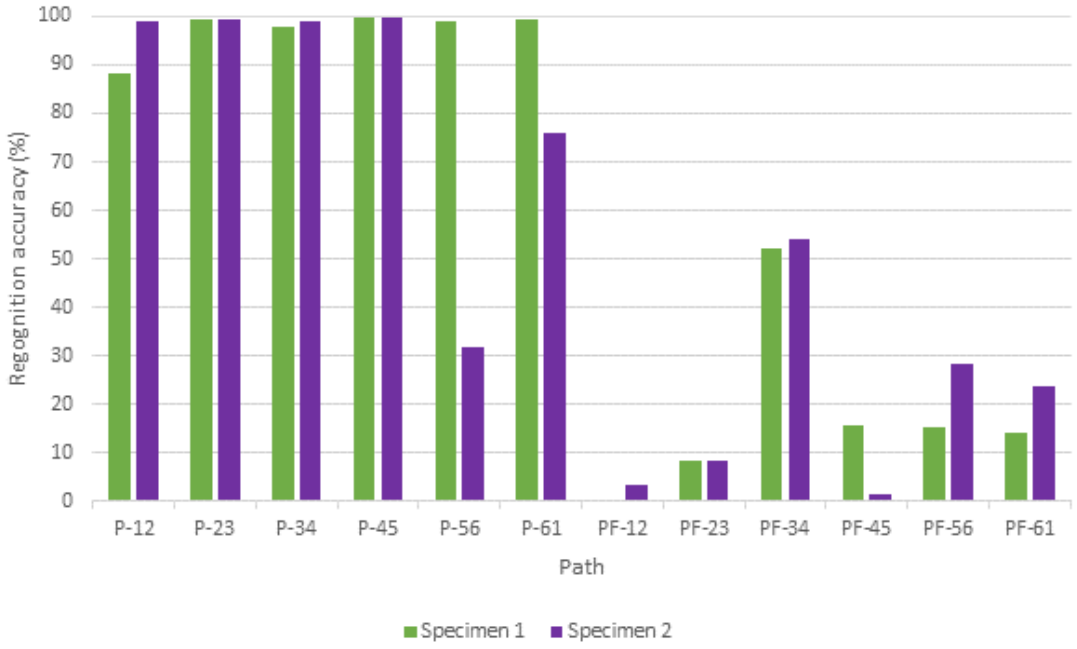

Figure 30: Data for testing different sides of the sensor facing the surface with magnets

4.2.11. Hall sensor calibration

The second experiment to increase the system reliability was made on the initial sensor calibration when turning on the device. The first algorithm used

for the sensor calibration was to read the sensor 50 times with a 100 μs delay between the reads and take the average value as the baseline, and set 10 Gaus above the baseline as a threshold value. The catch detection worked well with this method, but sometimes false positive catches were detected when playing augmented dodgeball.

In order to track the false positive calls, we investigated the following variables in order to see how they affect the calibration:

- Calibration Iterations (Times): 50, 250, 1000.
- Calibration Delay(μs): 100, 10000, 50000.
- Loop Iterations (Times): 5000.
- Loop Delay(μs): 100, 10000, 50000.

Calibration iterations mean how many times is the sensor value measured during the initial calibration step (done once when the device is turned on). Calibration delay is the amount of time between the readings when calibrating the sensor. Loop iteration is the number of times the sensor was reed after calibrating to evaluate the calibration effectiveness. Loop delay is the delay between sensor readings after calibration to evaluate the sensor calibration effectiveness.

We focused on the minimum and maximum measured magnetic flux density and the delta between these two values during the calibration on idle settings without any magnets present (Equation (1)). The lower the delta, the better the result.

$\delta = B_{max} - B_{min}\ (G)$, where

δ – delta

Bmax – maximum recorded magnetic flux density

Bmin- Minimum magnetic flux density

G - Gauss

We found that the increase in the calibration iterations and an increased delay positively affect the calibration. With this, the minimum Gauss-value becoming closer to zero. The maximum Gauss-value increases with a larger sample size. We can say that the calibration is shifting to a more positive baseline. The raw sensor data (vertical axis) readings can be seen in Figure 31. The blue line represents the raw sensor data reading, and the red line shows the baseline trend. The green circle represents the area that was initially used to take the readings for setting the baseline.

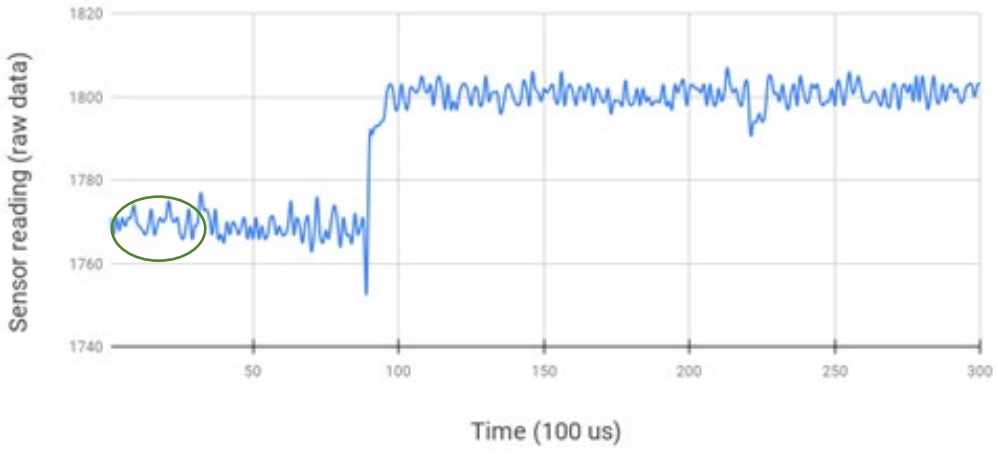

Figure 31: Raw data readings with 100 µs delay. The green circle marks the place where calibration values were measured using the initial calibration algorithm.

Another interesting thing to notice is that the readings at the beginning of turning on the devices are lower than the ones towards the end. We could determine that turning on the Wi-Fi module produces noise and can influence the sensor's readings if the calibration is done without considering that noise. The initial algorithm used only 50 readings with a 100 µs delay. This means that the baseline was decided before the shift in the baseline occurred. So the calibration algorithm was changed to have a waiting period after starting the device and take the readings after that. This means that the readings of The results of using different parameters can be seen in Figure 32. The old algorithm refers to the initial algorithm that took 50 readings with 100 µs delay between the readings and established a baseline as the average of these 50 readings. The new algorithm refers to the proposed algorithm with a calibration start delay, increased reading times, and increased delay between readings.

The specific changes that were made to the initial calibration algorithm:

• calibration delay (time between reading the sensor when calibrating) was changed (100 µs to 5000 µs),
• calibration iterations were increased (number of times the sensor was read; from 50 to 1000)
• the readings during the first 200 ms were disregarded from calculating the baseline value.

• loop delay (time between sensor readings after the calibration is done) was changed from 100 µs to 5000 µs.

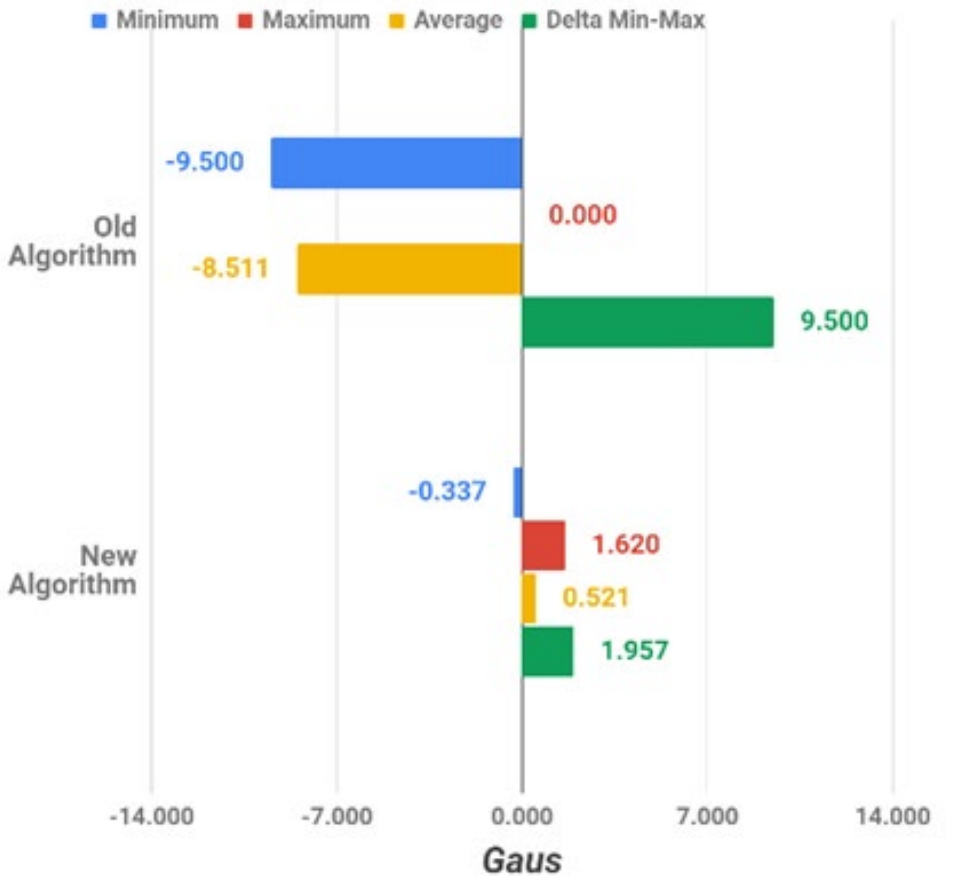

Figure 32: Comparison between old and new calibration algorithm

These changes resulted in a calibration time of about 5 seconds after starting up the device. Additionally, it is essential to keep the distance from any magnets during the calibration time, affecting the baseline value. We still preserved the initial 10 Gauss threshold value. We could not identify any false positive calls to the database in an idle testing situation because of having a steadier baseline. The devices with the modified sensor facing (P-side facing

outside) and the new algorithm were used in three public demonstration sessions, each approximately three hours long. Not only these demonstration sessions, but also on all private experiment sessions and demonstrations over approximately 300 minutes we could not identify any false positive calls made to the database.

4.2.12. Augmented dodgeball 3rd generation system

The third generation preserved the magnetic ball and sensor system as well as the display and brought the following additions to the augmented dodgeball system:

- The sensor position and direction were reviewed to get a better detection rate based on the results of calibration and experiments described on the previous section.
- Two-layer balancing was enabled
- Plus - mode was disabled
- The personal display was added
- Players shirt color represents their playing character

Sensor positioning

The sensor for the device remained the same, but the position was changed to the middle of the palm, and the sensor was placed outside of the glove worn by the player. The reason was that it turned out that one side of the sensor

was deemed to be significantly better at detecting a magnetic field than the other one. Moreover, the sensor was more resistant to the hit than previously thought. So, it was placed on the hand to the place where the contact with the ball would be most probable. Figure 33 shows the device with a sensor placed on the palm.

Figure 33: Glove with a sensor placed to the palm

Two-layer balancing

The first balancing layer involves letting players choose their virtual character (attacker, defender, balanced). In augmented dodgeball, players are aware of the fact that different player roles have different virtual parameters and who is better in what skill.

The second level of balancing is designed to adjust the game balance further. For example, when a team of adults plays against a team of children. In the

case of the second level balancing, the referee can, if desired, increase or decrease certain player's virtual parameters before the game. It also allows making one game longer or shorter depending on the playing requirements. The adjustment of game parameters can only be made before the game while setting up. Each player`s parameters can be adjusted individually, and these adjustments are not reflected on the screen but are hidden from the players in order not to label them as weak and strong ones.

At the same time, the plus mode of the game was disabled to avoid labeling the teams as in a leading and following behind and to avoid confusion in players that found the concept hard to understand during the game.

Notification devices

The changes in notification devices involve that during the game, all players wear a number shirt that color represents their player character on the field. The attackers wear red shirts, the defenders green ones, and balanced players wear a blue shirt. Players with the 3rd generation notification systems can be seen in Figure 34.

Figure 34: Players with their devices during the second playtest

The second addition to the notification device is the personal display [52] that gives information about the player`s current status on their wrists. That way, even during a game, when the player throws a ball or gets hit, they can see how many life-points they have without turning to the screen. Also, as the personal notification devices are equipped with LED strips, they can see other players remaining life points easily during the game and base some of their in-game actions accordingly. The device worn by the players can be seen in Figure 35. The device used is the M5 stack [85] that also incorporates a display and ESP32 microcontroller, which is equipped with Wi-Fi capabilities to send and receive data from the database.

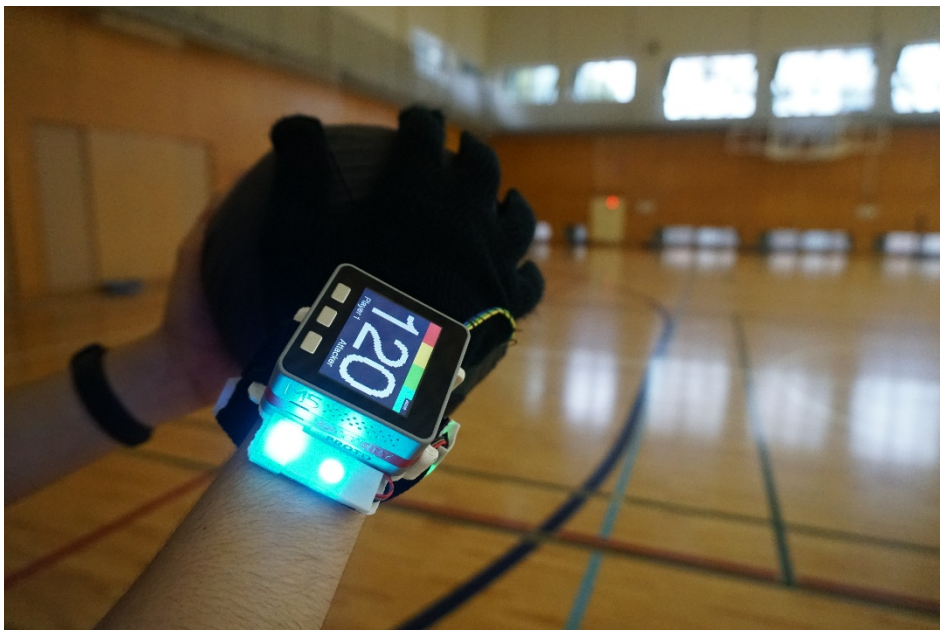

Figure 35: Personal display device worn by the player

5.Evaluation of augmented dodgeball

The following paragraph explains how we have tested and evaluated augmented dodgeball, both concept and the system. The evaluation chapter describes our two playtests that were carried out with the system on two different stages of the development, as well as observations, feedback, and findings from the discussions with other researchers. The first playtest was carried out using the 1st generation system. The second playtest used the 3rd generation system. The 2nd generation system was presented during the Super-human Sports Design Challenge and received many comments and was a subject of several discussions with the players and academic researchers, which led to the upgrades in the 3rd generation of the augmented dodgeball system.

5.1. User study nr 1

The user study consisted of the play part where the participants were introduced to the Augmented Dodgeball game and were asked to play it. The feedback from the users was acquired using a survey method [27], and observations of the game were made.

The augmented dodgeball game was designed to encourage people with different skill levels and physiology to play together and enjoy physical movements. We set the following hypothesis for the study:

- Introducing player roles would make the players act according to them.
- The player roles help to make collaboration during the game and therefore increases the enjoyment.
- Dodgeball will become a game of tactics.

5.1.1. Participants

Sixteen participants (2 female and 14 male) took part in the study. Their age was between 20 and 26, with an average age of 23. They were recruited through personal contacts. None of the participants played dodgeball regularly, and the players did not receive any compensation for participating in the test.

5.1.2. Procedure

Two independent game sessions were organized. Each of which had 8 participants. All of the games were played in teams of four. At the beginning of the experiment, we asked the participants to organize themselves into two teams by themselves. Then the rules of the dodgeball were explained, and the participants played a traditional dodgeball game to get accustomed to the basic rules. After the game was finished, the participants had a chance to proceed with the augmented dodgeball game or play another game of traditional dodgeball to get further acquainted with the rules. All of the participants in the first session thought one game was enough. All of the

participants in the second session decided to play traditional dodgeball one more time. So all of the participants in the first session played one game of traditional dodgeball, and all of the participants in the second session played two games of traditional dodgeball. After the traditional dodgeball, the rules of the augmented dodgeball were explained, and the participants took a small survey where they had to mark their skill level in dodgeball on a five-point Likert scale ranging from very good to very bad. We also asked if the player would like to play as an Attacker, Balanced, or Defense type of player. Then the teams for the Augmented Dodgeball game were formed based on the answers to the survey. The teams were assigned so that each team had all three player roles represented. When it was not possible based on the preference of the player, we assigned a player a new role based on their self-evaluation score. For instance, if we needed another attacker type of person, we assigned it to someone who had marked their skill level as very good or good. If we needed another balanced type of a player, we assigned it to someone who had marked their skill level as average, and if we needed another defensive player, we assigned it to the person who had marked their skill level as poor or very poor in the traditional dodgeball game, players with high attack skills tend to be more successful and have greater confidence in their skills. Then the players were asked to play the Augmented Dodgeball two times. During the interval time between those two games, we explained again about different player types and asked them to think about a strategy in their team. The players were not able to change their player roles between the

games. After the second game, we asked the participants to fill out a longer survey about their experience. The survey took 10 to 15 minutes to answer, and the majority of questions were claims where the players could indicate their level of agreement on a five-point Likert scale. There were also two questions to give a score about their experience, and they were also able to freely express their opinions in the comment section if they wished to do so.

5.1.3. Measures

The questionnaire that immediately followed the Augmented Dodgeball game consisted of 26 items. Most of the questions were adopted from related works[25], [30]. Some of the questions were modified to suit our case better, like making a clear distinction that the player should think about his/her experience during the Augmented Dodgeball game. Some questions were unique to this study. Those questions were specifically about the Augmented Dodgeball rules and elements designed into the game, like the use of scoreboard and player roles.

Some of the questions were negatively formulated in the questionnaire. For the analyses, both the wording and the scores were reversed for easier understanding. The questions that were negatively formulated in the questionnaire are marked with ´n´ in the results. Most of the questions were on a five-point Likert scale ranging from strongly agree to disagree strongly. Two questions asked the participants to mark a point on a scale from 0 to 100, and there was also a comment section at the end where all participants could

freely share their thoughts and suggestions about the whole experience. On the graphs, the numbers on the bars mark the percentage (%) of how many people answered like that.

5.1.4. Results

All the participants did not answer all the questions in the second questionnaire. This is likely because they skipped the page accidentally, as in all cases, all the questions on the whole page were unanswered. The missing data is classified as missing data at random (MTAR) [36]. No correlations were made, including the questions where some data was missing. Altogether, three questionnaires out of sixteen had some missing data. Each question had fourteen to sixteen players answering. As the missing data can be classified as MTAR, it does not have a significant effect on our overall results, and we also included the incomplete datasets in the analyses of calculating the mean and average values of the responses.

The graphs showing how much the participants agreed or disagreed with the presented statement are shown in the following sections. In the textual description, two outermost responses on the Likert scale were combined. The presented correlation is bivariate, two-tailed, and uses Pearson´s correlation coefficients. The significant result is measured at the level of $p \leq 0.05$.

Enjoyment and experience

The majority (88%) of the participants felt positive about playing Augmented Dodgeball (Figure 36). Only 6% indicated not feeling positive, and 6% had a neutral feeling about the experiment. The average was 4.3 points. 87% of players felt success during the game, 13% were neutral, and the average was 4.3. The same amount also felt ambition during the game, with the same average of 4.3 points. 93% admitted to having had more fun than they expected. Only 7% of people were unsure about that. The average was 4.5.

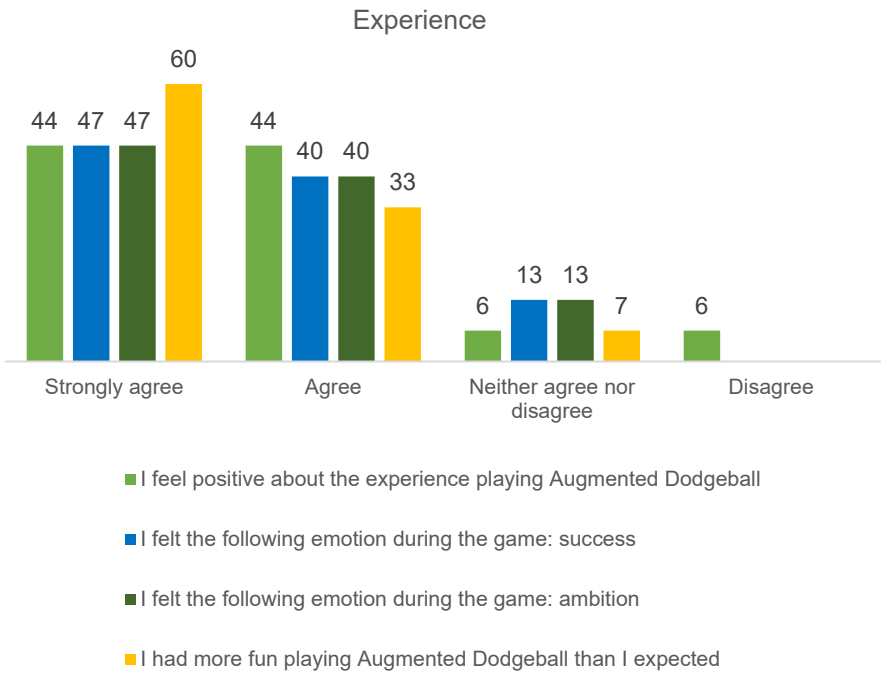

Figure 36: Players` experience playing the augmented dodgeball

The Augmented Dodgeball game had good effects on immersing the participants into the game (Figure 37). Although the number of people claiming they were able to forget the outside world is high, the participants

found it harder to forget they were inside of an experiment. 94% claimed that they forgot the outside world during the game, and only 6% stayed neutral in this question (average 4.5 points). 69% of the participants agreed that the time passed quickly while playing, 19% disagreed, an average of 3.8 points. 63% were able to forget that they were part of an experiment, where 25% were not able to do so (average 3.8).

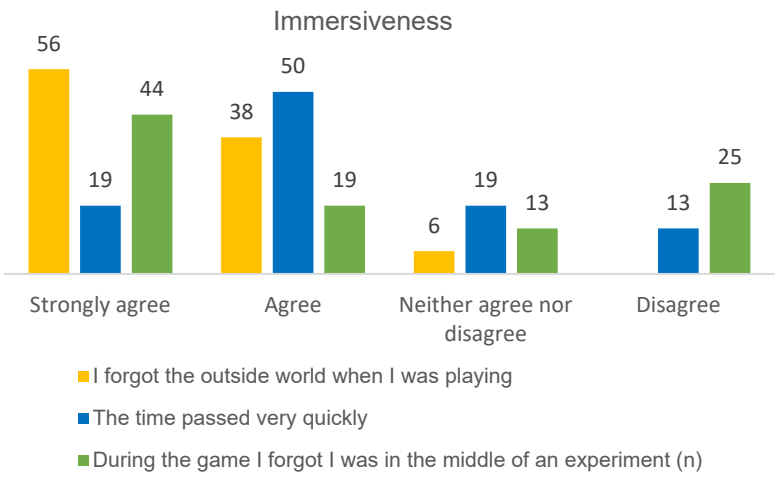

Figure 37: Impressiveness of the game

The participants liked the Augmented Dodgeball game (Figure 38). All players answering that question indicated that. All of the answered participants also said that they had fun playing the game. 60% even strongly agreed to the claim. 93% would play the game again. 40% of players said that they would have wanted to play longer. 54% disagreed with that. The reason might be extremely hot conditions during the play (35°C/95°F, humidity 85%)

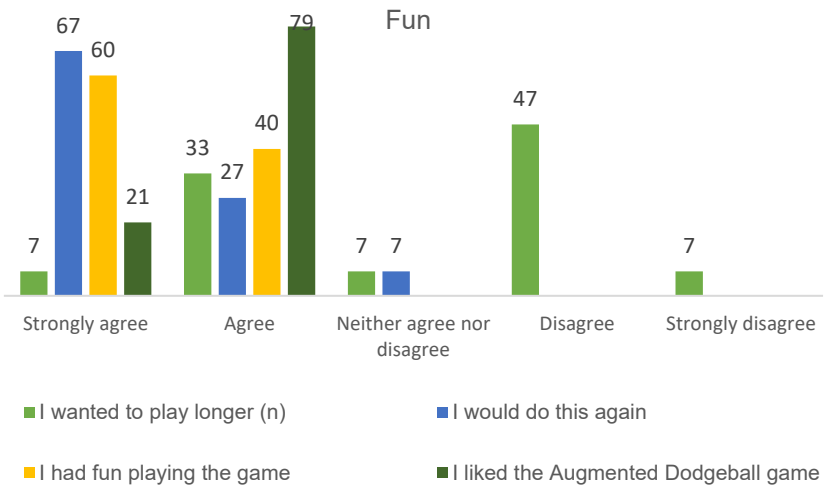

Figure 38: Participants had fun during the game

Game design

As the rules of the Augmented Dodgeball game were slightly different from the traditional dodgeball game, we wanted to get feedback on the rules design and add-ons as well (Figure 39). 87% indicated that the scoreboard where they could see how many life points everybody has and what their player roles are made the game more interesting. 14% of the people stayed neutral, and none objected to that claim. For 64%, it was always clear on how to play the game. 29% had some trouble with that, and 7% stayed neutral.

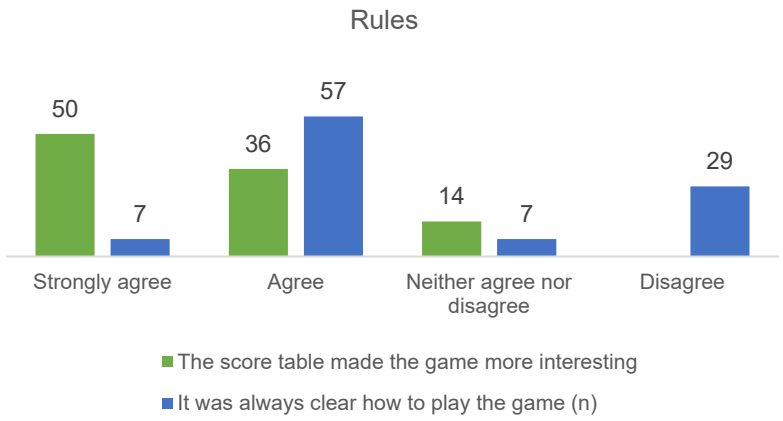

Figure 39: Rules and game elements

The augmented dodgeball game proved to be quite a competitive game (Figure 40). Half of the participants admitted to having some sort of strategy in their team, and 81% claimed to think about the strategy when they would play again. None of the participants disagreed about thinking about the strategy, but 19% stayed neutral. Although having strategy seemed to be important, winning the game had less importance for the participants. The average score is 3.2, indicating neutrality in this question. 44% of the participants marked that it mattered who won, for 31% it did not matter, and 25% felt neutral about that. 75% of the participants constantly checked the scoreboard, and only 13% did not check it all the time.

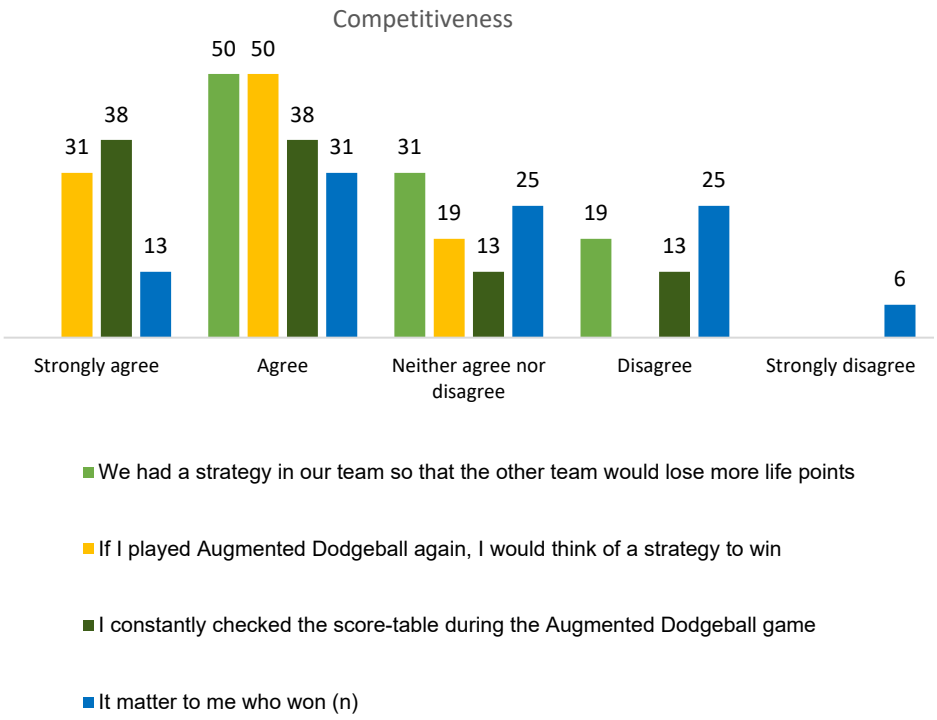

Figure 40: Competitiveness

The participants were also asked if they thought Augmented Dodgeball would be more of a laid-back game (0) or a competitive sport (100), with 50 marking the recreational sports. 75% of the participants felt it was more of a competitive sport, with 25% marking it with 100 points. 19% felt it was a recreational sport (50 points), and 7% indicated it was somewhere in between laid-back sport and recreational sport. The median was 74, placing it between recreational sport and a competitive sport (Figure 41). The lowest score was 45 and the highest 100.

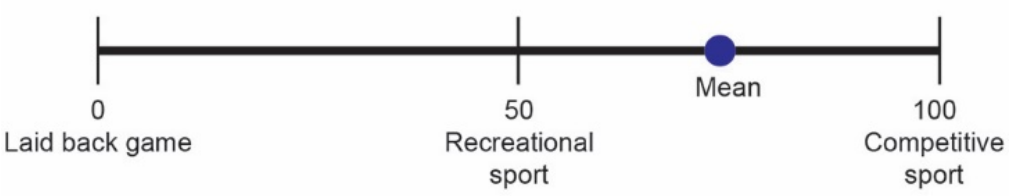

Figure 41: Classification of augmented dodgeball

Player roles

The game allowed people to choose their role in the game. We recorded a moderate positive correlation ($R=0.67$, $p<0.01$) between the self-evaluation of the player skill and the desired player role. That means that people with more confidence in their playing skills tended to choose more attacker player types and people with less confidence in their skills tended to choose more defense player types.

Comparison of participants with different skill levels

As the Augmented Dodgeball game was designed for people with different skill levels to be able to play together and enjoy being physically active, we also compared the questionnaire results among players with different skill levels. Five players indicated their skills as low (poor or very poor), 6 with average skills, and 5 participants with good skills (marked very good or good in the questionnaire). Participants from all of the groups felt positive about the experience, with averages being 4.2 for low-skill level players, 4.3 for average,

and 4.2 for high skill level players. The low-skill level participants reported feeling more successful than the high skill level participants. Averages being from low skill level 4.8 points, middle 4.6, and high 3.6. Although the overall score for the question “I would do this again” was high in all categories, it was the highest for middle-level players (5.0), followed by low-skill level players (4.8) and good level players (4.0). The low-skill level people also reported having the most fun during the game. Averages being 5.0 for low, middle - 4.6, and 4.2 for high skill level players. There was no significant difference between skill levels in the questions “I liked the augmented dodgeball” and “Please indicate your level of enjoyment,” with the averages being 4.3 and 77.8 for low skill level participants, 4.2 and 73.5 for average skill level, and 4.3 and74,4 for good skill level players. Good skill level people had slightly higher average scores for the questions “I find this kind of technology interesting, and I am willing to use it” and “The score table made the game more interesting”. With the averages being 4.8 and 5 for good skill level participants, 4.0 and 4.0 for average skill level, and 3.8 and 4.3 for low skill level participants, respectively. The high-skill level participants reported higher scores for the question “If I played the Augmented Dodgeball again, I would think of a strategy to win,” with the averages being 4.8, middle level 3.67, and 4.0 for low skill level players. There was a significant difference in how the participants with different skills saw the Augmented Dodgeball. On a scale from a laid-back game to competitive sports (Figure 41). The average for low-skill level

participants was 65 and 67 for the average skill level persons. For high-skill-level players, it was 91.

Comments

All the participants had a chance to leave comments about the Augmented Dodgeball system if they wished to do so. Most of the comments were very positive: “It is fun. The augmented environment made it more interesting.” “It was much fun.” “It was a very funny and enjoyable game, and I want to play again. It was like an RPG (Role Playing Game) game”. There were also suggestions like: “The registration device should be placed not on the helmet but the arm”, “I felt the field narrow especially longitudinal length,” and “I want killer technique”. The players found it sometimes hard to register that they are holding the ball: “It would be more fun to play if the device recognizes the ball more quickly.” But not always it was seen as a bad thing: “There was a time-lag between holding and throwing the ball, so it became one of the factors for tactics.”

Observations

During the augmented dodgeball game, some behavior of the participants differed completely from traditional dodgeball. Firstly, since the participants had to register who has the ball, the game was a bit slower, and some participants tried to use it to do actions that would not have been possible in the traditional game—for example, trying to grab the ball from the opposing

team member before they could register of having it. Secondly, especially in the second game of dodgeball, players started to pass the ball to the attacker type of the player and tried to throw the ball to the player in the opposing team who has less defense power. Thirdly, one team, after being told to think about their strategy between two Augmented Dodgeball games, reorganized their player placement so that the attacker type of the player would start the game as an infield player.

5.1.5. Discussion

Results showed that adding the player roles changed some of the behavior during the game and half of the players themselves reported having a strategy in the game and even more promised to think about it when they played again. Passing the ball to another player was one of the examples of people acting according to their player roles. Based on that, we believe hypotheses 1 and 3 were somewhat met, but there is still room to improve the enforcement of the player roles and tactics to the game. We believe that hypothesis 2 was met because the enjoyment of all participants was recorded, and there was no significant difference between different skill level players. It was interesting that different skill-level people saw the game differently. We believe that this also confirms hypothesis 2, as it can be seen as the game having different layers of enjoyment.

Limitations

One of the limitations of the Augmented Dodgeball is that it requires a special ball and a special harness to be worn by the player. That means that the number of players is limited by the number of hardware available. Also, to make the scoreboard visible for the players, an external display or a projection is required, which also sets limits to the place it can be played.

5.1.6. Future work

For future work, an appropriate virtual parameter upgrading mechanism will be designed to motivate players. This concept is similar to the handicap point system of golf' but redesigned to fit team sports. The handicap points in golf are used to equalize the score among varied skilled players. Also, handicap points can be upgraded when gaining more skills. This kind of upgrading mechanism is used to motivate the players to practice more. If this virtual parameter system is equipped with an appropriate upgrading system, it will contribute to keeping the players' motivation up. In traditional dodgeball, the players can become stronger by increasing their physical skills but by the use of virtual parameters. The players can also have a chance to become virtually stronger, making the gaming experience more versatile and exciting.

5.1.7. Conclusion

People get engaged in physical activities because of social communications and fun. What makes a game fun is the right amount of exertion and a feeling of the player that tells them that they can contribute to the outcome of the game. Augmented Dodgeball was designed to enable people with different

skill levels to enjoy playing together. To realize that, we used virtual parameters that the players were aware of and made dodgeball into a role-playing game with three different characters (Attacker, Defender, and Balanced) that the players could choose. The virtual parameters were assigned to characters based on the results of a game simulator that we developed for the game. The initial user study with 16 participants suggests that players with different skill levels enjoyed playing together and had fun during the game. The study also revealed that players with high and low skill levels reported seeing dodgeball differently. The players with more confidence in their skills reported seeing augmented dodgeball as competitive sports when the players who classified their dodgeball skill levels lower saw it more as a recreational sport. Also, observations showed that assigning player roles with virtual characters caused the players to act according to their role and focus on what their character was stronger in, and players were thinking about strategy for the whole team that suggests that virtual parameters also enforced a team play and communication between players.

5.2. User Study nr 2

User study nr 2 took place with the third generation augmented dodgeball systems that were developed after the first playtest and several discussions about game design and different game elements to be necessary to make the augmented dodgeball game more immersive and welcoming for new players

and to increase player satisfaction. Figure 42 shows players during the 2nd playtest.

Figure 42: Players during Augmented Dodgeball 2nd playtest

Claims:

- Augmenting team games help create social communication between players.
- Augmented team games make the playing experience more exciting.

5.2.1. Participants

Altogether 10 participants took part in the user study. Their age was between 22 and 30 years, with an average age of 26 years. The participants were recruited through personal contacts, the participation was voluntary, and none of the participants received any benefits for participation. All players signed a

consent form to participate in the study and agreed that the video and photo material could be used for academic purposes and to promote the Augmented Dodgeball game. The user study was carried out in two independent sessions, both having 8 participants. However, 2 participants were present in both sessions, so for them, only the results of the first session are considered. Additionally, we held the 3rd session with another set of participants, but during that session, the game systems did not work reliably, and the survey results are not included in the numerical analysis. However, the comments and observations during the failed session gave interesting insights about the game, and those are discussed in the observations and comments section as well as in the experiment conclusion section.

5.2.2. Procedure

One game session was organized. At the beginning of the experiment, we asked the participants to organize themselves into two teams of their liking. Then the rules of the dodgeball were explained, and the participants played two games of traditional dodgeball. After the game, the participants took the game experience questionnaire [14]. Then, the augmented dodgeball game was introduced to the players. The players were allowed to pick new teams if they wished to do so. However, the players decided to continue with the previous teams. Then the teams were given some time to discuss which player roles they will have during the game and select the player who is starting as an outside player. There were no limits on the users for choosing the player roles. After the teams had concluded on which player roles each player has,

they were given the augmented dodgeball wearable system. Then, two Augmented Dodgeball games were played. After the augmented dodgeball games, the participants took the game experience questionnaire again. After the game, the participants also answered open-ended questions about their experience.

5.2.3. Measures

The questionnaire that the players filled out after the traditional and augmented games were identical. The questionnaire composes of a core module (33 items), a social presence module (17 items), and a post-game module (17 items). All items were presented on a 5-point Likert scale ranging from “Not at all” (0) to “Extremely” (4). The significance of the difference is measured by a two-tailed paired Wilcoxon test with $p < 0.05$. The results are calculated as an average for each measure. Each measure consisted of 2 - 6 questions. The interview after the game consisted of open-ended questions where the participants were asked about their playing experience, the equipment, and suggestions on how the gaming experience could be further improved.

5.2.4. Survey result

The game experience questionnaire results are presented in Figure 43 and Figure 44. The blue columns indicate the average values of each category when playing traditional dodgeball (DB). The orange columns present the average results after the augmented dodgeball game (ADB). The players

reported an 87.5% increase in immersion (DB average 1.1, ADB average 2.1), 32,4% increase in positive affect (DB 2.4, ADB 3.1), empathy increased 29.3% (DB 2.1, ADB 2.7), negative feelings increased by 52.6% (DB 1.3, ADB 1.9), and flow increased by 40.4% (DB 1.7, ADB 2.4).

The survey showed no significant change in the tension, challenge, negative effect, negative feelings, tiredness, competence, positive experience, or returning to reality categories.

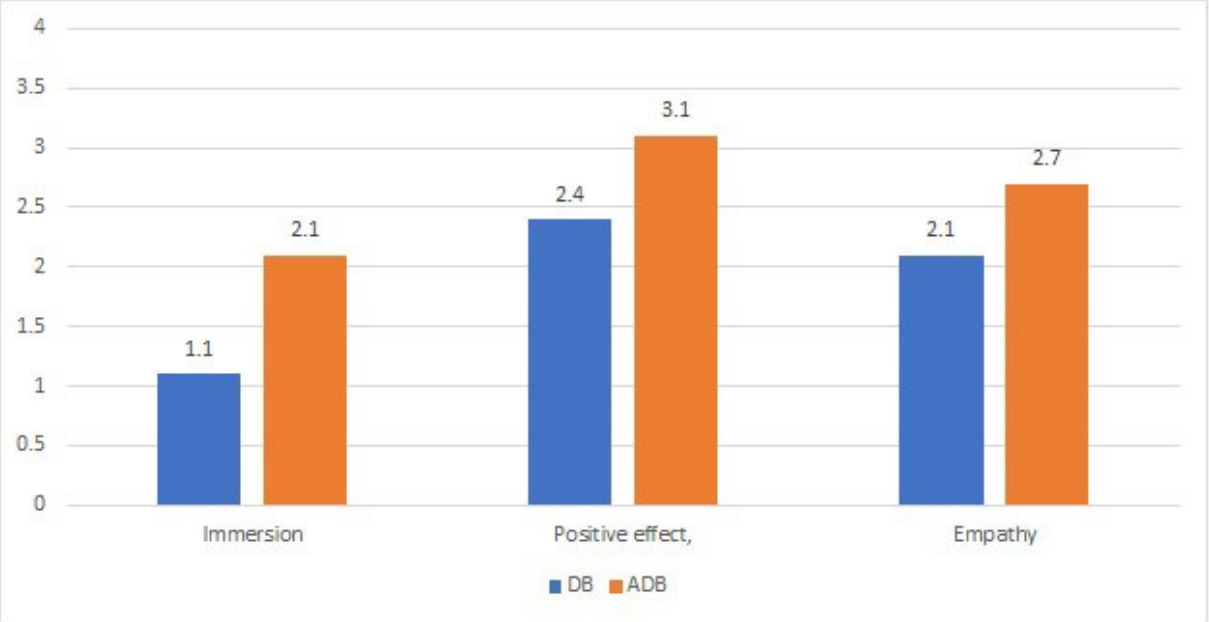

Figure 43: Results of the game experience questionnaire 1/2

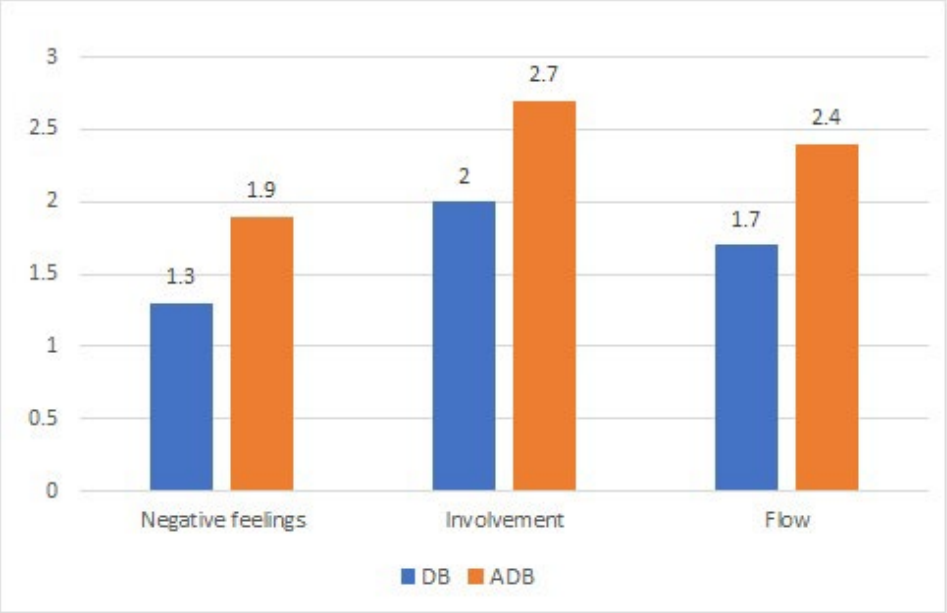

Figure 44: Results of the game experience questionnaire 2/2

5.2.5. Game metrics

Table 5 shows the game metrics of augmented dodgeball and traditional dodgeball game on that day.

As can be soon on table 5, the game time was significantly longer in augmented dodgeball game which was expected because of the game design. Some of the time was also spent on pauses, out of which about half were technical problems and about half were players asking questions about the game. Also, passing the ball among infield players increased a lot. It suggests that players were using tactics in the game.

Table 5: Game metrics

	Time	Pauses	Throws	Hits	Passes
Augmented game	12:30	4.5	47	18	6
Traditional game	2:58	0.5	13.5	4.5	0.5

5.2.6. Interview results

When comparing two games that they had experienced, players pointed out that they liked that there were different roles in the augmented version and that even when they got hit once, they could continue playing. Participants also noted that having different roles made them think about strategy. However, they liked the fast tempo and smoothness of the traditional dodgeball game.

Amount of interaction before the game: before the traditional dodgeball game, the players did not talk to each other much, only decided who should be the outfield player. On the other hand, before the augmented dodgeball game, players reported they had more discussions about player roles, their skill levels, strategy, and who and with what role should start as an outside player.

The participants said that they used strategies and planned them before the game had started.

Some players looked at their wrist devices to get information about their status during the game, but most preferred the screen for both for getting their and their teammates as well as the opposing team members` virtual parameters. Reasons for that being: getting all information in one place, and some players said that it is more comfortable to watch the screen than looking at their wrist device. The screen and watch were most often used when the players themselves and/or someone got hit by the ball.

When players were asked about whom they would like to play with, they indicated that in the case of augmented dodgeball, they would play with their friends as skill levels do not have so much importance in that game. However, in traditional dodgeball, they would prefer to be on the same team with someone good at the game.

Suggestions that the player had about improved the dodgeball game: make the game automatic (automatic hit detection), improve the devices so that the game could be more smoothly played, have some special skills or powers/power up-s during the game; construct a story, but be careful of not making too complicated plot.

Most players agreed that if they would play an augmented dodgeball game has an interesting concept, and they would play it again. But only if the system

would work seamlessly and would not cause interruptions and support fast tempo

5.2.7. Discussion

Here we are discussing the five main points that we found during our user studies and interviews and observations from demonstrating the augmented dodgeball system.

Target audience

Defining a target audience makes designing the game easier as it helps to decide the complexity of the system and set requirements for the hardware. From our experience, we find that targeting adults and teenagers makes the most benefit. First, they are the people whose life includes less physical activity and therefore need the extra push and excitement that augmented systems can give. Kids, on the other hand, are more active by nature and can more easily be encouraged to move. Of course, augmented games can be used to connect younger and older kids. According to our observations, kids also enjoyed the augmented version of dodgeball and were excited by the colorful LEDs on their hand, but in reality, paid less attention to what are their player roles and did not collaborate inside the team based on that. They enjoyed dodgeball as it was.

Hardware design

Designing a game that takes place in a virtual world and the real world with a real ball is challenging. First of all, the tempo of the game can be high, and the high speed is one thing that makes it exciting for the people. If the hardware can keep up with it and measure and detect all that is required, it makes the people trust the system and adds a lot to the gaming experience. On the other hand, when players find that the hardware is malfunctioning, they get frustrated very quickly, and instead of enjoying the exercise, they start to dislike it even more and get into arguments with other players. Hardware not working as expected also adds to the cognitive load of the players, as they do not trust the system or the judge and want to check the scores also on their own. This kind of behavior in augmented games is not desirable as the technology should be helping the player to enjoy the game. A good solution to hardware limitations is to make them features. In traditional games, people are used to the common rules, and changing them can result in dissatisfaction. On the augmented games, however, as they are new, participants are much more open to new and different rules. For example, introducing pauses in the game for inserting the data into the system. Players can then focus on the game, and when the pause is there, they can analyze their game, talk about strategy, etc. For the game creators, it allows them to verify their game design without the tremendous effort of a state-of-the-art system for sensors. Human input can also be used during the game, but in that case, players also expect

real-time updates, which can be complicated in fast-paced games like dodgeball and also when there are many people on the field.

Visual design

We describe an augmentation method that involves a virtual layer but is played in the real world without constantly being able to look at the screen. As the game is also fast-paced, it is important to let the players know about what kind of changes happen to the virtual world. The easiest way to do that is through haptic and visual displays that are easy to understand and that do not require too much attention from the players but at the same time give them enough information about the virtual world. For the virtual parameters that do not change during the game (like player roles in augmented dodgeball), it is good to use an analog visual sign (color /design of the blouse, add a symbol to their clothing, etc.) For things that change during the game (like life points), more dynamic solutions that can change during the game are required. In augmented dodgeball, we used a personal device that displays the number of life points and a scoreboard. The personal device is a good way to keep an eye on the player’s life points and can also be visible when throwing the ball, not necessary to make extra movements during a busy game as the display catches eye also when throwing the ball. The second one is good for giving an overview of how the game is going, and the whole team's scores can easily be viewed. That was usually used by players when they could take a little

break, for example, when there was no danger of getting hit by the ball immediately.

Procedure

Changing a regular sport to augmented sports is a great way to enrich the gaming experience. With the augmentation described in this paper, using virtual parameters to enhance peoples' powers, the hardware must be seamlessly integrated into the system. While working on our prototype with the helmet, we instructed the players to touch the ball on the helmet to "give it power in the virtual world". Players were quite cooperative to do the extra movement, although it was a movement not included in the traditional dodgeball. In our last prototype, the LEDs on the wearable device change color when the user is holding the ball, and the users were asked to make sure the color has changed. As the users could not do anything for the color to change, many of them disregarded the request and threw the ball as they wished. So, the game design should always see the player side of the use, not the system requirements. Moreover, for the player, each movement they are required to do must have a meaning in the game, not in the system.

Also, when augmenting an existing sport, it is a good idea to follow the sports as closely as possible, as the rules of existing sports have developed naturally over a long time and are familiar to the people. Augmentation can help it to make it more versatile, approachable to different skill levels, and strategic.

Player expectations

When designing a sports game, it is important to understand the expectations of the players and design for it. Players, when presented with a new game that bases on the existing one, are expecting all the benefits/good points to be carried over into the new game and are easy to be disengaged by not enabling them. In our augmented dodgeball tests, because of the limitations of the hardware in use, sometimes the tempo of the game was not fast enough. To avoid this kind of limit, the weak points and technology requirements should be disguised as game elements and features of the game. This allows us to shift the focus of the player to a different place and accept the shortcomings in the new game.

5.2.8. Limitations

This study is limited to one case study of Augmented Dodgeball. The design requirements have not yet been tested on other similar sports.

5.2.9. Conclusion

Being active plays an important part in gaining and maintaining both physical and mental well-being. As the daily amount of physical activity is very little for both school children and working adults, leisure time is increasingly important to provide physical activity. As social aspects of physical activity have a very high effect on the decision of whether to participate or not in the activity, it is crucial to design activities that can also enhance social relationships. Our case study showed that augmenting a team game with computer game elements

and giving players to play a role during the game does require more discussion and team collaboration than the game without augmentation, so we can say that augmented games in the way we described do work as a mean to enhance social communication. So, we can say that our first claim is supported by the players in our experiment.

The experiment results also support our second claim that augmenting games result in a more exciting gaming experience. We can see that the players felt more immersed and involved in the game as well as there was an increase in the amount of flow the players felt during the game.

Augmented team games have the potential to influence people into getting sports. However, they require careful game design and the equipment to work reliably, as otherwise, the improvements in game design are overshadowed by the frustration the players are having of operating the equipment as well as a loss of trust in the overhead system.

6. Augmenting volleyball (discussion)

This thesis has presented both a theoretical and a practical example on how to augment team games with a ball, what are the limitations and hardships of creating emerging and fun games that involve physical exertion by the player. As augmentation technology has lots of potential in creating very sophisticated and interesting games involving physical activity, the design principles and methods presented in this work must also apply to other sports. Next, a theoretical proposal for augmenting volleyball based on the methods and lessons learned so far is presented.

Volleyball was chosen as the example system because it is a popular sport among hobby players so it was easy to have discussions with them as well as a personal familiarity with the game. The augmentation points were first explored with an informal interview with a recreational volleyball player to find some weak points in the game and what kind of frustrations and fears the beginner players might have. Then the found knowledge was applied to steps 0 – 7 described in the augmentation chapter. Lastly, a concept for an augmented volleyball game was created.

6.1. Volleyball overview

Volleyball is a team game played by two opposing teams on the field. There is a net in between them, and the goal of the game is to make the ball touch

the ground on the opposing team's side. The ball cannot be held on hand, and it cannot touch the ground. That would mean the opposing team scores a point. So the ball is bounced on the hands of the players. The game starts with a serve move that is initiated by a player standing on the cask line of the field. The serve is supposed to go over across the net in the middle of the field. Then the opposing team can receive the serve, and they can have up to three touches to get the ball across the net again. Then all this repeats until the ball touches the ground. The team whose field side the ball touched the ground is considered the losing side, and the point is awarded to their opponent. [86] gives an overview of the rules and scoring of volleyball in the Olympics. Volleyball has a player role system incorporated into the game. At the recreational level, players rotate after each point is scored and play the roles of the place they happen to be during the game. So, each player plays and trains for all different roles.

6.2. Design steps

Game design:

What is the purpose of the augmentation? Is it to change the difficulty level? In what way? Who should be able to enjoy this game? Why are they not enjoying the game now? Are new gaming elements wanted? Whom will they benefit?

Answer: The purpose of augmentation is to reward the players for the beauty of the game (using three touches to get the ball over to the other side) and the effort they have put into the game despite having some disadvantage (it is harder to hit the ball over the new for a shorter person, inexperienced players are not very precise in directing the ball, etc.). Make players enjoy the game more by keeping the ball in the game for a longer time.

What is the shortcoming of the game in its original form that the designer is interested in approving?

Answer: The current scoring does not consider the beauty of the game and the effort players are putting into play

Player experience:

How is the winner of the game decided? What are the actions that give points/decide which team is leading?

Answer: The team that does not let the ball fall to their side of the field scores the point.

What are the qualities of the star player in the game? What is the “coolest” player in the game doing? What are all other players doing?

Answer: The players who are with fast reaction speeds and can precisely bounce the ball to the desired direction are the star players. Other players may

be afraid of the ball and just try not to interfere with the more courageous players.

Do players have different roles in the game? How do different players support each other during the game?

Answer: Yes, players have different player roles. Some players receive the first serve, the ones who raise the ball, and then the hitter who gets the ball across the net.

Environment design:

Where is the game taking place? Can we take it to some other place or dimension?

Answer: The game takes place on a field. It is probably the easiest place to play it, and adding more challenges to the game is not desired with the current design goals. However, for training or making a mini-game focusing only on one element could be done in some other place or condition.

Which senses of the players are using. Can we add a different sense? What happens if we limit some of the senses?

Answer: Main sense the players are using is their eyesight. In the current setting, limiting this sense would make the game more challenging.

Based on the design steps and discussion, the following improvements were proposed in order to make the game more approachable for all players:

Game design – reward beauty of the game

Player experience – allow beginner players to keep the ball in the game longer

Environment design – relax rules about where players can serve and apply net height based on perceived player skill level.

Based on these general points, we decided to incorporate the following elements into the game:

- Add style and collaboration points to the game. For example, when the ball is played with three touches to cross the field, the team would be awarded.
- Each player would have a different amount of style points for each element they perform. For example, if the element is hitting the ball across the net as the third touch, a shorter player would earn more points to their team than a taller player. A more novice player would score more points for the same kind of move than a more experienced one.
- Increase the limit of touches allowed by one team, but if the number is less or more than 3, give fewer points for the style.
- Allow players to save the ball even when it has hit the floor once.

6.3. System design possibilities

To realize this kind of augmented volleyball, we need the following systems.

Software:

- game parameters
- game engine
- game database

Tracking devices:

- which player is touching the ball?
- system to track the ball direction and hit speed (mainly for helping to set the individual skill level and style points and feedback for the player)

Notification devices

- game score
- The volleyball game, in its essence, is very fast-paced, so updating the scoreboard after the ball has touched the ground is enough. The touch can be inserted by the referee. An automatic touch detection and decision-making system, if the touch should or should not be counted, would be a possible design goal, but the game is also easily tested without that. The player touch system, on the other hand, is necessary to be reliable, as the information obtained by it would be very labor

intense for the referee to insert into the system manually and would probably require a re-watch from a video to recognize all elements.

The described game concept and design were also introduced to the recreational volleyball player, and it received good feedback in terms that the concept seemed interesting and the player would like to play this kind of game. However, the augmented volleyball is purely a theoretical game at this point. To get better feedback if the theories and game design work, as well as for the mechanical system development, the game should be created and evaluated in a playtest.

7. Conclusion

This thesis has analyzed augmented sports focusing on team games with a ball. The team games were chosen, and they, by their nature, include a social aspect. This is important because leisure time has increasingly become the main time when a person gets involved in physical activities, and in leisure time, people want to feel good and have positive experiences by choice.

The contribution of this thesis is the following:

- A theoretical base of design principles for augmenting team games was formed.
- Augmented dodgeball game and system was developed (with the augmented sports team in Nojima lab)
- Evaluation of the system is provided with two playtest and through discussions and observations.

From the work done, the following things can be concluded:

- Augmented team games can provide enjoyable physical activity both for skillful and less skillful people
- Augmented sports are possible to design to be more inclusive and promote collaboration between players in the same team

- Augmented sports promote interaction and social communication between players in the same team
- Augmented sports player satisfaction is heavily dependent on the systems in use functioning as expected
- Player expectations should be managed before the game, so players know how what to expect from the system and trust it
- Failure in system design causes stress, irritation, and a bad playing experience for the players
- Augmented games, while they can be played by children, are especially effective in promoting physical activity among teenagers and adults who seek some new and exciting experiences.

8. Summary

This thesis gives an overview of augmented team games with a ball. The theoretical part gives an overview of the ways to augment a game, the systems that can be used when augmenting to make the game experience smooth and enjoyable for the players. There are many ways to augment an activity. This thesis focuses on digital augmentation that can but does not have to be combined with some physical augmentation techniques like restricting or adding a physical sensation. Digital augmentation was chosen as the focus because it is an emerging field with lots of potentials to be used in game design. Thanks to digital augmentation technologies, games with physical exertion can be designed with more sophisticated rules and exciting content.

This thesis also presents a case study with an augmented dodgeball game that was designed based on the dodgeball game played around the world. The main design goals were to make people with different skill levels and backgrounds enjoy playing together, shift the focus of the game from only physical skills to the strategical game, and promote social interactions between players. To realize these goals, we designed a game that involved player roles with different attack and defense power. Moreover, the players could play until they had life points left. To realize this kind of game, systems for tracking the player who is interacting with the ball and notification systems

displaying the current state of the ball had to be developed. This thesis describes three different generations of systems used to enable the gameplay. The last part of the thesis concentrates on evaluating the designed systems. Each system was developed by following the recommendations and feedback from players, the audience, and the many visitors/workshop participants that took part in the demos, showcases, conferences, and events the augmented dodgeball system was presented. Results from the playtests and discussions showed a great interest in these kinds of augmented games, and therefore continuing development, design, and creating new games have the potential to get more and more people involved in physical activity and augmented gameplay.

References

[1] Steven Allender, Gill Cowburn, and Charlie Foster. 2006. Understanding participation in sport and physical activity among children and adults: A review of qualitative studies. *Health Education Research 21*, 826–835. DOI:https://doi.org/10.1093/her/cyl063

[2] Patrick Baudisch, Henning Pohl, Stefanie Reinicke, Emilia Wittmers, Patrick Lühne, Marius Knaust, Sven Köhler, Patrick Schmidt, and Christian Holz. 2013. Imaginary reality gaming: Ball games without a ball. In *UIST 2013 - Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology*, 405–410. DOI:https://doi.org/10.1145/2501988.2502012

[3] Peter Blank, Thomas Kautz, and Bjoern M Eskofier. 2016. Ball impact localization on table tennis rackets using piezo-electric sensors. In *International Symposium on Wearable Computers, Digest of Papers*, 72–79. DOI:https://doi.org/10.1145/2971763.2971778

[4] Woohyeok Choi, Jeongmin Oh, Darren Edge, Joohyun Kim, and Uichin Lee. 2016. SwimTrain. *Proc. 2016 CHI Conf. Hum. Factors Comput. Syst. - CHI '16* (2016), 1692–1704. DOI:https://doi.org/10.1145/2858036.2858579

[5] Timothy S. Church, Diana M. Thomas, Catrine Tudor-Locke, Peter T. Katzmarzyk, Conrad P. Earnest, Ruben Q. Rodarte, Corby K. Martin, Steven N. Blair, and Claude Bouchard. 2011. Trends over 5 Decades in U.S. Occupation-Related Physical Activity and Their Associations with Obesity. *PLoS One* 6, 5 (May 2011), e19657. DOI:https://doi.org/10.1371/journal.pone.0019657

[6] Mihaly Csikszentmihalyi. 2008. *Flow: The Psychology of Optimal Experience*. Harper Perennial Modern Classics.

[7] L Ponce Cuspinera, Sakura Uetsuji, F. J.Ordonez Morales, and Daniel Roggen. 2016. Beach volleyball serve type recognition. In *International Symposium on Wearable Computers, Digest of Papers*, 44–45. DOI:https://doi.org/10.1145/2971763.2971781

[8] Hayato Dogai, Maho Oki, and Koji Tsukada. 2016. SomaticBall: Ball-type device providing “sticking feeling.” In *ACM International Conference Proceeding Series*. DOI:https://doi.org/10.1145/3001773.3001810

[9] Charles Duhigg. 2012. *The Power of Habit: Why We Do What We Do in Life and Business*.

[10] Christian Eichhorn, Adnanee Jadid, David A. Plecher, Sandro Weber, Gudrun Klinker, and Yuta Itoh. 2020. Catching the Drone-A Tangible Augmented Reality Game in Superhuman Sports. In *2020 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*, Institute of Electrical and Electronics Engineers Inc., 24–29. DOI:https://doi.org/10.1109/VR.2019.8798056

[11] Kathrin Maria Gerling, Matthew Miller, Regan L Mandryk, Max Valentin Birk, and Jan David Smeddinck. 2014. Effects of balancing for physical abilities on player performance, experience and self-esteem in exergames. *32nd Annu. ACM Conf.* (2014), 2201–2210. DOI:https://doi.org/10.1145/2556288.2556963

[12] Dorothée Hefner, Christoph Klimmt, and Peter Vorderer. 2007. Identification with the Player Character as Determinant of Video Game Enjoyment. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 39–48.

[13] J Huizinga, Routledge & Kegan, Paul London, and Henley Boston. *HOMO LUDENS A STUDY OF THE PLAY-ELEMENT IN CULTURE*.

[14] W.a. IJsselsteijn, Y.a.W. de Kort, and K Poels. 2008. Game Experience Questionnaire. 1–9.

[15] Christos Ioannou, Patrick Archard, and Christof Lutteroth. 2019. Virtual Performance Augmentation in an Immersive Jump & Run Exergame. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, 1–15. DOI:https://doi.org/10.1145/3290605.3300388

[16] Katherine Isbister and Florian ‘Floyd’ Mueller. 2015. Guidelines for the Design of Movement-Based Games and Their Relevance to HCI. *Human–Computer Interact.* 0024, June 2015 (2015), 37–41. DOI:https://doi.org/10.1080/07370024.2014.996647

[17] Osamu Izuta, Toshiki Sato, Sachiko Kodama, and Hideki Koike. 2010. Bouncing star project: Design and development of augmented sports application using a ball including electronic and wireless modules. In *ACM International Conference Proceeding Series*, ACM Press, New York, New York, USA, 1–7. DOI:https://doi.org/10.1145/1785455.1785477

[18] Mads Moller Jensen, Majken K Rasmussen, Florian “Floyd” Mueller, and Kaj Gronbaek. 2015. Keepin’ it Real: Challenges when Designing Sports-Training Games. *Proc. ACM CHI’15 Conf. Hum. Factors Comput. Syst.* 1, (2015), 2003–2012. DOI:https://doi.org/10.1145/2702123.2702243

[19] Raine Kajastila, Leo Holsti, and Perttu Hämäläinen. 2016. The Augmented Climbing Wall: High-Exertion Proximity Interaction on a Wall-Sized Interactive Surface. *Proc. 2016 CHI Conf. Hum. Factors Comput. Syst.* (2016), 758–769. DOI:https://doi.org/10.1145/2858036.2858450

[20] Yusuke Kishishita, Swagata Das, Antonio Vega Ramirez, Chetan Thakur, Ramin Tadayon, and Yuichi Kurita. 2019. Muscleblazer: Force-feedback suit for immersive experience. In *26th IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2019 - Proceedings*, Institute of Electrical and Electronics Engineers Inc., 1813–1818. DOI:https://doi.org/10.1109/VR.2019.8797962

[21] Christoph Klimmt, Tilo Hartmann, and Andreas Frey. 2007. Effectance and Control as Determinants of Video Game Enjoyment. *Cyberpsychology Behav.* 10, 6 (2007), 845–847. DOI:https://doi.org/10.1089/cpb.2007.9942

[22] Miran Kondrič, Joško Sindik, Gordana Furjan-Mandić, and Bernd Schiefler. 2013. Participation motivation and student’s physical activity among sport students in three countries. *J. Sport. Sci. Med.* 12, 1 (March 2013), 10–18.

[23] Wanwan Li, Biao Xie, Yongqi Zhang, Walter Meiss, Haikun Huang, and Lap Fai Yu. 2020. Exertion-aware path generation. *ACM Trans. Graph.* 39, 4 (2020), 14. DOI:https://doi.org/10.1145/3386569.3392393

[24] Katsutoshi Masai, Yuta Sugiura, and Maki Sugimoto. 2017. ACTUATE racket: Designing intervention of user’s performance through controlling angle of racket surface. In *ACM International Conference Proceeding Series*. DOI:https://doi.org/10.1145/3041164.3041200

[25] Florian Mueller. 2002. Exertion Interfaces: Sport over a distance for Social Bonding and Fun. Massachusetts Institute of Technology.

[26] Florian'Floyd' Mueller and Nadia Bianchi-Berthouze. 2015. Evaluating Exertion Games. In *Game User Experience Evaluation*. Springer, 239–262. DOI:https://doi.org/10.1007/978-3-319-15985-0

[27] Florian 'Floyd' Mueller and Nadia Bianchi-Berthouze. 2010. Evaluating Exertion Games. . 187–207. DOI:https://doi.org/10.1007/978-1-84882-963-3_11

[28] Florian Floyd Mueller, Frank Vetere, Martin R Gibbs, Darren Edge, Stefan Agamanolis, and Jennifer G Sheridan. 2010. Jogging over a Distance between Europe and Australia. In *UIST 2010 - 23rd ACM Symposium on User Interface Software and Technology*, 189–198. DOI:https://doi.org/10.1145/1866029.1866062

[29] Florian "Floyd" Mueller and Damon Young. 2017. Five Lenses for Designing Exertion Experiences. *Proc. 2017 CHI Conf. Hum. Factors Comput. Syst. - CHI '17* (2017), 2473–2487. DOI:https://doi.org/10.1145/3025453.3025746

[30] Florian Mueller, Martin Gibbs, Frank Vetere, and Stefan Agamanolis. 2008. Design space of networked exertion games demonstrated by a three-way physical game based on Table Tennis. *Comput. Entertain.* 6, 3 (October 2008), 1–31. DOI:https://doi.org/10.1145/1394021.1394029

[31] Florian Mueller, Rohit Ashok Khot, Kathrin Gerling, and Regan Mandryk. 2016. Exertion Games. *Found. Trends® Human–Computer Interact.* 10, 1 (2016), 1–86. DOI:https://doi.org/10.1561/1100000041

[32] Kei Nitta, Keita Higuchi, Yuichi Tadokoro, and Jun Rekimoto. 2015. Shepherd pass: Ability tuning for augmented sports using ball-shaped quadcopter. In *ACM International Conference Proceeding Series*. DOI:https://doi.org/10.1145/2832932.2832950

[33] Takuya Nojima, Ngoc Phuong, Takahiro Kai, Toshiki Sato, and Hideki Koike. 2015. Augmented Dodgeball: An Approach to Designing Augmented Sports. (2015). DOI:https://doi.org/10.1145/2735711.2735834

[34] Yoonsin Oh and P. Yang, Stephen. 2010. Defining Exergames & Exergaming. In *Meaningful Play 2010*, 21–23.

[35] Tomoya Ohta, Shumpei Yamakawa, Takashi Ichikawa, and Takuya Nojima. 2014. TAMA: Development of Trajectory Changeable Ball for Future

Entertainment. (2014). DOI:https://doi.org/10.1145/2582051.2582101

[36] Jason W Osborne. 2013. *Best Practices in Data Cleaning: A Complete Guide to Everything You Need to do before and after collecting your data*. Sage.

[37] Russell R. Pate, Caroline A. Macera, Michael Pratt, Gregory W. Heath, Steven N. Blair, Claude Bouchard, William L. Haskell, Abby C. King, David Buchner, Walter Ettinger, Andrea Kriska, Arthur S. Leon, Bess H. Marcus, Jeremy Morris, Ralph S. Paffenbarger, Kevin Patrick, Michael L. Pollock, James M. Rippe, James Sallis, and Jack H. Wilmore. 1995. Physical Activity and Public Health: A Recommendation From the Centers for Disease Control and Prevention and the American College of Sports Medicine. *JAMA J. Am. Med. Assoc.* 273, 5 (February 1995), 402–407. DOI:https://doi.org/10.1001/jama.1995.03520290054029

[38] Frank J Penado and Jason R Dahn. 2005. Exercise and well-being: a review of mental and physical health benefits associated with physical activity. *Curr. Opin. Psychiatry* 18, 2 (2005), 189–193. DOI:https://doi.org/10/cfcxb2

[39] David Perez-Diaz-De-Cerio, Ángela Hernández-Solana, Antonio Valdovinos, and Jose Luis Valenzuela. 2018. A low-cost tracking system for running race applications based on bluetooth low energy technology. *Sensors (Switzerland)* 18, 3 (March 2018). DOI:https://doi.org/10.3390/s18030922

[40] Raquel Breejon Robinson, Elizabeth Reid, James Collin Fey, Ansgar E Depping, Katherine Isbister, and Regan L Mandryk. 2020. Designing and Evaluating “In the Same Boat”, A Game of Embodied Synchronization for Enhancing Social Play. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, 1–14. DOI:https://doi.org/10.1145/3313831.3376433

[41] Richard M Ryan and Edward L Deci. 2000. Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *Am. Psychol.* 55, 1 (2000), 68–78. DOI:https://doi.org/10.1037/0003-066X.55.1.68

[42] Shunsuke Sakai, Yohei Yanase, Yasutsuna Matayoshi, and Masahiko Inami. 2018. D-Ball: Virtualized sports in diminished reality. In *Proceedings of the First Superhuman Sports Design Challenge: First International*

Symposium on Amplifying Capabilities and Competing in Mixed Realities, 1–6. DOI:https://doi.org/10.1145/3210299.3210305

[43] Yuji Sano, Koya Sato, Ryoichiro Shiraishi, and Mai Otsuki. 2016. Sports support system: Augmented ball game for filling gap between player skill levels. In *Proceedings of the 2016 ACM International Conference on Interactive Surfaces and Spaces: Nature Meets Interactive Surfaces, ISS 2016*, 361–366. DOI:https://doi.org/10.1145/2992154.2996781

[44] Leon Straker, Pieter Coenen, David Dunstan, Nicolas Gilson, and Healy Genevieve. 2016. *Sedentary work. Evidence on an emergent work health and safety issue*.

[45] U.S. Department of Health and Human Services. 1996. *Physical activity and health: a report of the Surgeon General*.

[46] Amanda J Visek, Sara M Achrati, Heather Manning, Karen Mcdonnell, Brandonn S Harris, and Loretta Dipietro. 2014. *The Fun Integration Theory: Towards Sustaining Children and Adolescents Sport Participation*.

[47] Ilkka Vuori. 1998. Does physical activity enhance health? *Patient Educ. Couns.* 33, SUPPL.1 (April 1998). DOI:https://doi.org/10.1016/S0738-3991(98)00014-7

[48] Darren E R Warburton, Crystal Whitney Nicol, and Shannon S D Bredin. 2006. Health benefits of physical activity: the evidence Review. *CMAJ* 174, 6 (2006), 801. DOI:https://doi.org/10.1503/cmaj.051351

[49] Biao Xie, Yongqi Zhang, Haikun Huang, Elisa Ogawa, Tongjian You, and Lap-fai Yu. 2018. Exercise Intensity-driven Level Design. *IEEE Trans. Vis. Comput. Graph.* 24, 4 (2018), 1661–1670.

[50] Yongqi Zhang, Biao Xie, Haikun Huang, Elisa Ogawa, Tongjian You, and Lap-Fai Yu. 2019. Pose-Guided Level Design. (2019). DOI:https://doi.org/10.1145/3290

[51] Bo Zhou, Markus Wirth, Christine Martindale, Harald Koerger, Constantin Zwick, Heber Cruz, Bjoern Eskofier, and Paul Lukowicz. 2016. Smart soccer shoe: Monitoring foot-ball interaction with shoe integrated textile pressure sensor matrix. In *International Symposium on Wearable Computers, Digest of Papers*, 64–71. DOI:https://doi.org/10.1145/2971763.2971784

[52] 井上暢, 四條亮太, Rebane, Kadri, and 野島琢也. 2019. Augmented Dodgeball における プレイヤへの実時間情報伝達システムの開発. In *IPSJ Interaction*.

[53] 四條亮太, Kadri Rebane, and 野嶋琢也. 2017. 球技拡張のためのプレイヤ・ボールインタラクション検出デバイス. In *the 22nd Annual Conference of the Virtual Reality Society of Japan, September 2017*.

[54] Physical activity. Retrieved June 1, 2020 from https://www.who.int/news-room/fact-sheets/detail/physical-activity

[55] GAMIFICATION | meaning in the Cambridge English Dictionary. Retrieved October 5, 2020 from https://dictionary.cambridge.org/dictionary/english/gamification

[56] About – Exertion Games Lab. Retrieved October 5, 2020 from http://exertiongameslab.org/about

[57] Sports Party for Nintendo Switch - Nintendo Game Details. Retrieved August 4, 2020 from https://www.nintendo.com/games/detail/sports-party-switch/

[58] PlayStation Move – PlayStation VR Accessories. Retrieved August 4, 2020 from https://www.playstation.com/en-us/explore/accessories/vr-accessories/playstation-move/?smcid=pdc%3Aen-us%3Aps5-accessories%3Aprimary%2520nav%3Amsg-hardware%3Aplaystation-move-motion-controller

[59] Pokémon GO. Retrieved August 4, 2020 from https://pokemongolive.com/en/

[60] Home - Harry Potter Wizards Unite. Retrieved August 4, 2020 from https://www.harrypotterwizardsunite.com/

[61] HADO-Beyond Sports. Retrieved February 3, 2021 from https://hado-official.com/en/

[62] AUGMENTATION | meaning in the Cambridge English Dictionary. Retrieved September 13, 2020 from https://dictionary.cambridge.org/dictionary/english/augmentation

[63] Parents Code of Conduct - Colorado Rapids Youth Soccer Club. Retrieved September 16, 2020 from http://rapidsyouthsoccer.org/policies/parents-code-conduct/

[64] Who Wants to Be a Millionaire? - Wikipedia. Retrieved September 16, 2020 from https://en.wikipedia.org/wiki/Who_Wants_to_Be_a_Millionaire%3F

[65] The Voice (American TV series) - Wikipedia. Retrieved September 16, 2020 from https://en.wikipedia.org/wiki/The_Voice_(American_TV_series)

[66] Got Talent - Wikipedia. Retrieved September 16, 2020 from https://en.wikipedia.org/wiki/Got_Talent

[67] Masked Singer - Wikipedia. Retrieved September 16, 2020 from https://en.wikipedia.org/wiki/Masked_Singer

[68] Microsoft HoloLens | Mixed Reality Technology for Business. Retrieved October 5, 2020 from https://www.microsoft.com/en-us/hololens

[69] VIVE™ | VIVE Tracker. Retrieved October 5, 2020 from https://www.vive.com/us/accessory/vive-tracker/

[70] Azure Kinect DK – Develop AI Models | Microsoft Azure. Retrieved October 5, 2020 from https://azure.microsoft.com/en-us/services/kinect-dk/

[71] Wheelchair Basketball. Retrieved October 4, 2020 from https://tokyo2020.org/en/paralympics/sports/wheelchair-basketball/

[72] What Is Blind Soccer | Warriors. Retrieved October 4, 2020 from https://www.warriorsblindsoccer.com/history-of-blind-soccer

[73] Truffle hunting in Italy - Traditional truffle hunting and eating. Retrieved October 5, 2020 from https://www.beerandcroissants.com/truffle-hunting-in-italy/

[74] What is SUP Yoga? | ISLE | Blog. Retrieved October 4, 2020 from https://www.islesurfandsup.com/what-is-sup-yoga/

[75] Yanace on Twitter: "超人スポーツLunar G Ball. Retrieved October 7, 2020 from https://twitter.com/ya7ce/status/1040623982674763777

[76] How Do Swimming Touch Pads Work? Retrieved October 6, 2020 from

https://www.sportsrec.com/553132-how-do-swimming-touch-pads-work.html

[77] Sneaker sensors keep marathon runners on track. Retrieved October 6, 2020 from https://www.designnews.com/sneaker-sensors-keep-marathon-runners-track

[78] Train like a genius with the new adidas Smart Ball. Retrieved October 6, 2020 from https://www.soccer.com/guide/train-like-a-genius-with-adidas-smart-ball

[79] Welcome to the World Dodgeball Association. Retrieved August 25, 2020 from https://www.dodgeball.sport/federations

[80] World Dodgeball Federation | World Organizational Body For The Sport Of Dodgeball. Retrieved August 25, 2020 from https://worlddodgeballfederation.com/

[81] Sony Japan | FeliCa ウェブサイト. Retrieved October 8, 2020 from https://www.sony.co.jp/Products/felica/

[82] Arduino Uno Rev3 | Arduino Official Store. Retrieved October 8, 2020 from https://store.arduino.cc/usa/arduino-uno-rev3

[83] Digi XBee Ecosystem - Everything you need to explore and create wireless connectivity | Digi International. Retrieved October 8, 2020 from https://www.digi.com/xbee

[84] Adafruit HUZZAH32 – ESP32 Feather Board ID: 3405 - $19.95 : Adafruit Industries, Unique & fun DIY electronics and kits. Retrieved October 8, 2020 from https://www.adafruit.com/product/3405

[85] M5Stack - Modular Rapid ESP32 IoT Development Board - ESP32 dev kits– m5stack-store. Retrieved October 8, 2020 from https://m5stack.com/

[86] Olympic Volleyball Rules. Retrieved October 8, 2020 from https://www.sportsrec.com/262293-olympics-volleyball-rules.html