Movement Empowerment in a Multiplayer Mixed-Reality Trampoline Game

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ABSTRACT
Insufficient physical activity motivation is a major public health problem. Exergames—games requiring physical exertion—can be designed to support motivation. For example, granting superhuman movement abilities to players has been shown to support one's feeling of competence, an innate human need and a core intrinsic motivation factor posited by self-determination theory. In this paper, we present Super Stomp, a multiplayer mixed-reality trampoline game that empowers movement by exaggerating jump height both in the real world and in the game. We contribute a novel dual-trampoline game system and game mechanics for implementing engaging multiplayer gameplay. This provides an exemplar of satisfying the challenging constraints that real-world movement empowerment technology can impose on exergame movement safety and feasibility. We further contribute insights into the effect of empowering movement on need satisfaction through an in-the-wild study involving 26 participants who played Super Stomp at an indoor activity park.

CCS Concepts
•**Human-centered computing** → **Empirical studies in collaborative and social computing;** *Empirical studies in HCI;* User studies; •**Applied computing** → Computer games;

Author Keywords
Movement empowerment; mixed-reality games; exergames; social play; self-determination theory; trampolines

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INTRODUCTION
Lack of exercise is a major public health concern [5, 10]. One way to address the problem is to ensure people are motivated to exercise by satisfying their innate human needs. Games have potential to satisfy these needs, as they can offer a great amount of autonomy (e.g., players can choose which character abilities to enhance and freely explore the game world), can support competence by providing challenging tasks to master, and can support relatedness by including multiplayer features that provide an opportunity for social interaction and bonding. These components—autonomy, competence, and relatedness—are considered innate human needs to satisfy for optimal growth and function in psychological theories of human motivation [7, 9].

Games are also in a unique position to empower players by granting abilities beyond what people have in the real world; in other words, they can provide superhuman abilities, such as flying. This can be applied in both traditional video games and exergames (games that require require physical activity). Empowered, exaggerated movement in exergames and virtual reality has been shown to support competence [13, 17], which is a core component crucial to motivating people in general [7, 9], in games [31], and in exercise [20, 30].

In this paper, we contribute to exergame and movement empowerment research through the design and evaluation of Super Stomp, a novel multiplayer mixed-reality trampoline game that is played at an indoor activity park. Exergames in general have been studied in the wild in the past [21, 33]. To the best our knowledge, however, this is the first implementation and in-the-wild study of movement empowerment and of trampoline games, as well as the first use of movement empowerment in a multiplayer context.

Connecting multiple players in the same mixed-reality game using a dual trampoline game setup (i.e., separate trampolines, cameras, and screens that display the game for both players) is challenging. We contribute insights into how Super Stomp provides meaningful, competitive play while considering these challenges. Specifically, we address challenges posed by camera, tracking, and network latency and the peculiar property of trampolines that while they allow game-like superhuman jumping in the real world, switching from jumping to standing or walking is tedious and should be avoided. Trampolines also complicate social game design because for safety, only one person should be on the same trampoline at any given time. We additionally contribute insights into the experience of movement empowerment through a study conducted with 26 participants. The study provides an examination of the experience of playing Super Stomp, as well as an examination of participants' autonomy, competence, relatedness, and attitude toward the physical activity of trampolining [2, 27].

The remainder of this paper is structured as follows. We first review related work establishing the use of empowered movement in games. Then, we describe the design of our Super Stomp multiplayer mixed-reality trampoline game, including the challenges we faced in its design, as well as how empowerment is implemented in the game. Next, we detail our study, including the design, procedure, measures, and results. We conclude by highlighting key takeaways of this paper for designers of games with empowered movement.

RELATED WORK

Our work adds to a line of movement empowerment research in exergames, mixed-reality games, and virtual reality games. Exergame movement empowerment research has progressed from boosting a player's movement in the game world with physics simulation [15], to mixed-reality empowerment that uses digital manipulation and physical devices like trampolines and electrically-assisted bikes [1, 16, 18], and more recently to user studies that demonstrate positive effects on autonomy and competence [13, 17]. Jumping height and locomotion speed are common forms of exaggeration [15, 17, 18]. But, exaggerated flexibility has also been recently demonstrated [13]. Focus on flexibility and strength may be motivated by boredom caused by the requirement to repeat the same movements over and over again [29] or motivated by the fact that strength and flexibility develop very slowly in the real world. Thus, one cannot expect significant development during a player's journey through an exergame unless the game manages to engage the same players for several months.

Kajastila et al. conducted a lab-based controlled study to assess whether exaggerating jump height could aid in training novices to learn trampolining skills [18]. The study involved 29 participants divided into three groups: a control group that learned through self-training, a group that played a mixed-reality trampoline game with normal jump height, and a group that played a mixed-reality trampoline game with exaggerated jump height. Results from this study showed that while all groups significantly improved performance, the game groups had significantly higher engagement. Furthermore, exaggerated jump height did not negatively affect learning.

Granqvist et al. conducted a lab-based controlled study with 30 participants that compared three levels of kicks: realistic, moderately exaggerated, and highly exaggerated [13]. In the virtual reality experiment, players' movements were mapped to an avatar, and they were asked to kick targets at different heights. Results from this study suggest that medium exaggeration yields better performance, higher perceived competence, and more natural movement compared to realistic kicks, while high exaggeration generally diminishes this effect.

Hämäläinen et al. conducted a lab-based study with 46 participants who played Kick Ass Kung-Fu, a mixed-reality martial arts game in which players use real-world martial arts movements to defeat artificial intelligence opponents [15]. Participants were recruited from local martial arts clubs, and the study examined various levels of exaggerated jump height and horizontal movement in the game. Movement exaggeration was considered fun by the players. Also, exaggerating jump height "adds airiness to leaps and easy acrobatic moves, such as a cartwheel where you start from a crouching position and throw your legs upwards". However, exaggerating horizontal movement too much made estimating distances to the opponent difficult. Furthermore, the more experienced the player was at martial arts, the less exaggeration was preferred.

Other Ways of Manipulating Movement

Movement can also be empowered by having users stand on a sensor to simulate flying or swimming [13, 14]. However, there are other ways of manipulating players' movement besides exaggerating and empowering. For instance, games can grant players bullet time, in which the game is slowed down around the player to grant them more reaction time (e.g., for precisely aiming shots at enemies) [32]. Recently, this has been implemented in movement-based games in the virtual reality version of SuperHot [34]. As an example of anti-empowerment, giving players a weaker impression of performance through speed deception has been shown to result in better performance in endurance practice for cycling in real [26] and virtual environments [23].

What Our Research Adds

In contrast with the lab-based movement empowerment studies, our experiment was conducted in a natural environment, where people have autonomy to choose to play the game in a natural social context. As we discussed, social interaction is crucial for supporting the need for relatedness. Participants of previous movement empowerment research have also suggested multiplayer gameplay for added motivation [15]. To the best of our knowledge, our study is the first to examine empowered movement in a multiplayer context. Moreover, we provide additional evidence and insights on how empowering movement can support need satisfaction and result in a positive player experience. Finally, our research examines how to successfully overcome technological challenges posed by fast and highly dynamic movement in combination with the limitations of motion tracking and network latency, as well as the game design challenges posed by using a trampoline.

SUPER STOMP

Super Stomp is a multiplayer mixed-reality trampoline game in which a player jumps on top of another player and stomps them to the ground in order to score points. The player who scores the most points (i.e., jumps on top of the other player and stomps them to the ground the most) within a specific time

Figure 1. The goal in the multiplayer Super Stomp game is to score the most points within a given time frame by jumping on top of the other player.

limit wins the game (see Figure 1). Super Stomp was developed using the Unity game engine [35, 38] through an iterative design process. It was the first multiplayer game developed for the ValoJump mixed-reality trampoline game platform, which consists of a display screen, a trampoline, a camera, proprietary motion tracking software, and a touchscreen display for administrative purposes (see Figure 2). A number of single-player games were developed for the ValoJump platform first, exploring the unique design space of trampoline interactions.

Figure 2. The ValoJump mixed-reality trampoline game platform consists of a display screen, a trampoline, a camera, proprietary motion tracking software, and a touchscreen display used for administrative purposes.

Placing the Screen

Trampoline game research [16, 17] has noted that watching a screen while jumping is feasible. However, different screen setups have not been compared in prior research. In early development, we tested various screen placements with the development team (5 testers). We tested different screen distances ranging from a screen attached to the trampoline to a screen placed 3 meters away and also compared different vertical locations.

In our experience, it is best not to attach the screen directly to the trampoline, though this is desirable due to smaller space requirements. Instead, the screen should be placed at least a few meters away from the trampoline so that players do not need to tilt their heads up and down while jumping. Increased distance also improves safety, preventing jumpers from accidentally hitting the screen. With regards to vertical placement, it is better to place the screen low because it lets jumpers keep the trampoline bed in their field of view while jumping. This aids spatial awareness and preparing for landing impacts.

Designing for Safe Trampoline Interactions

Trampolines suffer from the problem that basic jumping can quickly become boring, potentially making the user feel the need to perform tricks like somersaults in order to keep the activity fun. Performing tricks on trampolines is risky, especially when the user is inexperienced [4, 19]. ValoJump's games are controlled through basic jumping and side-to-side movement, reducing the need to perform tricks in order to enjoy trampolining. In this way, the game platform aids in providing a safe trampolining experience. In addition, most trampoline injuries are the result of multiple people jumping on the same trampoline at the same time [4, 19]. ValoJump's games are played with only a single player on a trampoline. The multiplayer game Super Stomp utilizes a dual trampoline, display, and tracking sensor setup. Thus, even in this multiplayer game, only a single player is intended to be on the same trampoline at any given time.

The Problem of Designing Engaging Trampoline Play

Trampolines provide game-like superhuman jumping in the real world. At the same time, they impose severe limitations on movement, which constrains the design space. Transitioning from jumping to standing or running is very tedious, which means games should be designed in a way that keeps players jumping all the time. Furthermore, once launched in the air, players have no control over their jump trajectories. Motion tracking, display, and network latencies provide further complications.

The Stomp Mechanic

Before Super Stomp was developed, the most successful game on the ValoJump platform was Toywatch, in which a player protects a base by jumping at waves of inflatable toy enemies (see Figure 3). In this way, the simple act of jumping is turned into a fun game mechanic. From this experiment, the simple but surprisingly engaging key mechanic of Super Stomp emerged. In Super Stomp, the focus is again on simple jumping, but instead of jumping on artificial intelligence opponents, players try to jump on top of each other. Due to the inability to change one's trajectory mid-air, players have to predict the movement and try to control it by the way they launch into the air. Thus, there is a delay from observation to corrective action. Together with the unpredictability of the opponent, this creates a somewhat unstable feedback system that results in dynamic, varying, and sometimes surprising gameplay.

Designing Around Latency

In early experiments with Super Stomp, it was found that any kind of punching and kicking is not meaningful; due to latency, it was impossible to dodge or block, and combat regressed to random flailing. Thus, we were constrained from using direct interactions between players that are dependent on real-time poses. We overcame this constraint by implementing player

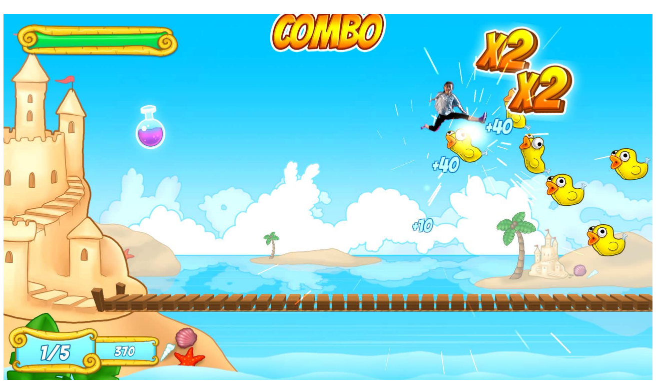

Figure 3. In Toywatch, a player protects a base by jumping at waves of inflatable toy enemies.

interactions in ways that would not suffer from the high latency. Since the player primarily acts by jumping, the naturally low frequency of the jumps helps to hide latency from the camera, motion tracking calculations, network, and rendering.

It is essential that players in Super Stomp see an accurate representation of where they and their opponent are located on the game screen. Otherwise, players would not be able to determine where and how to jump in order to stomp on their opponent. Thus, we implemented player movement in a way that would not suffer from the high latency present in synchronizing live video feed. Players move according to their tracked center of mass, which is synchronized with minimal delay and high frame rate since this is a simple position vector. The video feed has higher latency; however, the player's pose is not important to the gameplay. Therefore, the player's position in the video feed is quickly snapped to the updated position as soon as it is received, but the pose is updated later.

Instead of mapping the entire player's skeleton to an avatar (which is common in motion-controlled games [12, 29]), we chose to cut a video avatar around the player out of the background. The video avatar is rendered as a textured quad, using the camera view as the texture, with transparent background pixels. The video avatar is transferred across a network, and we use the player's outline as the interactive element in the game. This has a number of benefits. It allows the player to see their own actions without the additional latency of tracking algorithms. It allows small movements to be quickly registered as game input, and any small details in the player's movement provide immediate visual feedback. It also allows players to use any pose without having motion tracking artifacts present in calculating skeletal joint positions. This design may also enhance the feeling of empowerment as players can see a more direct representation of themselves performing a jump.

Detecting the Stomp

In Super Stomp, it is also essential that collisions between players are accurately calculated in order to detect when a stomp has occurred and which player did the stomping. However, the movement speed of players is exceptionally high given that they are constantly jumping on a trampoline; this issue is compounded by the fact that movement is exaggerated in the real world and in the game. The frame rate of the motion tracker determines the intervals in which collisions can be detected. In the game setup, this is dependent upon the camera's frame rate, which is 30 frames per second. This means that during one frame, which lasts approximately 33 ms, players have already moved a considerable distance. Thus, a collision that is detected during a frame might not accurately portray which player first overlapped another player to cause a stomp.

To overcome this issue, we use position data of the players from the frame in which players are detected to have collided, as well as data from the frame prior to this collision, to accurately calculate which player came from above another player during a collision. This allows us to determine whether a collision should be counted as a stomp and who should be credited with the stomp if so. This kind of direct player-to-player interaction would not be possible if we required precise elements of the players to collide in order to cause a stomp, such as the positions of their hands or feet, because the position of those small elements and the direction of a player's movement could rapidly change. Thus, our decision to use a player's outline for interactions allows us to detect when a player has stomped another player with high accuracy, even in conditions that are limited by delay and frame rate.

Emphasizing the Power of the Stomp

Since the *stomp* interaction is integral to the play of Super Stomp, much of the development focused on improving this feature. The stomp interaction involves detecting when players have collided with one another and provides aural and visual feedback when the stomp occurs. Given that providing superhuman abilities in games can support competence [13, 17], we made the design decision to emphasize power and mass so that players would feel like their stomps are superhuman. Power and mass are emphasized through a collection of effects as a stomp lands on the ground. The effects include air particle effects, a camera shake effect, shaking and shattering the ground, strong sound effects, and a wave of light that travels through the game environment as a player is stomped (see Figure 4). The stomped player also flattens on the ground, emphasizing the superhuman nature of the stomp and bringing a novelty factor that people found humorous and fun. Super Stomp is targeted for all ages; thus, the effects avoid gore but still show a clear consequence to stomped players.

Jump Exaggeration

Super Stomp empowers movement by exaggerating jump height in both the game and the real world. The amount of exaggeration in the game is more than ten times the real-world jump height. However, even with such an aggressive exaggeration, players can still easily control the game, and the exaggeration often goes unnoticed [18]. In the real world, jump height exaggeration is based on the characteristics of the trampoline. For high-performance professional trampolines, the in-game exaggeration is adjusted lower compared to more mainstream trampolines because the professional trampolines' superior springs allow players to jump much higher. Thus, less in-game jump height exaggeration is needed.

Figure 4. Air particle effects, a camera shake effect, ground shaking and shattering effects, strong sound effects, a wave of light, and flattening the opponent emphasize the superhuman experience in Super Stomp.

Horizontal Movement Exaggeration

Through earlier prototyping with the single-player games, we found that the real-world horizontal position of players could not be decoupled from avatar position in Super Stomp. If the player's physical position deviates from the player's avatar position, the player immediately feels disconnected from the game and may diverge from the ideal real-world jumping area. Some exergames provide gestures for navigating the virtual space; in Super Stomp, however, beginners generally need autonomy in the position of their arms and legs to balance themselves on the trampoline. Thus, we did not use gestures and opted to the real-world horizontal position to in-game avatar position, but with the difference from the center exaggerated.

The amount of horizontal movement exaggeration varies based on the width of the trampoline, since the system supports trampolines of various widths. In general, the narrower the trampoline, the greater the horizontal movement exaggeration. With a very narrow trampoline, this can have a negative effect on being able to accurately control the game. This has also been noted in prior research; while horizontal exaggeration was found to be enjoyed by players in Kick Ass Kung-Fu, too much exaggeration makes estimating distances difficult [15].

EVALUATION

We conducted a single-session user study to evaluate participants' experience in playing Super Stomp. The study was conducted at an indoor activity park in which the game is in daily use. Our measures included semi-structured interviews that were conducted to gain insights into the play experience. In addition, we used the 8-item, 7-point Likert scale version of the validated Physical Activity Enjoyment Scale (PACES) questionnaire to gain insight into how participants felt about the physical activity [22, 27].

Our final measure was the Ubisoft Perceived Experience Questionnaire (UPEQ), which is a validated questionnaire based on self-determination theory (SDT) using 5-point Likert scale questions [2]. SDT is a theory of human motivation which posits that people have three innate needs to satisfy for optimal function and growth: autonomy (feeling in control of one's own actions), competence (mastering challenging tasks), and relatedness (feeling a meaningful connection to others) [7, 9]. SDT is a valuable platform to understand exercise adherence and participation [36, 37].

Because our measures were based on self-determination theory, of which autonomy is a key component, we did not randomize or allocate (and therefore, force) participants to play Super Stomp for a specific duration of time. Instead, participants were recruited from the park after they finished playing Super Stomp. If the player agreed to participate, parental consent and child assent were obtained if the participant was under 15 years old. Consent was obtained directly from the

Autonomy	***N***	***M***	***SD***	***Mdn***
I was free to decide how I wanted to play.	26	4.58	.578	5.00
I could approach the game in my own way.	25	4.32	.945	5.00
The game allowed me to play the way I wanted to.	26	4.42	1.03	5.00
I had important decisions to make when playing.	26	3.50	1.50	4.00
The choices I made while playing influenced what happened.	26	4.08	1.20	5.00
My actions had an impact on the game.	26	4.54	.706	5.00
Competence	***N***	***M***	***SD***	***Mdn***
My gaming abilities improved with practice.	26	4.16	1.01	4.00
My mastery of the game improved with practice.	26	4.50	.648	5.00
I was good at playing.	26	4.27	.827	4.00
I felt competent at playing.	26	3.92	.977	4.00
I felt very capable and effective when playing.	26	4.08	.935	4.00
Relatedness	***N***	***M***	***SD***	***Mdn***
I really like the people I played with.	26	4.62	.752	5.00
I consider players I regularly interacted with to be my friends.	26	4.04	1.34	4.50
Other players were friendly towards me.	26	4.62	.752	5.00
What other players did in the game had an impact on my actions.	26	3.92	1.23	4.00
I was paying attention to other players' actions.	26	4.04	1.40	5.00

Table 1. The table presents results of measuring self-determination theory components using the UPEQ questionnaire, rated using 5-point Likert scales.

participant if she or he was at least 15 years old. Participants and interviewers were blinded to the purpose of the study. In fact, participants did not even know there was a study ongoing that they could participate in after playing Super Stomp, and thus, their experience playing could not be affected as a result of the study. A 5€ gift card to the activity park was given as an honorarium for participating in the study.

Equipment
ValoJump is a ValoMotion product launched in 2018. The ValoJump trampoline game platform uses a camera and proprietary motion tracking software to place in a game environment the player's video image after removing the background and possibly other modifications like scaling and rotation. The game is displayed on the screen next to the trampoline (see Figure 2). The trampoline contains no embedded technology, but the system is designed to support a variety of trampolines with different characteristics, such as size or bounciness. ValoJump supports multiple games, as well as training applications, and similar mixed-reality trampoline systems have been shown to support and enhance the practice of learning trampolining skills, in addition to providing an engaging experience for players [16, 18]. The ValoJump system is available in numerous trampoline and activity parks worldwide. The target audience for ValoJump ranges from toddlers to adults and from complete beginners to trampoline enthusiasts.

Participants
26 participants were recruited from an indoor activity park. Participants had a mean age of M = 12.2 yr (SD = 9.21 yr), median age of Mdn = 10 yr, and age ranged from 6 yr to 42 yr. It should be noted that the research team had experience working with children, and there were only few young children (5 players under the age of 9) involved in the study. 16 participants identified as male, 8 participants identified as female, and 2 participants did not list a gender. Only 3 participants stated they had played Super Stomp before this study, which is likely due to the fact that Super Stomp is relatively new to the ValoJump game platform. Playtime was subjectively measured via a questionnaire. Participants spent a mean of M = 8.58 min (SD = 9.20 min) playing the game; the median playtime was Mdn = 4.5 min.

RESULTS
The following results stem from the semi-structured interviews and the UPEQ and PACES questionnaires. Our study is grounded in self-determination theory; thus, we first present the results of measuring autonomy, competence, and relatedness using the UPEQ questionnaire combined with insights gained from the interviews. As the multiplayer aspect of the game is novel, we describe this in further detail. We follow that with how people felt toward physical activity, as measured by the PACES questionnaire and interview questions. We conclude this section with a discussion of players' experience with movement empowerment in Super Stomp.

Players Had High Autonomy and Competence
Autonomy in self-determination theory is a measure of feeling in control of one's own actions. We measured this using the UPEQ questionnaire. Specifically, we asked participants to rate how they felt at the moment about the game they had been playing in relation to the statements presented in Table 1 under the Autonomy heading. Autonomy was notably high in each question asked. This could have been due to artifacts of Super Stomp that allow for high degrees of autonomy, such as being able to stomp on an opponent using any pose the player desires. This could also be an artifact of the study design, in which players were recruited only after playing, and so, their autonomy was not negatively impacted by the study.

Figure 5. Spectators are seated around the two displays watching people play Super Stomp. Spectators were often cheering and interacting with the players.

Competence refers to being presented with and mastering challenging tasks. Games have tremendous potential to offer competence through such means as solving complex puzzles and completing difficult game missions. Movement empowerment has also been shown to support competence [13, 17]. As shown in Table 1, however, competence was the lowest rated of three components of SDT measured by the UPEQ questionnaire, though it was still generally rated quite highly. The lower rating could be due to the low mean playtime reported by players, which was $M = 8.58$ min ($SD = 9.20$ min). Jumping on a trampoline can quickly become exhausting, which could have contributed to the low mean playtime. This explanation can be coupled with the fact that only 3 participants had played this game before the study was conducted. Playing a game you have never played before for around 8.5 min certainly may have contributed to the lower competence score in comparison with the other components.

Players Had High Relatedness

Relatedness is a measure of our closeness to other people. This is considered an important component of many psychological theories of human motivation [3, 8, 11, 24]. As this is the first study to examine movement empowerment in a multiplayer game, we included several questions regarding this component in the semi-structured interviews, as well as background information to gain further insight into the multiplayer experience.

First, from the results presented in Table 1, it should be noted that relatedness generally scored quite highly. Interestingly, a question in our interviews that was unrelated to the multiplayer aspect garnered the highest praise for this aspect of the game. Specifically, we asked players, "What was the best thing about this game?" Answers to this question included many remarks about social play: "*That I got to jump on top of my friends.*","*That I get to play with a friend.*","*Crushing a friend.*", and "*Jumping on others in the multiplayer game.*"

We also inquired how the experience differs if they played against a friend versus playing against a stranger. We asked, "If you played with someone you knew and also someone you did not know, please compare the two experiences. For example, did you prefer one experience over the other, and why was that the case?" Of the 26 participants, half responded to this question. Those participants generally responded that they would prefer to play with friends and that it would motivate them to try harder to win the game. One participant stated, for instance, "*Yes because the friend one knows and one can try a bit harder against him/her, and then if it's someone you don't know...I don't try that hard against them.*" Another participant simply exclaimed their preference for playing with a friend by stating, "*Playing with a friend because I got to crush!*" A third participant stated, "*I would get more like a feeling of a competition that I would want to beat the friend.*"

Spectators Did not Negatively Impact the Play Experience

An interesting artifact of having the game located at an indoor activity park is that spectators watch others play. In fact, spectators often lined up to watch Super Stomp (see Figure 5). We asked several questions in the interviews and questionnaires to gain insights into how this affected the play experience. We began with the basic question, "Were people watching you as you played the game?" 22 of the 26 participants answered "*Yes*", while three participants stated that they were "*Unsure*", and one participant did not answer this question. Thus, the vast majority of participants reported that they were being watched as they played.

We further asked, "If people were watching you play, were they people you know, people you don't know, or a mixture of both?" 13 participants reported that they were being watched both by people they know and by people they do not know, 11 participants reported that they were being watched only by people they don't know, 1 participant reported that they were being watched only by people they know, and the remaining participant did not answer this question.

Expanding on the basic questions regarding spectators, we wished to know how this affected the play experience. Thus, we asked participants two open-ended questions during the interviews: "If people you know were watching you play, how do you feel that affected your experience with playing the game?" and "If people you did not know were watching you play, how do you feel that affected your experience with playing the game?" We found that spectators had either no effect or a positive effect on motivation regardless of being watched by someone they knew or someone they did not know. For instance, one participant stated, "*It gave me motivation to play better*". Another participant stated, "*It felt like it invigorated.*"

Players Had Favorable Attitude toward the Exercise

The Physical Activity Enjoyment Scale (PACES) questionnaire is a measure of how people feel about the physical activity they have been doing. It is rated on a 7-point Likert scale, and results of these questions are presented in Table 2. As can be seen in the table, participants generally had very favorable attitude toward the exercise. Furthermore, we asked participants, "If you have used a trampoline before, how did playing this game compare to your experience using a trampoline without a game?" A majority of participants reported that they preferred playing a trampoline game compared to trampolining without a game.

The minority of participants who preferred trampolining without a game generally stated that without a game, people can

Rate how you feel at the moment about the physical activity you have been doing.

	N	*M*	*SD*	*Mdn*
I find it pleasurable.	26	6.50	.860	7.00
It's a lot of fun.	26	6.73	.667	7.00
It's very pleasant.	26	6.54	.905	7.00
It's very invigorating.	26	6.38	.941	7.00
It's very gratifying.	26	5.92	1.06	6.00
It's very exhilarating.	26	6.12	1.37	7.00
It's very stimulating.	26	6.27	1.22	7.00
It's very refreshing.	26	5.73	1.59	6.00

Table 2. The table presents results of the Physical Activity Enjoyment Scale (PACES) questionnaire, rated using 7-point Likert scales.

focus on doing tricks, such as somersaults, which indicates that they find trampolining in general to be a fun form of physical activity. For example, one participant stated, "*I like to do somersaults and tricks on a trampoline. I'd rather be on the trampoline and doing tricks because I'm not that much of a gamer, but it's nice that I'm able to do something together with my boy.*" A common dilemma in playground and physical activity design is the trade-off between autonomy and safety. As we noted earlier, performing tricks increases the risk of injury while trampolining [4, 19]. Considering the seriousness of typical trampoline injuries, we chose to err on the side of caution. Importantly, the parent's statement indicates that a game such as Super Stomp can broaden the range of parent and child interactions at an indoor activity park.

Players Felt as if They Had Superpowers

Movement empowerment is an integral feature of Super Stomp. We have discussed how movement empowerment can support the feeling of competence, and Super Stomp scored highly on competence in the UPEQ. Super Stomp also scored highly on the UPEQ's autonomy and relatedness components, which lends credence that Super Stomp may support innate human needs. However, the positive results could be due elements of the game design other than movement empowerment. Thus, it was important to ascertain whether people actually felt that they had superpowers we gave them through the stomp mechanism and exaggerated jump height. We specifically asked in the interviews, "Did you, in some way, feel like you had superpowers while playing the game? Why or why not?" A majority of participants answered with a resounding, "*Yes*", and they stated that this was due to either the stomp mechanism or the jump exaggeration. For instance, two participants stated, "*Yes, because I was able to squish (flatten) the others.*" Another participant stated, "*Yes, because of crushing.*"

With regards to the jump height, one participant detailed that "*Yes, because one can jump so high in it that it looks like you are in some freaking jumping world where there are only characters that jump like all the way to space or something.*" Another participant stated, "*I had such a super power that I went there on the cliff [referring to a platform in Super Stomp] and jumped [with a high impact] down from there on top of [Player 2].*" Thus, a majority of players noticed the empowered movement, and it enhanced their play experience.

KEY TAKEAWAYS FOR EXERGAME DESIGN

From our study, we have gleaned insights into the play experience of a multiplayer mixed-reality trampoline game. Players responded positively to the questionnaires and interview questions. The words used most prominently to describe the experience of playing Super Stomp were *fun*, *nice*, and *pleasant*. The insights we have gained from the design and evaluation of Super Stomp lead us to three key takeaways for designers and researchers, articulated below.

Support Autonomy when Faced with Design Challenges

Developers of multiplayer mixed-reality games should design core mechanics in ways that support autonomy. In Super Stomp, we chose to support autonomy by allowing players to use any pose to cause the same result (see Figure 6). To accomplish this, we used the player's outline for interactions instead of relying on small movements or precise positions of skeletal joints to detect a stomp. We overcame latency issues by prioritizing data to be transferred. Critical information required to play the game is sent without delay (e.g., the player's center of mass), and less important information is sent later (e.g., the player's pose, which, due to our design, is purely a visual feature and not crucial to gameplay). By using the player's outline for interactions instead of relying on precise joint positions, we grant players freedom of movement to use any pose they wish to accomplish a stomp, thus supporting their autonomy. At the same time, this overcomes technical challenges of latency and imprecise pose tracking.

Empower Movement to Support Human Needs

Complementing prior work, we provide additional evidence that movement empowerment may support autonomy, competence, and relatedness. Supporting innate human needs might provide an incentive to exercise, which is important given that lack of exercise is a major public health problem. Super Stomp empowers movement primarily through exaggerated jump height. Through our study, we learned that a majority of participants noticed the exaggeration, and they found that it enhances their experience with the game. But, we have merely

Figure 6. Players can *stomp* using any pose they desire.

scratched the surface of the potential of empowering movement. Exaggeration is one way to grant empowered movement, and developers should explore further methods, such as slow-motion gameplay that grant players more reaction time.

Designing Multiplayer Trampoline Games Is Possible

Our work provides a novel example of solving a hard interaction design problem, which we hope provides inspiration for other researchers and designers. For exergaming and physical activity motivation, trampolines present an exciting but problematic technological platform. Trampoline jumping is exhilarating but physically exhausting, and the proliferation of trampoline parks and home trampolines indicates that trampolines have tremendous potential for physical activity motivation. On the other hand, serious injuries are common when people progress to tricks like somersaults or more than one person jumps on the same trampoline [4, 19]. Although previous work has suggested that mixed reality games can address this problem by making basic and safe jumping more exciting [16], before this paper, no viable multiplayer game mechanics had been identified. Our evaluation indicates that the Super Stomp core mechanics and game design are successful despite the challenges posed by latency and how a trampoline at the same time empowers and restricts movement, providing very little control over movement trajectory once launched in the air and making it difficult to stop jumping after gaining momentum.

LIMITATIONS

The primary purpose of the study we performed was to gain a greater understanding of movement empowerment in a multiplayer mixed-reality trampoline game. As such, we conducted the study in the wild, and we have gained valuable information from interviews and questionnaires by doing so. But, this was not a controlled study, and we cannot generalize our results beyond the Super Stomp game.

Questionnaires

It should be noted that while the PACES questionnaire has been validated with children [25], the UPEQ has not. Also, although the questionnaires have been validated with some populations, the questions were translated into a local language before distributing the questionnaires to participants. The translation of the questionnaires has not been validated, and the PACES questionnaire, especially, relies on adjectives (which are prone to issues with conveying the same meaning in multiple languages), most of which are relatively synonymous with one another. Thus, there is potential for some vital meaning to be lost in translation.

Health Benefits

Our work is motivated by the importance of physical activity for health, but we have made no attempt to validate the possible health benefits of Super Stomp. Instead, we use intrinsic motivation questionnaire data as proxy measures, based on research on the importance of intrinsic motivation to exercise adherence [6, 28, 36]. As Super Stomp cannot be played at homes and is currently only available at very limited locations, a larger scale and longer-term evaluation was not feasible and is left for future work.

CONCLUSION

We have presented the design and evaluation of Super Stomp, a novel multiplayer mixed-reality trampoline game. Games such as Super Stomp may aid in addressing the major public health problem of lack of physical activity by satisfying innate human needs. These needs may be satisfied by granting superhuman abilities in games, empowering the player's movement. But, the design of Super Stomp was challenging, primarily due to technical limitations such as latency, as well as the constraints trampolines pose on safety and movement. We overcame these issues using techniques that support autonomy in our core game mechanics.

Our study demonstrated potential of exergames with movement empowerment in satisfying each of the innate human needs specified by self-determination theory: autonomy, competence, and relatedness. Spectators enhanced the social experience by providing additional motivation to win the game. Players were made to feel as if they had superpowers and responded positively as a result. Our study was, to the best of our knowledge, the first to examine movement empowerment in the wild, as well as the first to explore movement empowerment in a multiplayer context. But, it was not a controlled trial, and further work is warranted to generalize our results and quantify the effects of different game elements and design choices.

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