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Superhuman sports in mixed reality: the multi-player game *League of Lasers*

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Abstract

In recent years, many promising developments have taken place around augmented, virtual and mixed-reality technology. One could wonder whether these technologies can be combined to yield a mix of video games and sports, involving physical activities previously deemed impossible: creating a *superhuman sport*. This work investigates how mixed-reality can be used to create a fun, intuitive and engaging superhuman sport. To this end, the game League of Lasers was developed, in which two teams compete in a mix between football and Pong, using the physical movement of the players as main means to interact within mixed-reality. An evaluation of League of Lasers with a user study with 32 participants showed that League of Lasers is perceived as a fun and immersive skill-based game.

Index Terms: Human-centered computing—Mixed / augmented reality Human-centered computing—User studies Human-centered computing—User interface design Software and its engineering—Interactive games

1 Introduction

Over the last years, interest in superhuman sports has been increasing, as shown e.g. by the large attractiveness of the Superhuman Sports Design Challenge, organised by the International Superhuman Sports Society [9]. Superhuman Sports propose a novel field, in which people can go beyond physical limitations with technology. The focus is on improving cognitive and physical functions of the human body, creating artificial senses and reflexes to participate in sports competitions: creating and exploring new experiences with these novel senses and reflexes by augmenting old sports, designing new sports, enhancing the training, and sharing with the audience locally and remotely.

League of Lasers is one such superhuman sport [19]. Its core mechanics revolves around reflecting a laser pulse to guide it towards a target. The game is similar to Pong in its basic gameplay: each team has its own target, so players of one team try to aim a laser pulse at the opposing team's target while defending their own (see Figure 1). The game is played using augmented reality (AR) goggles, i.e. a head-mounted device that allows the wearer to see virtual objects in the real world; for our current implementation, we used the Microsoft HoloLens, which can project virtual objects as holograms. Players interact with the game and the mixed-reality by physically moving around in the playing field. The game is played in a real world field, and players can physically see and interact with each other. The mirror that each player controls follows the movement of the player's head, thus running, jumping, strafing and ducking are all viable control inputs in League of Lasers.

We approached the following research question:

"How can mixed-reality be used to create a competitive multi-player superhuman sport?"

Answering this question posed some major challenges. First off, the design of League of Lasers requires all players to see holograms of in-game objects at the same real-world locations. This means that the game needs to have some sort of accurate positional tracking system for the players and the ability to share their positions with each other (Section 3). The second challenge was to create a fun and engaging game that would work well in a mixed-reality setting (Section 2). The final challenge was to fit the criteria of a superhuman sport, defined below.

1.1 Superhuman Sports

A superhuman sport can be defined as a sport combining "competition and physical elements from traditional sports with technology to overcome the somatic and spatial limitations of our human bodies" [7]. Specifically, superhuman sports should: rely on technology for human augmentation to enhance a human ability, involve physical fitness and skills, and finally are played for fun, competition and/or health reasons [9]. Therefore, designing a superhuman sport should focus on the following criteria [9]:

- *Human augmentation:* does the superhuman sport augment human senses and capabilities?
- *Fitness and skills:* does the superhuman sport require or train physical fitness and skills?
- *Fun and engagement:* is it fun and engaging for the participants?
- *Audience:* is it fun for the audience to watch the superhuman sport?

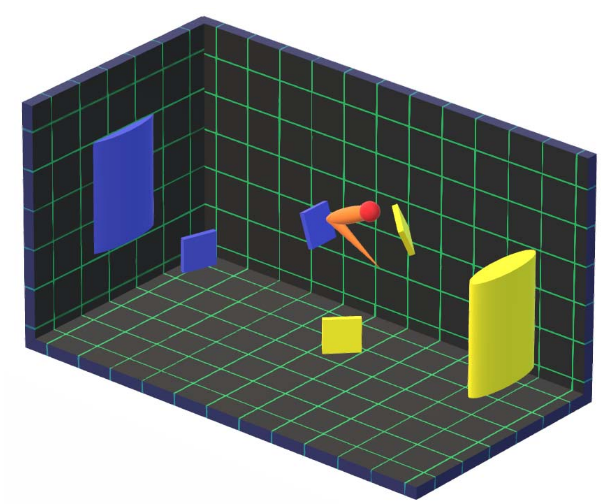

Figure 1: A game overview of League of Lasers.

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- *Inclusiveness:* can participants with different backgrounds practice in the superhuman sport?

There are two major approaches to implement a superhuman sport [7]: they can enhance players' physical abilities (for example, using exoskeletons) or augment the vision of the player with technology to mix reality with a virtual world. League of Lasers uses the latter approach and was designed to fit all the above mentioned criteria.

1.2 Related Work

Creating a superhuman sport using augmented reality devices is becoming increasingly popular. An example is *HADO* [1], in which two teams of three players compete against each other, with the goal of hitting the opponent with energy balls. Players can create a barrier in front of them, to block incoming energy balls. In *HADO*, the players only wear a head-mounted AR display and a gesture tracking wristband. This makes it easy for players to move around, just like they would in traditional sports, without being weighted down by heavy equipment.

These AR devices could also be used to create a diminished reality experience, as seen in *D-Ball* [13]. In *D-Ball* each player wears a head-mounted AR display on which only the ball, the playfield lines and the markers attached to the other players are visible, everything else is pitch black.

An example more akin to a traditional sport is *Augmented Dodgeball* [11,12], in which the traditional game of dodgeball is augmented to create a superhuman sport. In *Augmented Dodgeball*, there is a physical ball augmented with RFID technology, such that the players can charge 'energy' into the ball, determining how 'strong' a hit will be. Each player will also have certain stats like life points, attack points and defence points, creating different roles for each player. The spectators can use a Microsoft HoloLens to see the player's status. As mentioned by Nojima et al. [11], in the future, sports using a physical ball could be further augmented by using a *HoverBall* [10], which integrates a micro quadcopter into a ball. Such an augmented ball would allow for new types of ball-based sports.

Another example of a ball-based superhuman sport is *Imaginary Reality Basketball* [2], which has the twist of the ball being invisible. Imaginary reality games are games that mimic the respective real world sport, but without a visible ball. The ball only exists virtually and the players only know its position by observing the others play and by a small amount of auditory cues. This makes the players interact more directly with each other.

A superhuman sport could also be used to train for and become better in a traditional sport, an example being *Venga* [17], which showcases a climbing game in mixed-reality. In *Venga* players try to scale a real world climbing wall, while wearing a head-mounted AR display. Since the players only see what is happening in the virtual world, they will feel a fake sense of height, while still being at ground level. *Venga* creates a safe environment to tackle the hurdles and fear surrounding climbing on big walls.

Another example is *Kick Ass Kung-Fu* [4], in which players fight virtual enemies, by punches and kicks in real-life. Using a camera, the player's moves are translated to in-game attacks. *Kick Ass Kung-Fu* augments and motivates martial arts and acrobatics training.

Augmented reality could also be used to create new kinds of sports, like *Paintrix* [16], in which two teams compete to recreate a coloured picture as quickly as possible. The playing field consists of a grid of QR codes, representing the pixels, which the players have to paint in the correct colour using their smartphone as if it was a paintbrush. Another example is STAR [6], an AR multiplayer adventure shooter which leads players to collaborate while navigating a dangerous path and avoiding enemies.

Overall, the above examples show that Superhuman Sports are an emerging field of research and also a means for fostering physical activity in combination with engaging augmentations of human capabilities. In the following, we present the design of League of Lasers that augments human capabilities to allow for engaging physical activities.

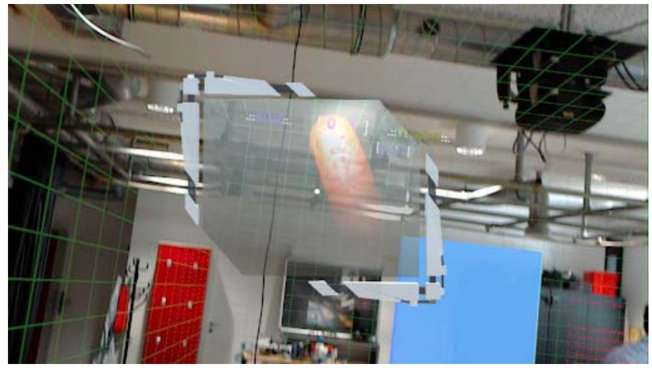


Figure 2: A League of Lasers player's view, through the HoloLens.

2 Game Design

League of Lasers[1] is a mixed-reality game designed to be a superhuman sport. The general gameplay partly resembles well-known games such as football and Pong. The game involves two teams, each with their own target to defend. Players use a (virtual) mirror to reflect a (virtual) laser pulse into the opponent team's target; upon success, your team is awarded one goal (see Figure 1). Players have to move around in a pitch/field to position their mirror within the virtual world. The game uses the Microsoft HoloLens' positional and orientational awareness to control the game.

Each player controls a virtual mirror on which the laser pulse will bounce off upon collision (see Figure 2). The mirror is virtually strapped to the player's head, following the rotation and position of the head. In essence, this means that jumping, crouching and running all are viable options to move the mirror. The orientation of the mirror will bend the laser pulse in different directions through reflection. In this way, players can guide the laser pulse to the target of the opposing team, possibly using the floor, walls and ceiling for strategic bouncing. The straightforward control scheme allows players of all ages and with different backgrounds to play League of Lasers, as long as they are mobile. However, large differences in height between players can lead to unfair advantages. With this game design and control scheme, the game implements the *Human augmentation*, *Fitness and skills* and *Inclusiveness* superhuman sports criteria (Section 1.1).

Currently, the game supports 2-6 players, with teams consisting of 1-3 players. The team that scored the most goals after 5 minutes wins the match. If both teams scored the same amount of goals, the match ends in a tie.

The minimal playfield size for a two player game is 6 x 4 meters, based on experience from test sessions. However, a larger field will improve the game experience with regards to field of view and being physically active. Therefore the recommended size for 2 players is 9 x 5 meters. Increasing the number of players calls for bigger fields, but more experimentation is required for a precise recommendation.

Since the virtual game world is only visible to the players, the audience will only see them, fully immersed in the game, run and jump around. While this is a rather hilarious sight, it gives the audience little information about what is going on in the game. Therefore, the game features a spectator view that shows the audience what is currently happening in the virtual world. The spectator view is a top-down representation of the game to be shown to the audience

[1] A League of Lasers trailer is available at: `https://youtu.be/Lluy0LOgDTg`

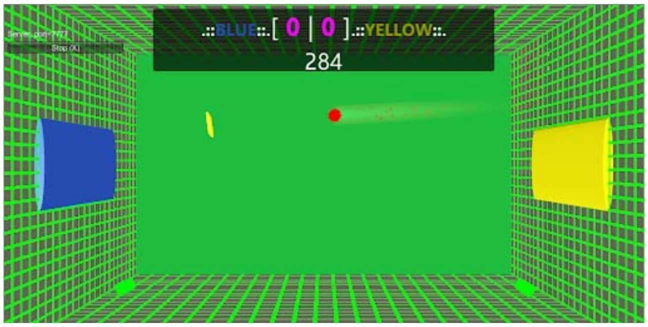


Figure 3: The spectator view.

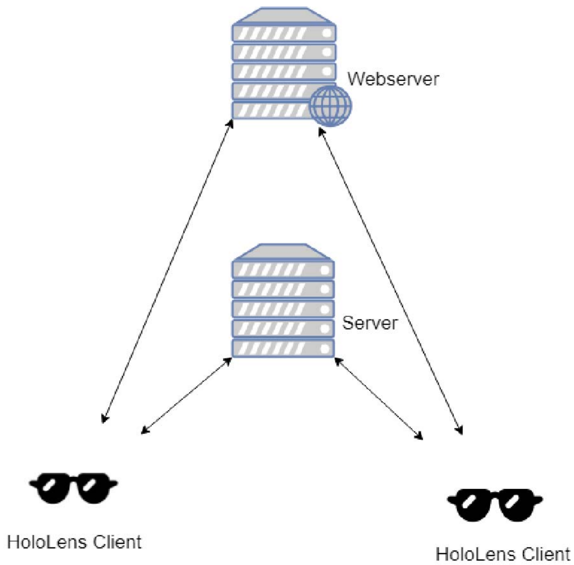


Figure 4: An overview of the communication between clients and the servers.

using a projector or large wall/screen (see Figure 3). In this way, the audience can easily follow what otherwise would not be visible nor intelligible to them. With this feature the game implements the *Audience* superhuman sports criteria (Section 1.1).

3 System Architecture

League of Lasers uses a dedicated client-server architecture, with the server being a traditional desktop application and the clients being run on the HoloLenses. The dedicated game server was chosen for two reasons: (i) it avoids overloading the HoloLenses with tasks, and (ii) it makes it easily possible to maintain the spectator view and project it to the audience.

Due to various challenges related to synchronising spatial positioning between HoloLenses, the clients get more authority than in a traditional client-server application. In particular, the game server relies on one so-called *master client*, to determine its initial internal representation of the game world, which is then shared with all other clients.

In addition to the aforementioned game server, another server is used as webserver, to upload and download files to and from the clients (see Figure 4 for an overview of the services).

In this section, the aforementioned systems are discussed including their design and technical choices, starting with the server, then the master client and finally the process of anchor parenting.

3.1 Server

The development of League of Lasers has had to overcome some technical challenges. One of them is that the real-world positions of virtual objects, such as the laser pulse and targets, should be exactly the same for all players. To ensure this, the server, which controls the virtual objects, needs to have an internal representation of the game world that matches the real world. In addition, the server must communicate this to the client devices as well.

In a HoloLens application, the virtual objects are projected in the space around the user. By default they are placed relative to the position of the user and not relative to the position of the room the user is in. In essence, this results in the user's starting location as being the origin position in the application. As a result, the user's starting position is the sole factor in determining the position of the projected holograms and, thus, replicating that exact same position is nearly impossible. In practice, this results in large offsets in the observed world between different players and play-sessions, so that holographic objects are never displayed at the same real-world position.

The HoloLens is able to create spatial anchors, which *anchor* holograms to real-world positions [18]. An object can then be 'parented' to such an anchor, which makes its position, rotation and scale relative to the anchor's position, rotation and scale, essentially using the anchor parented to as the origin for the object. Anchors can be serialised and shared among all HoloLenses, so that multiple players can see holograms in the same real-world position.

These anchors could be shared via the dedicated server, which would seem to solve the aforementioned synchronisation issue; however, that is not the case. While the anchors themselves consistently lock to their real-world position, their location within the game world differs per device and per session. The use of anchors only moves objects to the correct real-world location and does not offset the internal coordinate system in the game. This means that, for example, a cube can be at position (a vector with the x, y and z coordinates) [3, 1.5, 0.5] on device 1 (see Figure 5a), and at position [0, 1.2, 0] on device 2 (see Figure 5b), while being located at the same real-world position on both devices.

Another issue is that the desktop computer that runs the game server does not know the concept of spatial anchors, since the desktop application does not have the spatial perception capability and thus cannot place a spatial anchor. In essence, this means that the server does not know where the anchor is located and thus has no knowledge of the scene as observed by the clients. To tackle this issue, a master client is created, which shares its representation of the game world to the server.

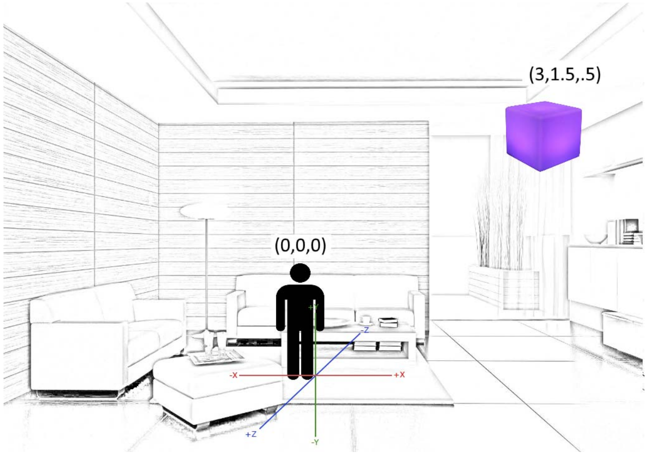
3.2 Master Client

As just discussed, game objects that need to be shown at the same location across devices need to be parented to an anchor, but the game server cannot lock these anchors to a real-world or in-game position, thus the server does not know where the anchors are located, relative to each other. In order to grant the server this knowledge, the master client, i.e. the first client that connects to the server, places the required anchors to build the pitch (see Figure 6).

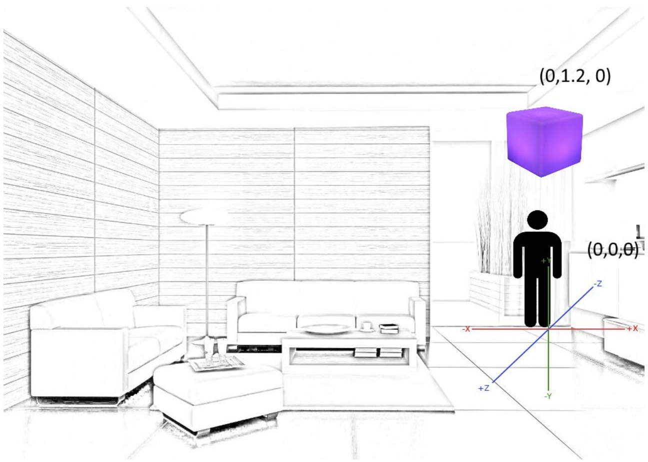
After the anchors are placed, their positions in the virtual scene are sent to the game server. The game server then changes the internal position of the anchors to the received positions, giving the game server a representation of the master client's world. The master client then serialises and uploads these anchors to the webserver, after which the anchors can be downloaded by the other clients.

3.3 Anchor Parenting

As the game server only knows what the master client sees, an object cannot be moved to another location via the network using standard positional data, as the coordinate system within each client is offset. The solution is to instead move objects relative to an anchor, which



(a)



(b)

Figure 5: The position of objects in the game when the game is started at different real-world locations, using spatial anchors.

Figure 6: Using anchors to set up a pitch within a room.

ensures that the position and orientation of objects is synchronised correctly between all clients. Meaning that all networked objects should be parented to an anchor at all times. Since anchors are only accurate in a 3 meter radius [18], multiple anchors were used (as seen in Figure 6). Game objects automatically switch to the nearest anchor to ensure accuracy (see Figure 7)

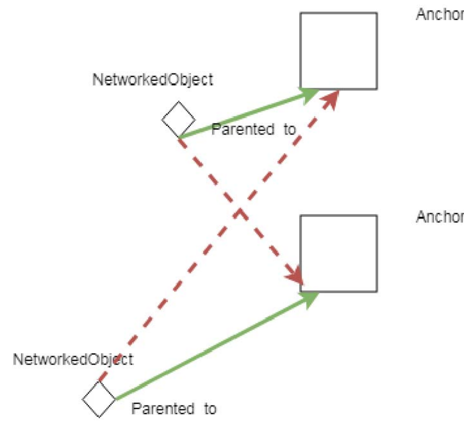


Figure 7: Spatial functioning of the anchor parenting system: *green arrows* mean that the game object is parented to that anchor, *red lines* mean that the distance is too large and the object is not parented to that anchor

4 User Study

To get a better understanding of the player's experience and attitude towards League of Lasers, a user study was conducted, measuring whether participants are immersed, engaged and physically active during a play session.

The study was conducted together with a demonstration of the game during an event at Delft University of Technology. Visitors at this event were invited to play a round of League of Lasers and fill in an anonymous questionnaire at the end. In total, 32 people participated in the user study, of which 9 were female, 14 were male and the rest did not disclose their gender. The average age of the group was 34 years.

4.1 Method

For this user study, 2 participants were playing against each other for 3 minutes. On a large projector screen, the spectator view was shown to the audience. The game was played on a playing field of 6 x 4 meter. During each match, we observed the participants playing. Afterwards, the participants filled in an anonymous questionnaire. The questionnaire was a combination of the "User Experience Questionnaire" (UEQ) [8, 14] and the "Game Experience Questionnaire" (GEQ) [5]. The UEQ questionnaire measures the user experience of interactive products, by placing two antonyms at the ends of a scale (e.g. fast and slow), and asking the user to indicate on a seven step scale which position applies best to the product. The UEQ measures six aspects [14]:

- *Attractiveness:* overall impression of the product. Do users like or dislike it? Is it attractive, enjoyable or pleasing?
- *Perspicuity:* is it easy to get familiar with the product? Is it easy to learn? Is the product easy to understand and clear?
- *Efficiency:* can users solve their tasks without unnecessary effort? Is the interaction efficient and fast? Does the product react fast to user input?
- *Dependability:* does the user feel in control of the interaction? Can he or she predict the system behaviour? Does the user feel safe when working with the product?
- *Stimulation:* is it exciting to use the product? Is it fun to use?
- *Novelty:* is the product innovative and creative? Does it capture users' attention?

Together, these attributes give an overview of the quality of the product, but not all of these aspects have the same value for our game. For example, perspicuity and attractiveness are deemed more important to our product than efficiency. The UEQ also comes with benchmarks to compare the rating of the product with other interactive products that used the UEQ questionnaire [15], and give the product a quality rating.

The choice to combine this questionnaire with the GEQ was made to obtain a wider image of League of Lasers. While games can be seen as an interactive product, their perceived quality is mostly based on how fun the game is, which is not measured by the UEQ. To account for this the core questionnaire from the GEQ was used [5]. This module contains 33 statements, for which respondents must state to which extent they agree with (on a scale of 1 to 5). The GEQ measures the game's experience on seven components:

- *Sensory and Imaginative Immersion:* was the player sensory and imaginatively immersed in the experience?
- *Flow:* is the player getting enjoyment in the process of the activity [3]?
- *Competence:* did the player feel competent/skillful?
- *Positive and negative affect:* did the player like the game or not?
- *Tension/Annoyance:* did the player experience stress? Did the game annoy players?
- *Challenge:* did the player feel challenged by the game? Was the game hard? Did the player feel pressured?

Combining these results not only gives a good overview of the perceived quality of the product, but also of its value as a game.

4.2 Results

The completed UEQ questionnaires were analysed and the mean values were calculated, as shown in Figure 8 and commented in Table 1. The mean results of the questionnaire show that, in general, the game is rated between 'above average' and 'good'.

The completed GEQ questionnaires were analysed by computing the average of all items corresponding to each of its seven components (see Table 2). For competence, immersion, flow and positive affect, higher values are better, with below 2 being bad, 3 being average and 4 and up being good. For tension and negative affect, lower values are better, meaning that 3 is still average, but values below 2 are good. Challenge should be in the middle with a score around 3, indicating that the game is not too easy, but also not too hard. A column showing our interpretations of the score was added to Table 2.

During the matches, we further observed lots of laughter and screaming. After getting more acquainted with the game, we noticed that the participants were increasingly running and jumping around, only being constrained by the small room.

4.3 Discussion

The results of the UEQ questionnaire and the GEQ questionnaire are discussed separately.

4.3.1 UEQ Discussion

Overall, the results of the UEQ questionnaire are positive. Especially the categories *Stimulation* and *Novelty* score high, being rated as good by the benchmark (see Figure 8). *Attractiveness* and *perspicuity* score lower, but are still rated as above average. *Perspicuity* and *Stimulation* are deemed especially important for superhuman sports (and, thus, for League of Lasers), since they are a relatively new concept and should be fun to play and easy to learn.

The benchmark and questionnaire for *Dependability* and *Efficiency* score low. This can be attributed to the types of questions in this category as not being quite applicable to video games. For example, *Efficiency* asks users to rate the product between the keywords *fast* and *slow*; normally these would be related to the performance of the application, but in this case it seems likely that players rated the gameplay speed (which was slightly lowered due to the small room dimensions), making the results in these categories somewhat unreliable. In addition, *Efficiency* also rates the practicality, which due to the current high price of the HoloLens was rated poorly; however, one can expect mixed-reality devices to drop drastically in price in the future. In the category *Dependability*, the keywords *unpredictability* and *predictability* are present. These can also be understood of the gameplay aspects, where unpredictability is not necessarily a bad thing, making the results of this category somewhat unreliable.

4.3.2 GEQ Discussion

In the GEQ results, the game is rated average to good in all categories (using our own interpretation). Again with this questionnaire some statements do not match the game, skewing the results to be more negative. An example being the statement: *"I was interested in the game's story"*, which is not applicable to League of Lasers.

The demonstration was the first time most respondents played League of Lasers, which is designed as a skill-based game that is easy to learn, but hard to master. It is therefore positive that, according to the GEQ, the game left most players with an average feeling of *Competence*, as this indicates that the players felt that they understood and somewhat mastered the game, but they could still improve. This can be attributed to the simple and focused interaction within League of Lasers: a more complicated experience would likely leave the player feeling less competent. As the results show, the *Challenge* is also just right, not too easy, but also not too hard. The good score for *Tension/Annoyance* further states that the game did not frustrate nor annoy the player.

Sensory and Imaginative Immersion is ranked average, but as this category asks questions not applicable to our game, the score of this category is effectively lowered. Since the game put most players into a state of *Flow* and the players found the game to have a *Positive affect*, we conclude that most players enjoyed the game and became immersed. Thus, the game implements the *Fun and engagement* superhuman sports criteria (section 1.1).

5 Conclusions

The game League of Lasers was designed, and developed using the Microsoft HoloLens, in order to assess how mixed-reality can be used to create a competitive multiplayer superhuman sport. A user study with 32 participants was conducted to evaluate the play experience and whether players are immersed, engaged and physically active during a play session.

League of Lasers augments the players' perception, allowing them to interact with the virtual world as if they interact with the physical world. League of Lasers deploys a motion tracking solution that builds upon the positional tracking capabilities of the Microsoft HoloLens. This allows players to run and jump around, stimulating physical fitness, especially on a large playing field.

The results of the user study show that League of Lasers, with its sports-like gameplay, is fun to play, intuitive and immersive for users, while remaining a hard-to-master skill-based game. The simple and focused interaction within League of Lasers favours that players quickly learn and understand the game and feel competent afterwards. From this observation, a major recommendation future superhuman sport designers results: *for short and engaging sport-like experiences in mixed reality keep the interaction simple and focused.*

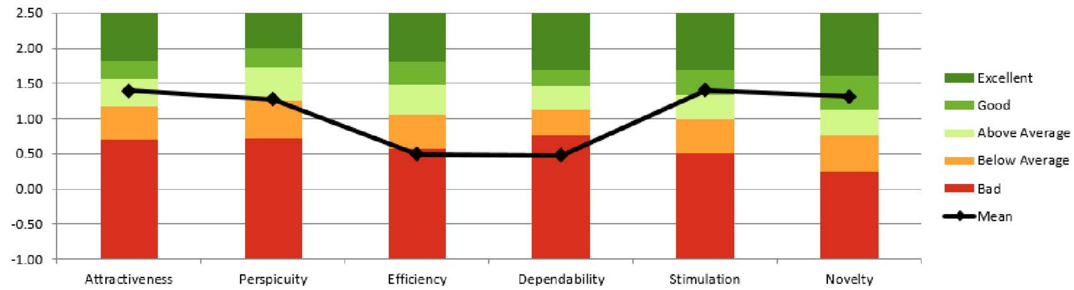


Figure 8: The UEQ benchmark, showing the computed scores for each of the categories and their meaning.

Category	Mean	Comparison to benchmark	Interpretation
Attractiveness	1.40	Above average	25% of results better
Perspicuity	1.27	Above average	25% of results better
Efficiency	0.49	Poor	In the range of the 25% worst results
Dependability	0.48	Poor	In the range of the 25% worst results
Stimulation	1.40	Good	10% of results better
Novelty	1.31	Good	10% of results better

Table 1: UEQ results

League of Lasers is a fun and competitive multiplayer game that relies on technology for human augmentation, and it has shown to promote physical fitness and skill. We can therefore conclude that League of Lasers fulfils the superhuman sports criteria is a successful and promising superhuman sport.

6 Future Directions

In the future, we want to test and evaluate League of Lasers with larger teams. League of Lasers supports multiple players per team, but this functionality was unfortunately not tested. It would be interesting to assess to which extent team play and coordination are possible in a mixed-reality superhuman sport.

An interesting direction for future work and research in superhuman sports like League of Lasers is audience participation. Unlike a regular sport, such augmented sports would make it possible for the audience to change certain factors in the game: for example, activate a power-up, which will could somehow influence the progress of the match. In League of Lasers, e.g. a power-up could modify the speed of the laser pulse, spawn another laser into the game, etc.

For the audience to be able to participate, they also need to be aware of what is happening in the game. The current spectator view developed, providing a top-down representation of the game, helps the audience overcome the lack of full immersion in the mixed-reality of the players. However, far more can be done in this regard. For example, a superhuman sport like League of Lasers could, use a dynamic camera system which switches between top-down, sideline or even first person viewpoints to give the audience the best view of the action. Unlike a regular sport, the game is fully visible in the virtual world, which makes it possible to have full control over a camera's location. Another possibility is to add replay recordings, e.g. after a team scored a point, which could show a goal from the best angle, perhaps even using a slow-motion effect.

Component	Mean	Interpretation
Competence	2.92	Average
Sensory and Imaginative Immersion	2.67	Average
Flow	3.63	Above average
Tension/Annoyance	1.66	Good
Challenge	2.64	Good
Negative affect	1.55	Good
Positive affect	4.02	Good

Table 2: GEQ results

Another direction is in sports field enhancements, which bring the real-world playing field into the game. By allowing the game to interact with physical obstacles, the actual playing field could be augmented and extended into virtual reality. In League of Lasers, the laser could for example bounce off real-world objects. This allows for creating all kinds of play fields where different tactics and strategies can be applied. The game could even allow the players to dynamically change the playing field, by moving real-world objects around.

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