SwimTrain: Exploring Exergame Design for Group Fitness Swimming

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ABSTRACT

We explore design opportunities for using interactive technologies to enrich group fitness exercises, such as group spinning and swimming, in which an instructor guides a workout program and members synchronously perform a shared physical activity. As a case study, we investigate group fitness swimming. The design challenge is to coordinate a large group of people by considering trade-offs between social awareness and information overload. Our resulting group fitness swimming game, SwimTrain, allows a group of people to have localized synchronous interactions over a virtual space. The game uses competitive and cooperative phases to help group members acquire group-wide awareness. The results of our user study showed that SwimTrain provides socially-enriched swimming experiences, motivates swimmers to follow a training regimen and exert more intensely, and allows strategic game play dealing with skill differences among swimmers. Consequently, we propose several practical considerations for designing group fitness exergames.

ACM Classification Keywords

K.8.0 Personal Computing: General-Games; H.5.3 Group and Organization Interfaces: Synchronous interaction

Author Keywords

Group fitness; swimming; exertion games

INTRODUCTION

People often exercise together instead of working out alone. There are a variety of reasons for why people want to exercise with others, for example, building social relationships, motivating themselves to exercise more, and extracting personal enjoyment out of the activity [6, 17, 32]. In recent years, sports industries have been aggressively releasing a variety of self-tracking products with social support features, such as sharing and comparing exercise records with other friends [1, 2]. Moreover, Human-Computer Interaction (HCI) communities have been actively studying methods to transform solitary exercises into socially enriched ones. For example, *Jogging over a Distance* enables a pair of distant joggers to run together through spatial audio feedback [29]. Similarly, *Swan-Boat* allows multiple treadmill runners to play an exergame in which two runners, as a team, collaborate to steer a boat, and two teams compete with each other in a boat race [3].

Group fitness is one of the most representative social exercises and includes any forms of fitness exercises performed by a group of people led by an instructor [45]. A large number of people visit local fitness centers every day to participate in various kinds group fitness programs, such as group spinning, rowing, aerobics, swimming, and yoga classes. As in social exercises, group fitness provides engaging and entertaining exercise experiences. Furthermore, an instructor of a group fitness exercise encourages participants to adhere to a training regimen and helps them to learn fitness skills and develop overall fitness levels.

A variety of design candidates for novel group fitness applications have employed interactive technologies. One approach is to provide opportunities for additional interaction; for example, Mauriello et al. proposed a wearable display for group running that shows pace or duration to a group of runners [22]. Interactive technologies also allow a group of remote exercisers to participate in group fitness, as in *Exer-Sync*, an exergame platform for a remote interpersonal synchrony [34]. More importantly, personalized workouts can be supported in the context of group fitness. For example, by coordinating user interactions in a virtual space, it may be possible to deal with heterogeneous workout goals and individual skill differences, as in conventional exergame design [30].

In this paper, we focus on instructor-led group fitness exercises, such as group spinning and swimming, in which an instructor guides a workout program, and members perform a shared physical activity. As a case study, we investigate group fitness swimming, which represents both a highly popular aerobic exercise and a challenging set of design constraints. For example, swimming allows a very small degree of freedom for additional movement, because it requires tightly coordinated movements of the entire body. In addition, swimmers tend to have limited opportunities for verbal social interaction (e.g., in-depth conversation) because it risks disturbing others' training regimens [41]. Seamless wireless network connectivity is also required for group coordination; however, periodic water submersion renders connectivity highly

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vulnerable. Prior studies have shown that swimming motions and audio feedback can be used for user interactions [13, 21], and wireless networking connectivity can be sustained if a Long Term Evolution (LTE) network is used [13].

Our aim is to build a group fitness swimming game that allows a group of people to perform mediated synchronous interactions over a virtual space. The challenge is to coordinate a group of people and deliver group awareness to them without information overload. At the same time, we want the players of the game to experience a similar degree of social awareness as in traditional group fitness exercises.

To this end, we designed SwimTrain, an exergame for group fitness swimming. In SwimTrain, each swimmer is metaphorically mapped to a compartment of a virtual train, and uses stroke rate to maneuver his/her own compartment. SwimTrain facilitates engagement through a combination of competition and collaboration, which encourages players to establish and maintain their highest sustainable levels of exertion.

SwimTrain interactions are based on localized cooperation within subgroups of three swimmers, spanning the swimmer immediately in front of and behind each player in the virtual space. This is based on the "peephole" design concept [14], which provides only a limited view of a larger information space (in our case, collective group awareness). Localized subgroup interactions also facilitate more directly interpersonal competition and collaboration across each round, with group-wide communication of overall rankings in rest phases.

We iteratively prototyped SwimTrain using waterproof smartphones and earphones. To explore user experiences, we conducted an experiment with eleven participants to investigate (1) how the feelings of social awareness during game play compared to real group fitness swimming, (2) whether and why the game motivated players to swim more intensely, and (3) how well the game provided balanced exertion experiences. The results of exit-interview analysis showed that SwimTrain enriches the social experience of swimming, motivate swimmers to greater levels of exertion, and allows swimmers to establish a strategy to win the game irrespective of their relative skill level. We conclude the study with practical considerations for designing group fitness exergames.

RELATED WORK

Social Exergame Design

Researchers in exercise psychology have revealed that people prefer exercising with others to exercising alone [6, 17]. In line with this finding, HCI communities have made a variety of attempts to employ social aspects in order to encourage people to engage in exercises. A typical approach is to allow people to share their exercise records with others. For example, *Nike+* and *RunKeeper* support comparing and sharing jogging records with friends [1, 2]. *TripleBeat* helps runners achieve their fitness goals by allowing them to compare to and compete against others using heart rate [15].

Another approach is to allow people to play traditional multiplayer video games using their physical effort instead of conventional controllers (e.g., a gamepad, a keyboard, or a mouse). For example, Ahn et al. allowed two treadmill runners to play a boat racing game, where a virtual boat is collaboratively controlled by their treadmill speeds. In *HapticTurk*, a player explores a virtual world using other player's collaborative movements, such as lifting up and tilting [11]. *Pulse Masters Biathlon* and *Heart Burn* are similar to a computer-based sports and racing games except that each player's avatar is controlled by his/her heart rate, not buttons [31, 42]. In *Nautilus*, players collaboratively control a virtual diving bell by physically moving on a interactive floor [43]. *Body-Driven* exergames allow multiple players to cooperatively play traditional video games (e.g., "Bubble Bobble" and "Bomberman") using their motions, which are recognized by a single top-view camera [20].

Moreover, several exergame studies have augmented a physical space. These exergames allow players to move around a physical world and interact with overlaid virtual objects. One example is *Paranoia Syndrome*, where users interact with RFID-tagged objects using their own PDAs while walking around physical rooms [16]. *Human Pacman* is an augmented-reality version of a video game, "Pacman", where players interact with an augmented physical space and other players (e.g., their team and opposing team members) using their head-mounted displays and touch sensors [12].

With advances of networking technologies, researchers have designed interactive systems that allow people to synchronously exercise with others from a distance. For example, *Sports over a Distance* project allows remote users to synchronously take a variety of exercises together, such as table tennis [25], air-hockey [24], shadow boxing [26], and jogging [29, 32]. Park et al. proposed interactive exercise platforms that allow exercisers to play exergames with heterogeneous exercise devices [33], and that enable remote exercisers who use different exercise devices to synchronize the rhythm of their body movements with that of others [34]. *RUFUS* system allows non-exercisers (or supporters) to send cheerful messages to a remote runner [46].

Furthermore, attempts have been made to augment traditional exercises by employing additional interaction opportunities. For example, Mauriello et al. employed a wearable display in a context of group running that shows the pace or the duration to followers [22]. Employing non-human objects (e.g., robotic drones) also opens up interaction design opportunities, such as non-human exercise partners [28, 44].

Our main contribution here is to explore exergame design in a novel domain, group fitness. We carefully consider the characteristics of group fitness and human beings' cognitive load, and propose a novel group organization scheme that employs the "peephole" design concept [14]. Further, we iteratively prototype SwimTrain through a user-centered design process and several exergame design guidelines [9, 27, 30, 35].

Swimming with Technology

Interactive technologies related to swimming or aquatic environments can be largely classified into: (1) tracking tools, (2) guiding/training tools, and (3) interactive games. Tracking/balancing tools generally support counting the number of laps completed and how many times a swimmer perform a

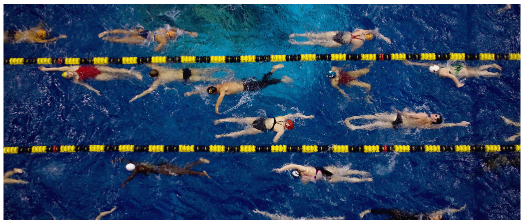


Figure 1: ‘Swimming in a line’ in group fitness swimming

certain swimming style, such as *Garmin Swim* and *Instabeat*. Further, *Finis AquaPulse* monitors a swimmer’s heart-rate and provides audible feedback.

Guiding/training tools help swimmers discover their appropriate paces and improve their swimming performances. *Finis Tempo Trainer* allows people to swim at a predefined pace by transmitting an audible beeping sound. *SwimMaster* [5] provides feedback corresponding to swimming motions by using wearable acceleration sensors for stroke monitoring and correction. Ukai and Rekimoto proposed *Swimoid*, an underwater robot that follows swimmers and provides visual feedback regarding their swimming behaviors [44].

Researchers have developed several exercise games for aquatic environments. The Games [4Health] Jam workshop at CHI 2013 explored various gamification scenarios, such as *Kweekvijver* (swimming with a fish float and scanning RFID tags scattered around the pool), *PiratenVlot* (an augmented reality floating platform), and *SwimNote* (an underwater music game) [10]. Pell and Mueller prototyped *Gravity Well*, an interactive system that enables exertion play under altered-gravity conditions under water [36]. *Dungeons & Swimmers* is a single-player game in which swimmers’ strokes (as game input) are used to interact with virtual objects in a game [21]. Choi et al. extended Dungeons & Swimmers to a multi-player game, where swimmers hunt down a virtual monster collaboratively by using swimming styles as game inputs [13].

UNDERSTANDING GROUP FITNESS SWIMMING

In this section, we first briefly introduce group fitness swimming to help readers understand our target exercise domain. We then elaborate on design insights gathered from expert interviews and observations of group fitness swimming.

What is Group Fitness Swimming?

As previously mentioned, group fitness is a form of fitness exercise performed by a group of people guided by an instructor. In line with this definition, we define group fitness swimming as a swimming exercise performed by a group of swimmers guided by an swimming instructor. One of the most representative forms of group fitness swimming is a group swimming lesson. Typically, many swimming pools provide group swimming lesson programs, where a group of people swim together in accordance with an instructor’s guidance.

Study Procedures

To better understand group fitness swimming and gather design insights, we conducted expert interviews and observed group fitness swimming situations. For interviews, we recruited three swimming instructors (E1, E2, and E3) from local swimming pools, all of whom were certified to teach swimming in Korea (e.g., certification as a lifeguard or swimming instructor). Each had more than four months of teaching experience (E1: 4 months, E2: 6 years, and E3: 4 years), and all instructors had conducted swimming lessons for a variety of groups of swimmers, such as children, students, and adults.

We conducted semi-structured interviews in person, focusing on the structure and content of group fitness swimming sessions. Each interview lasted an hour and was recorded for transcription. Furthermore, we participated in each instructor’s swimming lessons, and carefully observed group fitness swimming situations. After completing all interviews and swimming lessons, two researchers collaboratively clustered instructors’ comments and our observations according to the shared themes that characterized group fitness swimming.

Findings

Sharing a lane with other swimmers

All instructors reported that multiple swimmers shared each lane during group fitness swimming sessions. Typically, five to fifteen swimmers participated in each session, occupying one or two lanes: *“In the case of a class for elementary school students, two lanes were assigned with more than fifteen people. [...] For (adult) workers, one lane was assigned with about ten people.”* [E1]

In addition, we observed many lane-sharing situations in regular public swimming. Since a swimming pool has a limited number of lanes, swimmers often share lanes with others. In these instances, the lane is implicitly divided into two narrower half lanes, where the direction of swimming in each half lane is opposite to the other half lane.

Swimming at a similar pace in the same lane

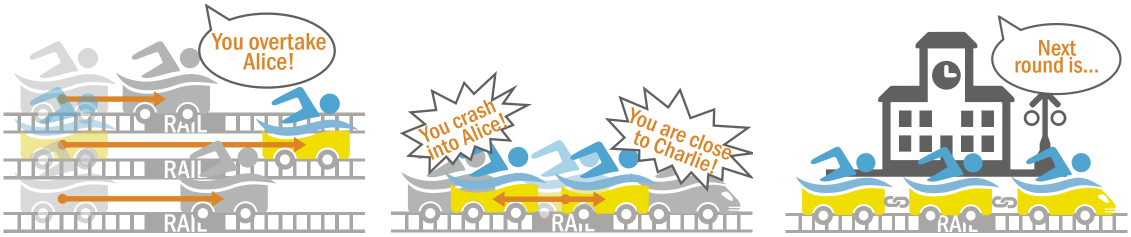
When multiple swimmers shared a lane, we observed that they swam in a line and at a similar pace while maintaining their distance from adjacent swimmers (see Figure 1). Swimmers often try to select a lane commensurate with their skill levels, but lanes can also be assigned: *“The swimming pool where I work has two types of lanes, a 1.3- and a 1.8-meter deep lane. I and other instructors allow skilled swimmers to swim in the deeper lane.”* [E1]

Because the speed of a lane is collectively negotiated by swimmers, lanes sometimes become shared by people who have different swimming levels. This often results in slower swimmers slowing down faster swimmers and causing congestion. To prevent this situation, slower swimmers typically give way to allow the faster swimmers to overtake: *“If I follow up the swimmer ahead and swim faster, the followed swimmer tells me to go first.”* [E1]

It is known that these behaviors stem from the social norms of the pool. For example, swimmers tend to avoid touching one another’s bodies (this is regarded as a taboo) and disrupting others’ training regimens [41].

Congestion in a lane

Traffic in a swimming lane can sometimes become congested. For example, swimmers often stop and wait for the swimmer ahead of them to create enough buffer space, and this has a knock-on effect: *“When too many people swim in a single*



(a) Compartment ordering phase (b) Train running phase (c) Train stop phase

Figure 2: Visual representations of three phases in SwimTrain

lane, they can collide with others. [...] The main reason for congestion is swimming skill differences among attendees. If a swimmer's skill level is significantly lower than that of other swimmers, I ask him/her to register for a different class more suitable to his/her skill level." [E3]

The instructors use several strategies to avoid congestion. Firstly, they limit the number of swimmers in a single lane, e.g., to no more than ten swimmers in a 25 m-long lane. Secondly, if there are too many attendees in one class, they allow swimmers to use different lanes according to their skill levels. *"There are generally two slow swimmers of twelve in a class. [...] I separate swimmers into two groups, the faster and slower swimmers, and lead them to use two different lanes according to their speed."* [E1]

In addition, instructors lead the faster swimmers to situate themselves ahead of the slower swimmers: *"Before doing multiple laps, I arrange swimmers in order of swimming speed and let the faster swimmer go first."* [E2]

Instructor support

An swimming instructor plays an important role in providing teaching directions, such as correcting swimming postures, guiding swimming pace, and offering detailed swimming programs suitable for the skill levels of the participants: *"I have different programs according to swimming competence, like novice, intermediate, competitor, and master. In a novice class, I lead swimmers to kick and walk in a pool in order to familiarize them with water. [...] In a master class, I progress with medley swimming."* [E3]

Depending on the characteristics of a group of swimmers, the instructors give different types of feedback both inside and outside of the pool. For example, when they teach novice swimmers or children, they stay in the water and manually correct incorrect postures. In case of intermediates and competitors, they guide the swimming pace, and measure the time taken to complete a specific number of laps: *"I give them feedback about when they should breath over as I follow them. Also, I sometimes measure lap time."* [E2]

Design Insights

Our preliminary exploration about the characteristics of group fitness swimming offered several design insights for group fitness swimming exergames. Primarily, we should consider recreating the lane-sharing experience that is a fundamental characteristic of group swimming classes. We should also consider different swimming patterns in the lane-sharing situation, such as following other swimmers while maintaining distance from them, moving out of the way, and overtaking slow swimmers. Furthermore, we should take into account congested lane traffic in the game design. Congestion can be viewed as both a problem and a design opportunity. On the one hand, the problem of congestion can be mediated by balancing skill level differences (which cause a lane to be congested) in a virtually shared space [30]. On the other hand, we can also regard congestion as an opportunity, e.g., to leverage the thrill of avoiding or participating in physical collisions [27]. Finally, we could encourage swimmers to engage in a training regimen by integrating an instructional component into the game design. For example, a virtual coach could provide feedback regarding users' performance.

GAME DESIGN

Considering the characteristics of group fitness swimming and well-known exergame design guidelines, we designed SwimTrain, an interactive exergame for group fitness swimming in which multiple swimmers set their own target exertion levels with social competition, and maintain those targets through collaborative interaction. In this section, we first describe the game flow of SwimTrain. We then propose design rationales based on the "peephole" design concept and past work on exergames. We also show design revisions through a preliminary user study involving an initial prototype.

Game Flow

In group fitness swimming, people sharing the same lane should swim at a similar pace and maintain appropriate distance from adjacent swimmers to avoid violating social norms of the pool. If a person swims at a slower pace, he/she should give way to allow others to overtake, or select a different lane commensurate with his/her swimming competences.

We represented this characteristic of group fitness swimming in the game by using a train metaphor. In SwimTrain, each swimmer plays the role of maneuvering a compartment of a virtual train using his/her stroke rate, which is defined as the number of strokes per unit time. The train metaphor transforms the lanes of a swimming pool into virtual train tracks. Compartments along the same track (seen as the linked compartments of a train) should run at the same speed and maintain a certain distance between them to avoid collisions. This metaphor naturally exploits the social norms of physical contact avoidance in group fitness swimming. In addition, we employed the related metaphor of compartments racing for

Previous order	Current order	Narration
Alice–**You**–Bob	Alice–**You**–Bob	*"Alice is behind you!"* or *"Bob is ahead of you!"*
Alice–**You**–Bob	**You**–Alice–Bob	*"Alice overtook you!"*
Alice–**You**–Bob	Alice–Bob–**You**	*"You overtook Bob!"*

Table 1: Corresponding narrations to the change of orders in the CO phase

position allowing free overtaking, which is a reflection of the social norms of respect for others' training regimens.

SwimTrain consists of multiple rounds, where each round is divided into three phases: a competitive phase called *Compartment Ordering* (CO), a collaborative phase called *Train Running* (TR), and a short rest phase called *Train Stop* (TS). Each phase has a different goal, and swimmers play rounds repeatedly for as long as desired. Figure 2 shows a visual representation of the phases.

- **Compartment Ordering** In this phase, compartments race against other compartments. Each swimmer's current stroke rate at any given time is measured and aggregated using mean stroke rate. The game determines the order of compartments using individuals' aggregate stroke rates. Whenever a swimmer perform a stroke, he/she is informed of changes of order of other compartments immediately ahead of and behind his/her compartment, as shown in Table 1. At the end of the phase, the aggregated stroke rate of each swimmer becomes his/her own target stroke rate for the following TR phase. Players are awarded points according to the final order of the compartments.

- **Train Running** In this phase, compartments are placed along the same track and run in a circle (like a merry-go-round), such that the head compartment is arranged behind the tail compartment. Each swimmer should continuously match his/her current stroke rate with the target stroke rate established in the previous CO phase. A compartment shifts with the movement of the current stroke rate relative to the target stroke rate; for example, a compartment shifts forward when the given stroke rate is higher than the target stroke rate, and shifts backward when the given stroke rate is lower than the target stroke rate. Moreover, a compartment collides against adjacent compartments determined in the CO phase if the current stroke rate is much higher or lower than the target stroke rate. We set five ranges of differences between the current stroke rate and the target stroke rate (i.e., *too fast*, *fast*, *matching*, *slow*, and *too slow*), and provide auditory and vibro-tactile feedback to players corresponding to a certain range, as shown in Table 2. Vibro-tactile feedback simulates physical contact with others. The longer each swimmer matches their current stroke rate with their target rate, the more the points they receive. In addition, points are deducted whenever they collide against adjacent compartments.

Ranges	Feedback descriptions
Too fast	*"You crash into Bob!"* with vibro-tactile feedback
Fast	*"You are right behind Bob!"*
Match	*"Keep going!"*
Slow	*"Alice is right behind you"*
Too slow	*"Alice crashes into you!"* with vibro-tactile feedback

Table 2: Feedback descriptions corresponding to a range of differences between the current and target stroke rate (Alice is ahead of a player, and Bob is behind a player)

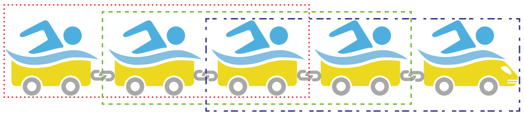


Figure 3: Visual representation of peephole sub-group chains

- **Train Stop** In this phase, the virtual train stops. Every swimmer takes a rest for a short time. The game determines the final rankings of swimmers in the round by calculating a weighted average of points gained in each phase (i.e., the CO and TR phases) depending on the duration of the phases. Swimmers are also given information regarding the next round, including the durations of each phase.

Design Concept: Peephole

To provide social awareness to all participants through game feedback, it is important to consider the corresponding effect on cognitive load. Movements of the body demands high cognitive load [27], and swimming is one of the most complex physical exercises requiring highly coordinated movement of the entire body. Providing too much feedback during swimming could consume significant mental resources, and information overload could easily result if each player was continually updated on the status of every other player.

Taking into account the limitations in human cognitive capabilities, we employed the "peephole" design concept to provide a limited view of a larger information space [14]. The peephole pattern is frequently applied to hand-held devices with small displays as a means of navigating large information spaces [18, 23, 37]. To build suspense, many computer war-games also use the peephole pattern to realize the *fog of war*, which allows a player to initially identify only limited playable terrain until the player's explorations reveal it.

Peephole design sometimes imposes a cognitive burden if users are asked to construct a detailed view of a large information space using a limited view [37]. Therefore, our main concern is to allow swimmers to play the game with a minimal amount of information and no need to mentally reconstruct the overall information space. To this end, we first divide the entire group of players into chained subgroups, where each player participates in a subgroup with two virtually adjacent players, an "ahead" player and a "behind" player. As shown in Figure 3, each subgroup overlaps two other subgroups. Chains of subgroups thus organize players into a single group.

While players are swimming in the TR and CO phases, our game allows each compartment to interact only with immediately adjacent compartments in the same subgroup, instead of with every other compartment. By deliberately limiting interactions, players do not suffer from information overload; they only need to concern themselves with the movement of their own bodies and that of adjacent compartments. Information regarding the entire group (e.g., the rankings of swimmers) is provided only in the short rest period (the TS phase). In other words, each player can feel the presence of every other player only when he/she need not care about the movement of his/her own body, and the resulting cognitive load is low.

Furthermore, we eliminate actual interdependence between subgroup compartments by leveraging ambiguity in a way that gives rise to pseudo-cooperation. During the TR phase, the adjacent compartments to each player do not actually move in a manner determined by the players ahead and behind—they remain fixed with respect to the target stroke rate of the player. The distance to each adjacent compartment is determined by each player's stroke rate, regardless of the stroke rates of others. Thus, our game does not support actual synchronous cooperation with others, but offers the illusion of cooperation. This pseudo-cooperation reduces unpredictability and complexity, so that each player only needs to focus on how well he/she matches his/her stroke rate with the target stroke rate.

Design Rationales

Group fitness swimming instructor

In group fitness swimming, the instructor dictates the number of laps to be completed in a particular swimming style. They also teach basic swimming skills, encourage people to swim more and longer, and guide the swimming pace. In SwimTrain, a virtual instructor plays a similar role to a real instructor. For example, it provides an interval training program including the exercise and recovery periods. Swimmers are encouraged to find and maintain their appropriate swimming pace through feedback from the virtual instructor.

The metaphors underlying the SwimTrain game world were carefully designed to follow the natural structure of conventional interval training while exploiting the benefits of gamification [38]. For example, our virtual instructor provides feedback not as explicit pace information, but as positional information within the context of the game world. If the given stroke rate is different from the target stroke rate, the virtual instructor provides feedback in terms of distances from adjacent compartments (e.g., *"You are following right behind Alice!"*) rather than as pace data or comparisons.

Intuitive interaction between the game and players

According to exergame design guidelines proposed by Park et al., intuitive interactions can be formed by using the fundamental actions of a target exercise [35]. SwimTrain uses stroke rate as the primary action because a stroke is one of the core mechanics of swimming. The game mechanics do not encourage or interpret additional body movements (e.g., symbolic head shaking) because swimming requires highly harmonic motions of entire body and allows a limited degree of freedom for additional movements. Our game does, however, provide both auditory and vibro-tactile feedback regarding how well players perform their target actions (i.e., establishing a high stroke target in the CO phase and matching it in the TR phase), to allow players to engage more deeply in the game and help them improve their movement [27, 47].

Motivating with competition, cooperation, and micro-goals

To motivate players, our game incorporates competition and cooperation in the CO and TR phases respectively. We also set micro-goals for each phase, as proposed in [9, 35]. In the CO phase, players compete against one another in terms of aggregated stroke rate, with faster rates leading to compartment overtaking. Conversely, the goal of the TR phase is to match their current stroke rate with their target rate.

Providing balanced exertion

To involve players with varying swimming skills, we considered providing a balanced exertion experience by referring to previous design guidelines [30].

- **Measuring effort-based exertion** To reduce the influence of varying physical abilities, we considered employing physical effort, such as heart-rate and oxygen intake, to measure exertion. We ultimately used stroke rate as a measure of physical exertion, because it is positively correlated with energy cost (defined as required energy for a unit mass body to move a unit distance) [19].
- **Dynamically adjusting exertion levels** Our game allows each player to set his/her target exertion level through competition. They can vary their target stroke rate according to workout goals, stamina, swimming skills, and daily dispositions. For example, players can deliberately set a lower target rate in the CO phase to leave enough energy to guarantee successful stroke rate matching in the TR phase.
- **Abstracting exertion to low resolution** In the CO phase, each player only perceives the state of swimmers who are virtually adjacent to them, rather than the entire game state. Moreover, the TR phase provides feedback about how well players perform a stroke in terms of quantized distances from virtually adjacent compartments, instead of detailed numbers. Our representation provides ambiguity as to the actual swimming paces involved, so that players can engage in the game more collaboratively.

Supporting strategic game play

An exergame incorporates exercise and gaming, so that winning the exergame depends not only on skill at the exercise, but skill at the game. SwimTrain determines the final rankings of each round by calculating a weighted average of points gained during the CO and TR phases according to the duration of the phases. The best strategy to win the game is to set the highest target stroke rate of all swimmers in the CO phase and to consistently maintain it for the duration of the TR phase. Obviously, this strategy cannot be accomplished for most swimmers. Instead, players should establish their own strategies to win the game. For example, a player can set a low target stroke rate and maintain it as long as possible if he/she is not confident that he/she can keep up a high stroke rate. We also varied the duration of each phase so that players would need to continually reevaluate their strategy based on their relative abilities in speed and endurance.

Preliminary User Study and Design Revision

To evaluate user experiences of our game at an early stage, we implemented an initial prototype of SwimTrain and conducted a user study with four participants. Through qualita-

Rounds	CO	TR	TS
R1	60 s	60 s	50 s
R2	60 s	120 s	80 s
R3	40 s	40 s	30 s
R4	40 s	80 s	-

Table 3: Round settings for the preliminary user study

tive interviews, we revised our initial design to the final version, which has been described.

Initial prototype

The initial prototype directly informed players of their rankings during the CO phase every four seconds (e.g., *"You take second place!"*) and did not refer to other players by name. It used narration and spatial earcons to notify players of their stroke rates at any given time relative to the target stroke rate, as proposed in [29]. For example, a spatial sound icon (e.g., the "click-clack" sound of a train) was heard ahead of a player with the virtual instructor's directions (e.g., *"You are fast!"*), if they stroked faster than the the target stroke rate. Finally, the game used different patterns of vibro-tactile feedback according to the situation. For example, a long vibration signalled at the beginning of each phase and short, repeated vibrations indicated a collision with an adjacent compartment.

Preliminary user study

We recruited four participants from our campus online community. Two participants were male. Each participant has more than two years' swimming experience, and their ages ranged from 24 to 31 years. We allowed participants to play the initial prototype of SwimTrain in four separate 25 m lanes of a pool. All participants began the game at the same time and played four rounds in total, except for P4, who skipped the third round due to exhaustion. The setting for each round is listed in Table 3. After the experiment, we conducted a group interview for 45 minutes. The session was recorded and transcribed. Two coders clustered answers according to shared topics, leading to four main findings:

- **Limited social awareness through auditory feedback** All participants reported that they felt some social awareness through auditory feedback. However, P1 commented that he wanted to know who the other players were.
- **Limited human sensory capability while swimming** Even though participants only needed to focus on the narration during swimming, they could still not identify the direction of origin of the spatial earcons. They also felt the vibrations but did not realize different patterns of them.
- **Overexertion due to competition** Competitive factors drove highly intense exertion. For example, P2 reported overexertion to get a higher rank in the CO phase, but he failed to keep up his own pace during the TR phase.
- **Inappropriate duration of each phase** We found that the duration of each phase could have a significant influence on exhaustion. P4 reported that the duration of the TS phase (i.e., the phase for rest) was too short, whereas the other phases were too long (she became exhausted and could not help but rest during the third round).

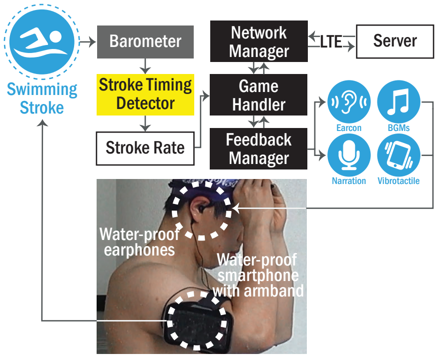


Figure 4: Overall architecture of SwimTrain

Design revision

Based on the findings of the preliminary user study, we revised the initial design. First, we allowed players to set their own nicknames, and let the virtual instructor call the nicknames of other players who maneuvered adjacent compartments. By doing this, players would be more aware of other players. Second, we decided not to use spatial earcons, since they did not provide a sufficiently salient sense of direction while swimming compared with explicit narration. Third, to reduce the resulting intensity of competition, the final design employs ambiguity of ranking information. The virtual instructor thus provides feedback on overtaking events rather than on overall user ranking at short-duration intervals.

Ambiguity was also employed in the redesign of the TR phase. Initially, the virtual instructor explicitly informed players of differences between their current stroke rate and the target stroke rate (e.g., *"You are too fast"*). We revised the text of narration to provide socially-enriched swimming experiences by presenting the distance between adjacent compartments (e.g., *"You are following right behind Alice"*).

Finally, we adjusted the duration of each phase, in particular doubling the time allocated to rest in the TS phase, in order to promote more sustainable patterns of exertion and recovery.

IMPLEMENTATION

We implemented SwimTrain on the Casio G'zOne Commando LTE, which is a rugged smartphone that can be immersed at 1 m for up to 30 minutes. This smartphone supports the Android operating system (v4.0.3 API 15) and has a variety of sensors, including an accelerometer, a gyroscope, a magnetometer, and a barometer.

As shown in Figure 4, the smartphone was secured on a swimmer's upper arm with an armband, and operated four different modules of SwimTrain: the stroke timing detector, the network manager, the feedback manager, and the game handler. Auditory feedback was delivered through water-proof earphones connected to the smartphone.

Stroke Timing Detector

Our game mainly depends on stroke rate; therefore, it is important to accurately detect stroke timing. Past work has proposed a barometric signal-based stroke detection algorithm

Types	Min.	1st Qu.	Median	3rd Qu.	Max.
Pressure Diff. (hPa)	2.19	8.19	13.29	16.19	26.08
Stroke time (s)	1.21	1.85	2.06	2.32	3.86
Stroke rate (s^{-1})	0.26	0.43	0.49	0.54	0.83

Table 4: Distributions of preliminarily collected data (Qu.: quartile

that has yielded accuracy values of 95.1% [13]. This algorithm reports a stroke point by detecting a significant local maximum from consecutive barometric signals. To lower data progressing overhead, consecutive stroke points are ignored for a certain amount of time after a stroke point has been detected, because a swimmer cannot complete a single stroke again in a short time. We employed this algorithm with an revised signal smoothing scheme.

Our implementation device reported barometric signals every 30 ms with the SENSOR_DELAY_FASTEST setting of the Android SensorManager class. We passed signals with similar periods to a single stroke (i.e., for a period of 1.5 seconds to that of 4 seconds, or 0.25 Hz to 0.67 Hz) through a Butterworth band-pass filter, which is one of the most representative infinite impulse response (IIR) filters. We then found a stroke point in the passed signals using the algorithm mentioned above. The stroke rate is the reciprocal of the interval between two consecutive stroke points.

This algorithm exploits two types of thresholds, a pressure threshold and a time threshold. The former determines whether a local maximum is significant by comparing the difference in value between the local maximum and minimum peaks, whereas the latter relates to the time taken to disregard consecutive significant peaks. To set the two threshold values, we collected barometric data for four major styles exemplified by eight skilled swimmers with at least six months' swimming experience. All participants were recruited from a swimming club at the authors' campus, and five participants were male. From the collected barometric signals, we manually tagged every significant local maximum peak (i.e., stroke point), indicating that the swimmer's arm was at the deepest point underwater, and local minimum peak, indicating that the swimmer's arm was at the highest point out of the water. We then analyzed the distributions of value differences between local maximum and minimum peaks and the time taken to complete a single stroke (see Table 4).

We determined the values of each threshold by employing outliers identification; we set a threshold as the lower boundary of non-outliers ranges, which were defined as follows:

$$[Q_1 - 1.5(Q_3 - Q_1), Q_3 + 1.5(Q_3 - Q_1)]$$

where Q_1 and Q_3 are the first and third quartile, respectively. The pressure threshold was fixed as 2.20 hPa, because the lower boundary was lower than the minimum. The time threshold was set as 1.15 seconds.

Game Handler

The detected stroke rates were processed according to the given operating phase. During the CO phase, consecutive stroke rates were aggregated to the target stroke rate. Considering reduced stamina over time, we calculated the target stroke rate as follows:

$$Y_t = \alpha X_t + (1 - \alpha) Y_{t-1}$$

where Y_t is the exponential moving average (EMA) of stroke rates at time t, X_t is a measured stroke rate at time t, and α is a smoothing factor. From the traces of stroke rates in our preliminary data collection, we empirically set α as 0.11.

Range	Lower bdy. (s^{-1})	Upper bdy. (s^{-1})
Too slow	$-\infty$	0.35
Slow	0.35	0.43
Match	0.43	0.54
Fast	0.54	0.62
Too fast	0.62	∞

Table 5: The intervals of value differences between the given and target stroke rate (bdy.: boundary)

During the TR phase, the game determined whether players matched their given stroke rate with their target stroke rate. We differentiated the given and target stroke rate into five intervals: *too slow*, *slow*, *matching*, *fast*, and *too fast*. We empirically determined the boundaries of each interval (see Table 5) based on inter-quartile ranges of stroke rates collected from the preliminary data collection in Table 4.

Network Manager

Each player's target stroke rate and current stroke rate were transferred to the server as User Datagram Protocol (UDP) packets through the LTE network, which is the most robust electromagnetic networking technology underwater [13]. The server responded with information regarding adjacent compartments, rankings, and the settings of the subsequent rounds (e.g., the duration of each phase).

Feedback Manager

To synthesize text narration into voice in real time, we employed Google's Text-To-Speech (TTS) engine, which supports multi-language voice synthesis without a network connection. We also played background music during the TS phase, provided simple vibro-tactile feedback when collision occurred, and delivered sound icons at the beginning of each phase (e.g., the sound of the horn of a locomotive), using built-in Android functions.

USER STUDY

To explore user experiences of SwimTrain, we conducted group interviews with eleven participants after they had played the game. The main purpose of this study was to investigate: (1) how well and why participants felt socially aware while playing the game, in comparison with real group fitness swimming; (2) how the game motivated players to swim; and (3) how the game provided balanced exertion experiences.

Participants & Procedures

We recruited eleven participants (P1 to P11) through our online campus community using several criteria: (1) experience in swimming in the four major swimming styles (i.e., front crawl, back crawl, butterfly, and breaststroke), and (2) ability to swim 200 m in at least one of swimming styles above, regardless of speed. Our participants consisted of eight males

No.	CO	TR	TS
R1	60 s	60 s	90 s
R2	40 s	90 s	120 s
R3	60 s	60 s	90 s
R4	60 s	120 s	-

Table 6: Round time settings for the user study

and three females, and ranged in age from 21 to 24 years. They all had at least one year of swimming experience.

We divided the participants into six- and five-member groups, and conducted the study on separate days in three separate lanes of a 25 m pool. Before the experiment, we instructed the participants on SwimTrain for 15 minutes, and allowed them 10 minutes to warm up. Each group played four rounds of SwimTrain, as shown in Table 6. We allowed paired participants to swim in a shared lane starting from opposite ends of the pool. Following the game, we conducted group interviews for 45 minutes. The entire interview session was recorded and transcribed. We then performed analysis using the open-coding process by first segmenting transcribed answers into sentence units and clustering them based on shared concepts. We then grouped these concepts into common categories. We iteratively performed those processes until there was consensus between two coders. The detailed description of our analysis process is explained in [8].

Results

Enriched social experiences during swimming

Participants reported that the use of peephole-style feedback and referring to other players by their nicknames evoked feelings of social awareness and presence, and helped form social bonds with other players: *"Even though each player used a separate lane, it [SwimTrain] felt like swimming in a single lane all together [...] Since it kept announcing the nicknames, it made me wonder who that person was."* [P8]
"This game allowed me to feel like I was swimming together with other people, and evoked a friendly feeling, even if I was swimming alone." [P7]

In addition, several participants [P1, P3, P5] commented that SwimTrain is well-suited to remote play: *"If I join an online swimming community, the people in it would be from different regions. Since it would be hard to meet them all together in one place, it would be great to utilize this type of tool [SwimTrain] for training."* [P5]

Motivating highly intense workouts

SwimTrain is based on repeated rounds of intense activity and recovery, as in interval training program [7]. By employing a training program as a game rule, SwimTrain drove players to swim more intensely, even to exhaustion. Several participants [P3, P5, P6, P11] remarked that the directions of the in-game instructor motivated them to swim more intensely: *"When I swim alone, I get to take break as much as I want. In this game, a rest time is fixed, and a narrator instructs me to resume swimming. That makes me work out more."* [P6]

The ambiguous peephole feedback (e.g., overtake information within a subgroup, instead of explicit rankings of all group members) also contributed to an increase in exercise intensity, since it made participants [P4, P8, P9, P11] feel more direct and personal pressure: *"I was motivated to swim intensely, because the game said that someone was chasing me, or that I was chasing others."* [P9]
"I felt the strain when I heard a message like 'Someone is right behind you.' So I swam faster." [P11]

Confusion due to limited information

Even though our peephole ambiguous feedback provided motivation and social awareness, some participants [P5, P7, P8, P10] experienced confusion due to the ambiguity and the limited amount of information. They wanted more explicit information about the overall progress of the game: *"The racing game shows me how close the opponent is. However, this game [SwimTrain] just notifies me if someone is behind or if someone has overtaken me. I hope it provides information about how close the other swimmers are in more detail."* [P8]
"I want the game to represent my pace in numbers." [P10]

Dealing with differences in skill level

Participants debated the pros and cons of the appropriate competence of swimmers to play SwimTrain. Two participants [P3, P8] commented that SwimTrain could involve swimmers with different swimming competence in contrast to real group fitness swimming: *"In group swimming, I often bumped into other swimmers and waited till others made a turn because my swimming skill was better. This game allows me to swim at my own pace, and, at the same time, makes me feel as if I am swimming with others"* [P8]

Two other participants [P1, P7] commented that SwimTrain is more suitable for swimmers with similar competences: *"It will be fun to play this game with swimmers of matching skill. If not, tension or motivation seems to decrease."* [P1]

Interestingly, participants overcame different skill levels by strategically setting and maintaining the target pace. Initially, participants tended to reach a high target stroke rate in order to take first place in the CO phase. However, as the rounds progressed, participants [P3, P5, P6] tried to establish their own strategies according to their competence and conditions: *"I intentionally swam slowly in the CO phase and kept up my pace consistently. So, I ended up winning first place in that round. I guess it is possible to play this game with swimmers who have different skill levels because keeping up your own pace results in a higher ranking."* [P3]
"It was challenging to keep up my pace because I spent too much energy in the first CO phase. I started to deliberately control my pace from the beginning of each round after getting to know this" [P5]

DISCUSSION

The design challenge of SwimTrain was to gamify group fitness swimming by coordinating a group of swimmers, and yet deliver group awareness without causing information overload. To this end, we used the peephole design concept [14] and organized multiple subgroups to deliver detailed awareness information only at the subgroup level. For the game world, we employed a train metaphor to transform the lanes of a swimming pool into virtual train tracks and to map swimmers to virtual compartments. We incorporated the established method of interval training and the key skill of tactical pacing through the use of three distinct phases: a competitive phase of compartment racing (for establishing target stroke rates), a collaborative phase of compartment collision avoidance (for maintaining target stroke rates), and a rest phase for group-wide updates and recovery. Our user study results confirmed that SwimTrain provided an excellent means of fostering interpersonal bonds and introducing socially-enriched exercise experiences without information overload.

Our work adds to the body of existing work on exergame design in aquatic environments [10]. In particular, by exploring design opportunities for group fitness swimming, we significantly extend prior work on swimming technologies for guiding and training such as SwimMaster [5] and Swimoid [44]. Furthermore, as described below, our design process provides practical design guidelines for group fitness exergames.

Intra-subgroup Interaction Design

When designing a group fitness exergame involving a group of people, we should carefully design subgroup game play and subgroup member interactions. In SwimTrain, we leveraged the train metaphor to coordinate user interactions such that three players compete against and cooperate with one another. In general, our train metaphor can be applied to other group fitness exercises; for example, in group cycling, a group of bicyclists keeps a paceline for training. In practice, subgroup play design largely depends on the type of group fitness exercise. For example, in group fitness swimming, members do not have specific roles, but in group cycling, cyclists often take turns to be the leader of a paceline to distribute the burden imposed on the leader due to air resistance. While our train metaphor is a simple way of group coordination, it is possible to design more complex subgroup game play, but its complexity should be properly restrained to avoid causing significant mental and physical overload. For example, MobyDick, a collaborative exergame allowing four swimmers to hunt down a virtual monster, periodically informs each player of all the others' statuses and their in-game actions [13]. However, in their user study, it was found that the players had a hard time keeping track of the game progress due to information overload and physical exhaustion [13]. While our focus was mainly on coordinating subgroups and delivering subgroup awareness, we emphasize the fact that the designers should also carefully consider how to deliver global group awareness as described later.

Subgroup Formation Methods

We can use a variety of criteria when forming subgroups. SwimTrain dynamically formed subgroups according to players' exertion levels in each round; players were arranged in order of their aggregated exertion during the CO phase, so that a player's adjacent players in a virtual space would have similar exertion levels. It is also possible to form a subgroup based on geographic proximity of participants as well as their roles. For example, in group cycling, a leader can form a subgroup with his/her immediate followers, and multiple subgroups can be formed. When we organize subgroups, heterogeneity of user roles may exist. A subgroup can even include co-located or remote supporters. For example, RUFUS attempts to form a subgroup by matching a runner with multiple remote supporters, thereby enabling subgroup interactions of remote cheering [46].

Inter-subgroup Interaction Design

We now consider how to coordinate inter-subgroup interactions and how to support global awareness. SwimTrain leveraged the train metaphor to cooperatively link adjacent subgroups. Consequently, all subgroups form one large group like a virtual merry-go-round, and adjacent subgroup members collaborate with one another to avoid compartment collision. To avoid information overload, global awareness information was delivered only during the rest phase by narrating the final ranks of all the members. Instead of cooperative inter-subgroup coordination, we could adopt an alternative design choice of allowing each subgroup to compete with the other subgroups. For example, in SwanBoat, two treadmill runners form a team to steer a boat, and multiple teams compete with one another in a boat race [3]. In this case, multiple runners are involved in group running, and global awareness is delivered by visually displaying overall subgroup states.

LIMITATIONS AND FUTURE WORK

Our work aimed to deepen our understanding of designing group fitness exergames and to explore practical design implications based on our iterative design process and qualitative user study results. Our game design could be further improved with an additional design iteration in the future. An interesting future work would be to conduct a controlled experiment and quantitatively evaluate usability and user experiences by adopting well-known questionnaires [4, 39].

Furthermore, it would be beneficial to observe repeated play over longer periods of time. Our experiment results showed that players established a strategy to win the game as the rounds unfolded. It would be interesting to observe how players become accustomed to play the game and employ different strategies, and to evaluate whether group fitness exergames improve retention rates of group fitness exercises.

In SwimTrain, stroke rate was used as a proxy measure for performance, which was found to be appropriate for our study participants. However, the game mechanics of SwimTrain could also be configured with other metrics such as stroke length and heart rates, as in prior studies [29, 31, 42].

We did not explicitly consider lane traffic congestion. However, congestion can be seen as opening up new gameplay opportunities, since players then need to deal with the risk of physical collisions while keeping target stroke rates that avoid virtual collisions. The resulting uncertain physical collisions could provide more surprising experiences [27, 40].

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REFERENCES

1. 2015. Nike+. (2015). `http://www.nikeplus.com.br/`.
2. 2015. Rukeeper. (2015). `https://runkeeper.com/`.
3. Miru Ahn, Sungjun Kwon, Byunglim Park, Kyungmin Cho, Sungwon Peter Choe, Inseok Hwang, Hyukjae Jang, Jaesang Park, Yunseok Rhee, and Junehwa Song. 2009. Running or gaming. In *Proceedings of the International Conference on Advances in Computer Entertainment Technology (ACE '09)*. ACM, 345–348.
4. William Albert and Thomas Tullis. 2013. *Measuring the user experience: collecting, analyzing, and presenting usability metrics* (2nd. ed.). Newnes.
5. Marc Bächlin, Kilian Förster, and Gerhard Tröster. 2009. SwimMaster: a wearable assistant for swimmer. In *Proceedings of the 11th International Conference on Ubiquitous Computing (UbiComp '09)*. ACM, 215–224.
6. Mark R. Beauchamp, Albert V. Carron, Serena McCutcheon, and Oliver Harper. 2007. Older adults' preferences for exercising alone versus in groups: considering contextual congruence. *Annals of Behavioral Medicine* 33, 2 (2007), 200–206.
7. L. Véronique Billat. 2001. Interval training for performance: a scientific and empirical practice. *Sports Medicine* 31, 1 (2001), 13–31.
8. Philip Burnard. 1991. A method of analyzing interview transcripts in qualitative research. *Nurse Education Today* 11, 6 (1991), 461–466.
9. Taj Campbell, Brian Ngo, and James Fogarty. 2008. Game design principles in everyday fitness applications. In *Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work (CSCW '08)*. ACM, 249–252.
10. Alan Chatham, Ben A. M. Schouten, Cagdas Toprak, Florian 'Floyd' Mueller, Menno Deen, Regina Bernhaupt, Rohit Khot, and Sebastiaan Pijnappel. 2013. Game jam. In *CHI '13 Extended Abstracts on Human Factors in Computing Systems (CHI EA '13)*. ACM, 3175–3178.
11. Lung-Pan Cheng, Patrick Lühne, Pedro Lopes, Christoph Sterz, and Patrick Baudisch. 2014. Haptic turk: a motion platform based on people. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*. ACM, 3463–3472.
12. Adrian David Cheok, Kok Hwee Goh, Wei Liu, Farzam Farbiz, Siew Wan Fong, Sze Lee Teo, Yu Li, and Xubo Yang. 2004. Human pacman: a mobile, wide-area entertainment system based on physical, social, and ubiquitous computing. *Personal and Ubiquitous Computing* 8, 2 (2004), 71–81.
13. Woohyeok Choi, Jeungmin Oh, Taiwoo Park, Seongjun Kang, Miri Moon, Uichin Lee, Inseok Hwang, and Junehwa Song. 2014. MobyDick: an interactive multi-swimmer exergame. In *Proceedings of the 12th ACM Conference on Embedded Network Sensor Systems (SenSys '14)*. ACM, 76–90.
14. Peter Dalsgaard and Christian Dindler. 2014. Between theory and practice: bridging concepts in HCI research. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*. ACM, 1635–1644.
15. Rodrigo De Oliveira and Nuria Oliver. 2008. TripleBeat: enhancing exercise performance with persuasion. In *Proceedings of the 10th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '08)*. ACM, 255–264.
16. Guido Heumer, Darren Carlson, Sree H. Kaligiri, Supriya Maheshwari, Waqar-ul Hasan, Bernhard Jung, and Andreas Schrader. 2006. Paranoia syndrome—a pervasive multiplayer game using PDAs, RFID, and tangible objects. In *Third International Workshop on Pervasive Gaming Applications on Pervasive Computing (PerGames '06)*.
17. Maea Hohepa, Grant Schofield, and Gregory S. Kolt. 2006. Physical activity: what do high school students think? *Journal of Adolescent Health* 39, 3 (2006), 328–336.
18. Bonifaz Kaufmann and David Ahlström. 2013. Studying spatial memory and map navigation performance on projector phones with peephole interaction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. ACM, 3173–3176.
19. John Komar, Pierre M. Leprêtre, Morgan R. Alberty, Julien Vantorre, Ricardo J. Fernandes, Philippe Hellard, Didier Chollet, and Ludovic M. Seifert. 2012. Effect of increasing energy cost on arm coordination in elite sprint swimmers. *Human Movement Science* 31, 3 (2012), 620–629.
20. Sami Laakso and Mikko Laakso. 2006. Design of a body-driven multiplayer game system. *Computers in Entertainment* 4, 4, Article 7 (2006).
21. Haechan Lee, Miri Moon, Taiwoo Park, Inseok Hwang, Uichin Lee, and Junehwa Song. 2013. Dungeons & swimmers: designing an interactive exergame for swimming. In *Proceedings of the 2013 ACM Conference on Pervasive and Ubiquitous Computing Adjunct Publication (UbiComp '13 Adjunct)*. ACM, 287–290.
22. Matthew Mauriello, Michael Gubbels, and Jon E. Froehlich. 2014. Social fabric fitness: the design and evaluation of wearable E-textile displays to support group running. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*. ACM, 2833–2842.
23. Sumit Mehra, Peter Werkhoven, and Marcel Worring. 2006. Navigating on handheld displays: dynamic versus static peephole navigation. *ACM Transactions on Computer-Human Interaction* 13, 4 (2006), 448–457.

24. Florian ‘Floyd’ Mueller, Luke Cole, Shannon O’Brien, and Wouter Walmink. 2006. Airhockey over a distance: a networked physical game to support social interactions. In *Proceedings of the 2006 ACM SIGCHI International Conference on Advances in Computer Entertainment Technology (ACE ’06)*. ACM, Article 70.

25. Florian ‘Floyd’ Mueller and Martin Gibbs. 2007. Building a table tennis game for three players. In *Proceedings of the International Conference on Advances in Computer Entertainment Technology (ACE ’07)*. ACM, 179–182.

26. Florian ‘Floyd’ Mueller, Martin Gibbs, Frank Vetere, Stefan Agamanolis, and Darren Edge. 2014. Designing mediated combat play. In *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction (TEI ’14)*. ACM, 149–156.

27. Florian ‘Floyd’ Mueller and Katherine Isbister. 2014. Movement-based game guidelines. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI ’14)*. ACM, 2191–2200.

28. Florian ‘Floyd’ Mueller and Matthew Muirhead. 2015. Jogging with a quadcopter. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI ’15)*. ACM, 2023–2032.

29. Florian ‘Floyd’ Mueller, Frank Vetere, Martin Gibbs, Darren Edge, Stefan Agamanolis, and Jennifer G. Sheridan. 2010. Jogging over a distance between Europe and Australia. In *Proceedings of the 23nd Annual ACM Symposium on User Interface Software and Technology (UIST ’10)*. ACM, 189–198.

30. Florian ‘Floyd’ Mueller, Frank Vetere, Martin Gibbs, Darren Edge, Stefan Agamanolis, Jennifer G. Sheridan, and Jeffrey Heer. 2012. Balancing exertion experiences. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI ’12)*. ACM, 1853–1862.

31. Ville Nenonen, Aleksi Lindblad, Ville Häkkinen, Toni Laitinen, Mikko Jouhtio, and Perttu Hämäläinen. 2007. Using heart rate to control an interactive game. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI ’07)*. ACM, 853–856.

32. Shannon O’Brien and Florian ‘Floyd’ Mueller. 2007. Jogging the distance. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI ’07)*. ACM, 523–526.

33. Taiwoo Park, Inseok Hwang, Uichin Lee, Sunghoon Ivan Lee, Chungkuk Yoo, Youngki Lee, Hyukjae Jang, Sungwon Peter Choe, Souneil Park, and Junehwa Song. 2012. ExerLink: enabling pervasive social exergames with heterogeneous exercise devices. In *Proceedings of the 10th International Conference on Mobile Systems, Applications, and Services (MobiSys ’12)*. ACM, 15–28.

34. Taiwoo Park, Uichin Lee, Bupjae Lee, Haechan Lee, Sanghun Son, Seokyoung Song, and Junehwa Song. 2013. ExerSync: facilitating interpersonal synchrony in social exergames. In *Proceedings of the 2013 Conference on Computer Supported Cooperative Work (CSCW ’13)*. ACM, 409–422.

35. Taiwoo Park, Chungkuk Yoo, Sungwon Peter Choe, Byunglim Park, and Junehwa Song. 2012. Transforming solitary exercises into social exergames. In *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work (CSCW ’12)*. ACM, 863–866.

36. Sarah Jane Pell and Florian ‘Floyd’ Mueller. 2013. Gravity well: underwater play. In *CHI’13 Extended Abstracts on Human Factors in Computing Systems (CHI EA ’13)*. ACM, 3115–3118.

37. Roman Rädle, Hans-Christian Jetter, Jens Müller, and Harald Reiterer. 2014. Bigger is not always better: display size, performance, and task load during peephole map navigation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI ’14)*. ACM, 4127–4136.

38. Chad Richards. 2014. Using an invisible coach to help players achieve fitness goals in exergames while retaining immersion. In *Proceedings of the First ACM SIGCHI Annual Symposium on Computer-Human Interaction in Play (CHI PLAY ’14)*. ACM, 299–302.

39. Richard M. Ryan. 1982. Control and information in the intrapersonal sphere: an extension of cognitive evaluation theory. *Journal of Personality and Social Psychology* 43, 3 (1982), 450.

40. Jesse Schell. 2014. *The Art of Game Design: A Book of Lenses* (2nd. ed.). CRC Press.

41. Susie Scott. 2009. Reclothing the emperor: the swimming pool as a negotiated order. *Symbolic Interaction* 32, 2 (2009), 123–145.

42. Tadeusz Stach, T. C. Nicholas Graham, Jeffrey Yim, and Ryan E. Rhodes. 2009. Heart rate control of exercise video games. In *Proceedings of Graphics Interface (GI ’09)*. Canadian Information Processing Society, 125–132.

43. Hanna Strömberg, Antti Väätänen, and Veli-Pekka Räty. 2002. A group game played in interactive virtual space: design and evaluation. In *Proceedings of the 4th Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques (DIS ’02)*. ACM, 56–63.

44. Yu Ukai and Jun Rekimoto. 2013. Swimoid: a swim support system using an underwater buddy robot. In *Proceedings of the 4th Augmented Human International Conference (AH ’13)*. ACM, 170–177.

45. Cary H. Wing. 2014. The evolution of group fitness: shaping the history of fitness. *ACSM’s Health & Fitness Journal* 18, 6 (2014), 5–7.

46. Paweł Woźniak, Kristina Knaving, Staffan Björk, and Morten Fjeld. 2015. RUFUS: remote supporter feedback for long-distance runners. In *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '15)*. ACM, 115–124.
47. Monica Zaczynski and Anthony D. Whitehead. 2014. Establishing design guidelines in interactive exercise gaming: preliminary data from two posing studies. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*. ACM, 1875–1884.