A Physical Three-Way Interactive Game Based on Table Tennis

Florian 'Floyd' Mueller Martin R. Gibbs
Interaction Design Group
Department of Information Systems
The University of Melbourne
Australia

floyd@exertioninterfaces.com, martin.gibbs@unimelb.edu.au

ABSTRACT

Physical leisure activities such as table tennis provide healthy exercise and can offer a means to connect with others socially; however, players have to be in the same physical location to play. We have developed a networked table tennis-like game that is played with a real paddle and ball, augmented with a large-scale videoconference. Similar to networked computer games, this concept can support more than two locations: our "Table Tennis for Three" is a physical interactive game, based on traditional table tennis; however, it is playable by three players in three geographically distant locations. We hope that Table Tennis for Three has potential to achieve similar benefits known from traditional collocated physical leisure activity such as exercise, enjoyment and bringing people together to socialize.

Categories and Subject Descriptors

H5.2. Information Interfaces and presentation (e.g., HCI): User Interfaces.

General Terms

Design, Human Factors.

Keywords

Table-tennis, ping pong, Exertion Interface, physical, tangible, videoconferencing, sports, active, exhausting, sweat, team spirit, social interaction, network, bonding, rapport, connectedness.

1. CASUAL PHYSICAL LEISURE GAMES

Casual physical leisure activities, such as table tennis, are an important part of people's lives. The benefits of leisure activities on personal well-being have been widely discussed: from a mental health perspective, leisure is believed to have a beneficial effect on psychological well-being by promoting positive moods and it can help overcome loneliness [13]. From a physical health perspective, athletic leisure activities contribute to a healthier body, reducing the risk of obesity, cardiovascular disease, diabetes, and more [14][15].

Figure 1. Table Tennis for Three.

In particular, table tennis is a popular leisure activity, played worldwide by players of all ages and capabilities. Table tennis helps to develop hand-eye coordination, agility and reflexes and can contribute to general fitness [19] [10]. Due to its relatively low entry barrier, it can also serve as ice-breaker for social interactions. In fact, research has shown that many of the benefits of leisure are the result of its capability of fostering companionships and friendships [13]. These social benefits that can increase participants' well-being and mental health have been pointed out as being also of benefit to the growth of social capital [20] [21]. The author of the book "Bowling Alone", Putnam, argues that social capital requires social networks, which are most effectively developed through participation in shared activities [21]. In particular, casual physical leisure games can provide a focus for social activity. They can be helpful in facilitating social introductions, provide an opportunity to develop networks and reduce social isolation, and hence have potential to support the development of social capital. These activities can facilitate bonds between individuals, resulting in loyalty and team-spirit. However, the players have to be in the same physical location to play a game.

2. NETWORKED GAMES

One way for allowing players in geographically distant locations to enjoy leisure activities together is through networked computer games. These games offer participants a shared experience; however, they often fall short in providing a personal, casual interaction, characteristic to collocated casual physical leisure activities. The interaction support is often limited to text- or audio-only communication. Computer games with their gamepad interaction are often criticized for their support of a sedentary lifestyle and social isolation of their players. In contrast,

traditional casual leisure games support physical and athletic interactions such as jumping, kicking, throwing, and running.

Latest industry developments have recognized the potential of such traditional physical games and new products use accelerometers in game controllers [17] or track player's movements via a webcam [22] in order to encourage physical activity; however, such approaches lack adequate force-feedback when the player's avatar collides with a virtual object. Moreover, unlike most other computer games available on these platforms, these games do not support distributed participants, but rather require the players to be collocated in front of the same screen. If networked versions are available, they are often limited to an audio-only communication channel and do not offer what Vossen [23] describes as a gameplay of "offense and defense" in which a player can actively prevent the other player from achieving his/her goal. This concept is one out of three core elements that Vossen uses to categorize games, and it can play a significant role in competitive, physical games, however, it is neglected by current implementations. We acknowledge that physical activities do not necessarily require this characteristic, for example, a 100m track and field event specifically prohibits participants to physically interfere with one another through clearly marked lines that cannot be crossed. However, many traditional physical leisure activities can be described in terms of "offence and defense" and we believe it contributes to their success; hence we aim to leverage this aspect in our distributed environment through deliberate design features.

3. CASUAL PHYSICAL NETWORKED GAMES

To provide an opportunity to maintain and create social connections with others who live far apart, we have incorporated mental and physical interactions similar to a table tennis game with telecommunication technology to create a new experience that allows participants to enjoy a casual physical leisure activity together although geographically apart.

We oriented our design for a distributed casual activity on a traditional collocated social leisure game: table tennis. Our aim was to create an enjoyable physical activity that players would associate with and use for social interactions, similar to a game of table tennis. We particularly paid attention to the aspect of a shared experience, sometimes described as playing "together" despite a competitive gameplay, using the aforementioned notion of "offence and defense" in our design. Furthermore, we wanted to support a physicality that people would clearly associate with a player's physical skills. We subscribe to the view by Vossen [23] who describes the difference between physically moving chess pieces and physically hitting a tennis ball by explaining that both players could be instructed over the telephone how to perform their particular move, however, in the chess example the person on the remote end would be considered the player, in the tennis example, the local performer would be considered the player, the remote person a coach.

Breakout for Two [5] has demonstrated that a physical leisure activity (kicking a soccer ball) can be enjoyed by two geographically distant participants. Evaluation showed that the physical activity is superior in promoting a social bond between the players compared to a similar mouse-keyboard interaction. Ishii et al. have already used a table tennis table, paddle and ball in their early (1999) work on "computer supported collaborative play" and an "athletic-tangible interface" [2]. We draw on these approaches by enabling the players to use recognizable equipment and physical skills, which we believe is advantageous to a mouse-keyboard interaction for three reasons: a) Users might be already familiar with the artifacts, making adoption easy and hopefully engagement immediate. b) Artifacts such as balls and physical gaming skills have been successfully used for social leisure for many years across the world. The sheer usage of these artifacts might contribute to a social experience, either through the familiar handling or through their physicality. c) Using physical body interactions that support exertion can provide a superior connectedness experience than a non-exertion interface [5].

In order to support distributed participants, we adopted the gaming idea from *Breakout for Two* [5], which uses virtual shared targets to simulate a shared goal experience for the distributed players. However, we are interested in the experience beyond the two-player support of this game, Ishii's game [2] and others (see related work), and therefore created our game to be playable by three players, in three locations, to demonstrate the potential of this concept for novel gaming experiences enabled through the networking aspect. We can envision adding more players, however, we consider the current approach an important step to begin to understand the relationships between multiple geographically distant participants if provided with a physical leisure activity.

4. RELATED WORK

Industry and research have recently increasingly investigated the convergence of computing technology and leisure gaming activities. Related work derived lately from a sports perspective, and the term *Computer Supported Cooperative Sports* [7] has been coined. Not many systems, however, support distributed physical activities along with a communication channel between the participants, for example *Long-Distance Sports* are described by Marriott [24], but the author focuses on commercial products that have limited capability in terms of distributed interaction. Mueller et al. [5] coined *Sports over a Distance*, based on the concept of *Exertion Interfaces*, which were surveyed by Bragt [40].

Most advanced prototypes exist in research labs; however, they often lack the notion of "offense and defense" or do not provide a communication channel for social interaction between the participants, and rarely support more than two locations. For example, *Telephonic Arm Wrestling* is a networked arm wrestling machine [25]; there exists several instances installed in museums that include a videoconference to arm-wrestle another visitor over the distance, however, only two can wrestle at the same time [26].

Dance Dance Revolution Ultramix [27] is a home version of the popular exertion arcade game, in which the players follow dance instructions on the screen with their feet on touch sensitive tiles. It can be very exhausting, but also quite social, drawing large crowds when good dancers "enter the stage", however, only two players can dance at a time. The console game market shows a trend towards full body movement as input device for leisure purposes: *Dancing Stage Fusion* [28] was the first game that combined the use of the dance mat with a webcam, demanding more sweat from the players by making them dance with their feet

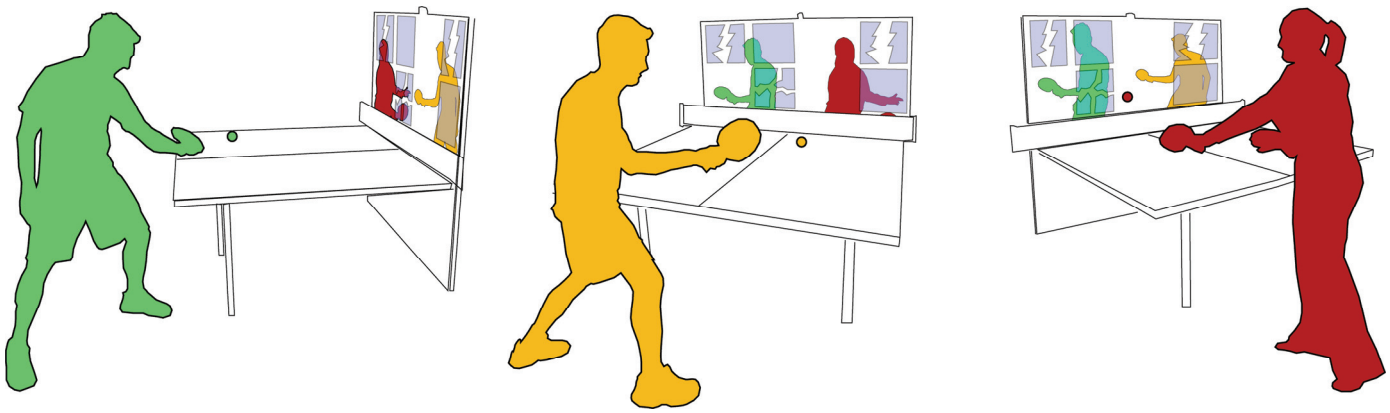

Figure 2. The blocks are shared across the stations, a hit is visible to all players.

and hands alike. The *Bodypad* [29] also supports larger body movements as input control through pressure sensors on the hands and legs, replacing button presses in console games. Two players can fight each others' avatars, but only in front of the same screen. Nintendo with the introduction of their *Wii* console has made a step towards body movement and away from traditional button presses: in order to hit the virtual tennis ball, the player uses the controller like a racquet; however, it does not support inclusion of a videoconference as yet [17]. Three players can play ping pong with *TriPong* [18], but they need to be on the same table.

NetGym [30] supports physical activity between geographically distant participants: two separated exercise bicycles are networked and the cyclist cycles with an avatar representing the remote user. The *Virtual Fitness Center* [31] uses a similar approach: the physical movements conducted are used as input to modify the representation of 3D virtual environments from map information. Reversely, the map information affects the pedaling efforts. *Fitcentric* [16] offers a similar commercial product, but without video or audio support.

Airhockey over a Distance [32] is an airhockey game that is playable by players in different locations: it uses a physical puck that is shot out at the remote end by puck cannons whenever the player hits the puck across the middle line. The physical game object can exist only on one table at a time to create a shared physical experience; however, it is only playable by two people simultaneously.

Push'N'Pull is a networked exercise machine, which the players use as interface for a cooperative game, augmented with a high-definition videoconference [7], but supports only two simultaneous users. *Virtual Tug-of-War* [8] is a group physical activity in which two teams of high-school students were involved in a tug-of-war 13 miles apart from each other; however there was no communication channel. *Jogging the Distance* [9] uses a spatialized audio channel to play back the remote jogger's audio relative to their running speed in order to create a "jogging together experience". This example supports a communication channel between the participants; however, it is limited to two locations. A game that supports videoconferencing for multiple players was demonstrated by Faust [33]: Players use wooden batons augmented with vibration elements to control a bouncing ball on the screen.

Several researchers have built virtual reality [3][41] and augmented reality versions [1][12] of table tennis. However, they either lack force feedback of the ball hitting the paddle, or are not playable by distributed participants. Our approach does not require the players to wear any technology, because we believe wearing devices such as head-mounted displays might negatively affect the social interaction between the players. We wanted to support a simple "show up, grab a paddle, and play" approach, which we believe is conducive to social interaction and enjoyment.

Some researchers have started investigating theoretical frameworks for movement-based interactions: Benford et al. [34] created a framework for sensible and sensable systems, and Bellotti et al. [35] provides another framework for physical interaction. Larssen et al. [36] tested both frameworks against two Eyetoy games, but does not come to a conclusion which framework is more suitable. Dourish [37] developed foundations of embodied interactions; however, he is more concerned with any type of tangible interface rather than focusing on physical exertion networked play.

5. TABLE TENNIS FOR THREE

Our current prototype can be played from three geographically distant locations, and although it has different rules than table tennis, the use of a table tennis table, a paddle and ball inspired us to name it *Table Tennis for Three.* It provides a health benefit by encouraging physical activity and training reflexes as well as hand-eye coordination. The gameplay is based on the successful elements of *Breakout for Two* [5], but we developed enhanced rules that allow for support of three locations. Just like table tennis, we believe our game is easy to learn and supports a sense of achievement quickly. Through the inclusion of a videoconference, we aim to support similar benefits known from traditional physical leisure activities such as exercise, enjoyment and bringing people together to socialize.

The main advantages of *Table Tennis for Three* are that it is built out of off-the-shelf components, and in contrast to *Breakout for Two,* it requires much less floor space: half a table tennis table plus room for the player to move around. Furthermore, we

provide evidence that the concept can support at least three stations simultaneously for minimal extra cost. These advantages make the system easily replicable for other researchers. We are planning on releasing instructions on how to set up a table to invite others to build their own stations in order to investigate how many players can play at the same time and still have fun. However, *Table Tennis for Three* is not aimed to replace traditional table tennis, but rather be the "next best thing" if the participants cannot be in the same location together.

6. GAMEPLAY

Each player has a paddle and a ball and steps up to the table. The table is set up so that the ball can be hit against the vertically positioned opposite half of the table [Figure 1]. This setup is familiar to table tennis players who practice on their own by playing the ball against the board. The vertical part of the table is painted white to also serve as projection surface for a videoconference of the other two players. Projected on top of the videoconference are eight semi-transparent targets that players have to hit with their ball. These targets, or blocks, "break" when hit by the players. The blocks are synchronized across the three tables, so the other players see the same block layout and the same block states [Figure 2]. If a block is hit once, it cracks a little. If it is hit again (regardless by which player), it cracks more [Figure 3]. If hit three times, it breaks and disappears, revealing the underlying videoconference completely: the player broke through to the remote players. However, only the player who hits the block the third and final time makes it disappear and receives the point. This adds an element of strategy to the game: a player can try to snatch away points by hitting blocks that have already been hit twice by the other player. Each broken block scores one point, and once all blocks are cleared, the player with the most points wins the game [Figure 4].

Figure 3. Shared virtual targets are overlaid on top of the videoconference.

7. IMPACT

With *Table Tennis for Three*, we want to give people the opportunity to create and maintain their social bonds with others who are far away. We believe the physicality of the table tennis game contributes to the social interaction, facilitating a better sense of rapport than a traditional mouse-keyboard interaction. We have provided evidence for this claim in prior work [5]. With our current prototype, we want to demonstrate that our concept not only allows for enjoyable games, but can also offer novel experiences that are untypical in traditional settings, such as engaging three players in three locations. We would like to encourage designers to develop more stations to explore what other experiences are possible in such an augmented environment. We also like to see a shift in thinking of what social purpose networked computer games can achieve: Massively Multiplayer Online Games (MMOGs) that are designed with interaction in mind could be one application. We also would like to challenge the conventional virtual reality thinking behind force feedback; it does not always require expensive equipment to provide a realistic force feedback experience.

We believe computer game interaction paradigms explored by devices such as the *EyeToy* and *Wii* will increase in popularity due to their social support for additional players, but also their appeal to local audience members, and we would like to encourage their designers to include video and audio support for networked play. Furthermore, we would like to promote an approach without expensive fragile technology, but rather traditional equipment such as balls and racquets. Advances in this direction might result in support for a wider range of leisure activities, and might also include more contact or team sport games. This could even lead to sports competitions between teams in different countries: Olympics over a distance!

Figure 4. Table Tennis for Three is a competitive game.

8. TECHNICAL IMPLEMENTATION

Each station has a *Table Tennis for Three* table and a Windows computer. They are connected via a TCP/IP network. The tables are standard table tennis tables, and all equipment is available off-the-shelf, which makes rebuilding easy.

8.1 Videoconferencing

The videoconferencing implementation is deliberately kept independent from the technical gameplay component in order to provide an optimal videoconference experience. Developing a videoconferencing system is not a trivial task, and many open-source and commercial systems claim to offer the best compromise between bandwidth limitations and image and audio quality. These software (some of them are hardware) implementations balance the most effective compression codecs

with en- and decoding CPU requirements, deal with varying network throughputs, provide circumventions for firewall issues, and minimize acoustic noise- and echo effects. In order to utilize the always latest advances in videoconferencing technology, we implemented the *Table Tennis for Three* gameplay independently and placed the application window on top of the videoconference program as a separate half-transparent layer. This ensures that any researcher who wants to recreate the system can take advantage of their existing videoconferencing infrastructure and is not locked into a proprietary system that might be outdated quickly. For our implementation, we used *ConferenceXP* [38], which provides support for multiple locations and offers high-resolution video transmissions in local area networks. The gameplay software is programmed with a transparent background, which allows the players to see the underlying videoconference, however, the hardware-acceleration of the graphics card needs to be turned off to allow for this transparency effect to work. We are not using any special graphical effects that require the hardware acceleration, and have not noticed any delay affecting the gameplay due to the deactivation.

In our current setup, we are using a videoconferencing resolution of 640x480 pixels with 25 frames per second to support the fast moving actions the players exhibit during game play. The images are captured by consumer webcams, equipped with wide-angle lenses and attached on top of the vertical half of the table tennis table. The camera is able to capture most of the action space participants engage in while hitting the ball, however, if the ball drops below the table, the player is out of view. We had considered mounting the camera through a hole in the middle of the vertical half of the table, however, the difference in perspective was marginal compared to the top position. This position was also more on eye level with most participants.

The audio is captured with the Bluetooth headsets which the players are wearing. We were experimenting with directional microphones, however, the impact noise of the table tennis ball was often captured on top of the players' voices. Furthermore, the nature of the game requires the players to move around intensively and talking when collecting balls behind the table or at the remote end of the room was hardly picked up by stationary microphones. We therefore decided to ask the users to wear a Bluetooth headset which presents a low-cost wireless transmission of audio for our purposes. Due to the fact that we only used the microphone functionality of the headset, the user could also wear the device on their shirt's collar, often preferred to the time-consuming adjustment and positioning to the ear. The audio-out is sent to speakers located under the table in order to allow spectators to hear and for us to observe (with a handheld video camera) what was being said during the evaluation. This setup however often created echo issues, with the microphone picking up the audio coming from the speakers. Several users commented on this, and a proposed alternative setup would be to route the audio through the headset to avoid this issue. We are aware that we compromised our initial goal to provide a non-technical approach for the user, similar to table tennis, where she or he can just show up, grab a paddle and start playing. Although we carefully trialed several models, we found no Bluetooth headset very suitable due to battery issues, inconvenient buttons, pairing issues after recharging with the PC and awkward fit to the ear.

8.2 Gameplay

The game of hitting the blocks and the accompanying score is implemented in Flash, which synchronizes its game state via a Flash media server. Flash provides a familiar visual development environment for Internet-based game developers, and hence our choice of framework should make developing additional games for our platform appealing for game designers. Each table acts as one client, which talks to the server that is responsible for distributing the latest block states and scores amongst the other clients. Our approach also supports uncertain networking conditions across various implementation conditions, because we are supporting an HTTP fallback mechanism in case ports are unavailable due to firewall restrictions. Although we have not tested our system across large distances, the aforementioned provisions of using external software packages that support varying network conditions make a public Internet-based implementation feasible.

8.3 Impact Detection Mechanism

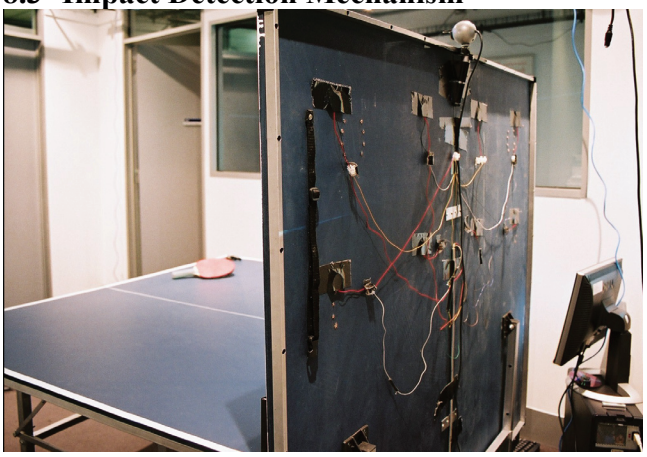

Figure 5. The sensors attached to the back.

In order to detect the impact point of the table tennis ball on the vertical part of the table, we experimented with high-speed vision detection cameras. However, the fast speeds a table tennis ball can reach [39] require a high shutter speed, which in turn profits from bright illumination of the area. Additional lighting affects the projection of the videoconference, so we decided against this approach, and chose an audio-based detection system. Eight piezoelectric sensors are attached to the rear of the backboard in locations corresponding to the gameplay blocks projected on the front of the backboard [Figure 5]. The sensors detect the sound vibrations in the wooden board created by the ball striking it. This approach is similar to the system described in [2], however, we were not able to achieve a highly accurate system with four sensors (which should cover the entire surface through interpolation), and therefore opted for the use of eight sensors. Preliminary tests revealed that it was very important for the players that all of their hits were properly counted by the system, and we consequently focused on a reliable, accurate detection.

The one sensor that receives the vibration signal first, exceeding a certain threshold, determines the location of the impact. After an A/D conversion and data acquisition with 25 kHz into a PC, software concludes which of the bricks should be cracked, and sends it to the game engine. We can report results of a simplified

test which showed that over 95% of hits were detected, and the location was identified correctly over 90% of these hits.

8.4 Network Delay

Due to the separation of videoconferencing component and gameplay engine, we are able to update the videoconferencing software if any technological advances become available. Any networking delay is therefore determined by the quality of the implementation of the videoconferencing component and the condition of the network. The additional bandwidth required when game data is transmitted consists of a few bytes. Our gameplay approach of using the impact of the physical action – hitting the blocks- instead of transmitting the physical action itself, was chosen to minimize the effect of network delays. Players are focused on the ball and we found that the visual and auditory effect upon a successful strike occurred with reasonable immediacy within our LAN environment, however, we have yet to test it over a long-distance Internet connection.

9. PRELIMINARY EVALUATION

We are currently examining quantitative and qualitative data we gathered from 41 participants, who have played *Table Tennis for Three* for at least half an hour. Our work-in-progress analysis shows preliminary positive results, in particular that the players had "fun" and found the game engaging.

The evaluation using questionnaires and interviews indicated that the participants enjoyed playing the game and they could see such an exertion network game being helpful in facilitating rapport between people who are physically apart but want to stay in touch. In particular, they expressed a strong sense of "playing together" and commented on the fact that it "gave them something to talk about". The affordance of the physicality of the game allowed participants to quickly engage and interact, and most players reported that they had fun, considered it a workout, forgot the world around them when playing, and wanted to play again. Our work provided further evidence that exertion can contribute to a sense of social bond between geographically distant players. Designers of similar games might particularly be interested in knowing that our participants liked to practice their skills beforehand, possibly informing their design choices. However, at least two participants reported on a negative experience and one called it "annoying". Both players mentioned they had trouble understanding the other players over the limited VoIP audio channel, which was probably one factor that affected their experience. Further analysis should shed light on this, and ultimately might result in design recommendations for future physical games between multiple locations.

10. FUTURE WORK

Having utilized various technologies and techniques to allow for running *Table Tennis for Three* over a public Internet connection, we can now test the system from three geographically disperse locations. Evaluation of the user experience will show if the game can establish a sense of connectedness between players who have never met before the game and possibly never will in the future.

An additional aspect we are currently investigating is the support of multiple local players. However, how does the interaction between the players change if you swap the team-partners: the player next to you is no longer your teammate, but opponent, and the remote person becomes your teammate?

We are also currently working on creating a conceptual framework out of the results that encompasses the geographical distance, the gameplay, the physical activity and the social interaction in order to further understand the interrelationships between these components and to provide guidelines for future instances of networked exertion games.

11. CONCLUSION

Table Tennis for Three aims to combine the advantages of networked computer games (supporting multiple geographically distant players) with the advantages of traditional physical leisure games (providing a social and health benefit). We presented a gaming system that is oriented on traditional table tennis, and showed its potential for novel gaming experiences through augmentation of a networking component. *Table Tennis for Three* uses an acoustic-based detection system to determine the ball's impact, and combines gameplay with a videoconferencing component in order to support social interactions between geographically distant participants. Players who played the game reported that they had fun and wanted to play again. Several players said that the game created a sense of social rapport, and that they were excited about being able to play together over a distance, which gave them "something to talk about". This adds support to the claim that physical activity can be beneficial to social interaction. However, we had at least two participants who did not enjoy the game. We propose that, similar to sports in general, networked exertion games are not for everybody, but the people who enjoy the competitive full-body interaction can benefit from a health and social aspect. We believe the physical activity with a real ball and table can add to the experience of playing a casual game together, although being apart. Further demonstrations of *Table Tennis for Three* might provide insights that can aid designers of future distributed physical games that aim to support social interactions.

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