Sports over a Distance

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Abstract

Sport is a domain full of movement-based interactions. These interactions typically have positive health effects as well as an impact on social bonding. We have investigated ways in which computer augmented devices can lead to new sport experiences and explored opportunities to combine physical activities with remote social bonding. Three prototypes have been implemented which showcase movement-based interaction in sports. "Breakout for Two" allows non-collocated users to play a physically exhausting ball game together. "FlyGuy" gives users a hang-glide experience controllable through body movement. "Push'N'Pull" uses isometric exercise equipment over a network to encourage users to complete a cooperative game whilst performing intense muscular actions. A comparison of these applications shows that such movement-based interaction in a networked environment allows players in different locations to achieve a work-out and also to socialize. Based on these projects, we conclude with practical design implications for future Exertion Interfaces.

Introduction

A Scenario

Coming home late from work, the only thing that keeps Jane's spirits up is her scheduled weekly meeting at the sports club with her friend Sarah. Upon entering the gym, Jane greets Sarah and their other friends and they start a competitive, but fun, 5-set match of tennis. They have been doing this for years, and as much as she and Sarah enjoy the workout, they also enjoy catching up on what is happening in each other's lives. It is a routine interaction for both of them, but from on onlooker's perspective, the scene is quite novel. Jane and her tennis partner Sarah are not in the same room. In fact, they are not even in the same city. The visual and audio interaction is all through a networked environment: a high quality videoconference allows each to see and hear the other at all times; large mechanical devices ensure that the ball's speed, spin and direction are detected, transferred over the network, and applied to the ball on the remote side. For Jane, the physical experience of playing tennis with her friend is just as if she was on the other side of the net, when in fact she is on the other side of the world. The technology of this remote sports experience allows her to continue having weekly matches with Sarah, even after relocating a few years ago. The physical distance has not created a social distance between them.

This scenario entails the many benefits of movement-based interaction in the domain of sport: an interaction which can help one to meet new people, support staying in touch with old friends and family, provide health benefits, and maintain an active social life. We believe that new sport devices grounded on concepts of movement-based interaction and allowing for the unique opportunity to connect with others from a distance could be a great benefit to society.

Social Benefits of Sports

People enjoy social contact, but unfortunately in modern society, they increasingly lack opportunities to interact [1]. Often, possible participants of an activity are miles apart and thus refrain from getting together. Networked computer games strive to bridge the physical distances between people, but fall short in two areas: they are criticized for isolating players [2], limiting physical interaction to button presses on mouses, keyboards and game pads.

Physically exerting activities can be helpful in facilitating social interaction for both men and women of all ages. Sports clubs, for example, not only function as places to exercise, but as social spaces [3]. Team sports assist the making and sustaining of friendships and are encouraged for their character-building benefits. When moving to a new town, one is often recommended to join a sports club to meet others. International sporting events demonstrate sports' ability to overcome language, cultural and racial barriers. With 240 million people in more than 200 countries playing soccer (football) regularly [4], nearly 1.5 billion viewers tuned in to watch the World Cup games in 2002 [5]. The United Nations recognizes the humanitarian benefit of sport through their agenda on "Sport for peace and development: building a peaceful and better world through sport and the Olympic ideal" [6]. Almost every country in the world followed the call to the Athens Olympics 2004: 202 countries participated [7].

Physical activity not only encourages social interaction and fosters friendships, it can improve one's overall well-being and quality of life [8]. However, with current sports, participants have to be in the same physical location. We are inspired by the power of traditional physical activity supporting social bonding, and have been working on augmenting it with the ability of networked game technology to connect people over a distance.

Exertion Interfaces and Computer Supported Collaborative Sports

The authors have simultaneously, but independently, worked on interfaces that combine physical exertion with networking technologies centered on the concept of play. Here we describe our designs, report on experiences and present commonalities and differences in our approaches. We also elaborate on conceptual frameworks and present opinions on how to design future successful movement-based interaction games.

Computer Supported Collaborative Sports

"Computer Supported Collaborative Sports" (CSCS) is an exploration into the design of computer applications which require sport-like input activities to achieve collective game experiences, mainly executed over a distance [9]. If the sports game is played by parties that are physically apart, most commonly through the use of network technology, we use the term "Sports over a Distance" [14]. Ishii et al. [10] have already extended the CSCW (Computer Supported Collaborative Work) conceptual framework to include fun and play, in contrast to work, and use the term "Computer Supported Cooperative Play" (CSCP). Wadley et al. in their use of CSCP include conventional computer-game entertainment [11]. CSCP is similar to CSCS, especially in that both provide for social interaction. However, while sport is a type of play, not all play is defined as sport. Hence, CSCP and CSCS can be quite different. Sport can be defined as "organized play that is accompanied by physical exertion" [12], and while conventional computer-game interfaces may be able to support some forms of networked play, most of these interfaces cannot support the extent of physical interaction needed in order to provide for the benefits of sport in a CSCS environment. Interfaces allowing for a range of physical interaction similar to traditional sports are needed in order for CSCS to exist.

Exertion Interface

An "Exertion Interface" is defined as an interface that deliberately requires intense physical effort [13]. Exertion Interfaces can be expected to be physically exhausting when used for an extended period of time. Such interfaces have existed in traditional sports from the beginning; an example is the use of balls for kicking and throwing.

Exertion Interfaces are not suited for commonly used applications where traditional keyboard interfaces are more appropriate (e.g. word-processing and programming). However, in supporting social interactions, we believe Exertion Interfaces can be advantageous. The design concept of Exertion Interfaces moves in the opposite direction of most current interface design trends; although easy to learn, Exertion Interfaces' requirements of skill and strength are hard to master. By facilitating increased connectedness between remote participants [14], as research has shown, these interfaces are beneficial in social contexts. Exertion Interfaces are designed to support physical interaction and thus meet the requirements for interfaces needed in CSCS.

Sport and Competition

Sport often seems to imply competition amongst either individuals or teams. However, in some sports activities such as dancing and acrobatics, people aim for the feeling of being together in synchronized movement. We present examples that are centered on cooperation as well as competition.

Application Domains for CSCS

CSCS applications provide physical interaction and socialization between players, but, most uniquely, they allow for these types of interactions to happen between non-collocated players. With the ability to connect remote players, we see several areas where CSCS applications could be beneficial, including the following:

- Distributed Offices
- Family Homes
- Schools

The benefits of physical activity have been acknowledged by the corporate world and used to foster bonding and team spirit within organizations. Team-building activities are used to introduce project members and teach valuable work and social skills which ideally transfer into the corporate workplace [15]. Multinational companies with distributed offices often have employees work together across different branches, and because of the distance between project members, may not be able to incorporate valuable team building exercises. While coordination of these projects can be done through emails and instant messages, project members may find it challenging to communicate with and trust their project teammates whom they have never met [16] [17]. Support for social interaction is generally limited. We see a great potential for CSCS applications to facilitate social communication in these distributed offices.

Family members separated by distance either because of far away jobs or personal decisions such as divorce or separation face the challenge of staying in touch with one another. With the implementation of CSCS devices in the home, family members would not only be able to communicate, but could have fun together as well.

CSCS applications have the potential of involving people from different parts of the world. Lessons such as learning a new language or culture could be facilitated by a valuable CSCS component in the classroom.

Design Challenges

Designing CSCS games is not as simple as taking an existing sport and applying it to a distributed setting; a few challenges do exist. One challenge is supporting physical interaction with not only the game pieces (such as a ball or a bat), but with possibly the other players as well. In games such as football, basketball, and hockey it is part of normal game-play to make body contact with other players. If these sports are to be implemented in a CSCS environment, force feedback from game pieces as well as players needs to be recreated, which can be quite difficult, especially with current technology. Not all sports require physical contact with other players. In tennis and volleyball, players are separated by a net, and play from opposite sides of the court. However, non-contact sports still pose the challenge of replicating the physical interaction with game pieces, such as in smashing and throwing a ball.

From our CSCS work, we present two recommendations to designing *Sports over a Distance* games that address these challenges:

1. Modify a sport interaction to involve just one game piece, such as a ball, that can only be at one place at one time. This may simplify the implementation into the networked domain by limiting simultaneous actions. Better yet, it could create a new sports game, as demonstrated in our *Breakout for Two* example.
2. Focus on providing a new sensation and experience by leveraging the technological opportunities that lie in a ubiquitous computing

environment. In our *FlyGuy* project, we took something that is not possible in the real world (flying), incorporated virtual and networking technologies, and provided participants with a unique experience.

Three Implementations of Sports over a Distance

We have built three prototypes that serve as demonstrators of CSCS using Exertion Interfaces. *Breakout for Two* was developed at Media Lab Europe in Ireland in the Human Connectedness Group and showcases an exertive ballgame that can be played over a distance. The *FlyGuy* is a collaborative project with partners from Germany, Japan, Mexico and the United States that focuses on providing a flying sensation requiring control through body movement, a sensation that cannot be easily experienced without a pervasive computing environment. *Push'N'Pull* has been designed by the CSIRO ICT Centre in Australia to see whether the use of greater physical activity results in a stronger feeling of interpersonal connectedness. All applications connect remote players via a network and encourage social interaction. We believe our work is just the beginning of new and exciting research into the CSCS domain.

Breakout for Two

Figure 1 Breakout for Two

Breakout for Two is a cross between soccer, tennis, and the classic computer game "Breakout", in which the player tries to break through a wall of bricks [18]

(Figure 1). The players, who can be miles apart from each other, both throw or kick a ball against a local, physical wall. On each wall is a projection of the remote player, enabling the participants to interact with each other through a life-sized video and audio connection (Figure 2).

Figure 2 Setup on each side

The two players can talk and see each other at all times. For the players, it feels like they are separated by a glass window that splits the two parts of the field (Figure 4).

Figure 4 Framework of the two sites

The players kick or throw the ball in the direction of the other player, but it comes back, bouncing off the wall. Eight semi-transparent blocks are overlaid on the video stream, which each player has to strike in order to score (Figure 6).

Figure 6 Semi-transparent blocks overlaying the video

These virtual blocks are connected over the network, meaning they are shared between the locations. If one of the two players strikes any of them once, they "crack". If that block is hit again, it cracks more. On the third hit, the block "breaks" and disappears. This analogy was chosen to portray the idea of "breaking through" to the other person on the remote end. The player only receives a point if the block breaks. This scoring theme creates an entertaining and interesting game because the players can watch what the other player is doing, waiting for her/him to hit a block for the second time, so they can then snatch the point by hitting it for the third and final time. To avoid a purely tactical game and encourage intense physical activity, an impact-intensity measurement component was added. If the player hits the block hard, it would automatically crack twice. A really hard strike would break the block completely in one go. For this, the impact intensity was measured and mapped onto a three-point scale. The harder the player hits a block, the more it cracks. For a description of the technical implementation, see [14].

Evaluation

We were interested in the feedback from players, and therefore recruited 56 participants from youth hostels, local universities and private contacts for a game session (average age 26) [19]. They were split up into teams of two, and were either asked to play *Breakout for Two* or an analogous computer game controlled with a keyboard, which was utilizing the same life-size videoconference. The two players were in two separate locations and had not previously met each other; in fact, their first interaction was through the videoconference.

Questionnaire

After the participants played the game, they were presented with a questionnaire, containing 60 items. It was designed to gain insight into how well the participants got to know one another and how the system could be improved. The questions were to be answered on a Likert-scale from 1 to 5, ranging from "strongly agree" to "strongly disagree".

Results

Statistically significant results of the questionnaire showed that the exertion-game players rated the interaction with their new game-partner higher in contrast to the keyboard players: they said they got to know the other player better, had more fun, became better friends, and, surprisingly, were happier with the transmitted audio and video quality, although the quality was identical between the two games (using t-tests, two-sample and assuming equal variances, $p<0.05$).
One participant mentioned he would like to see such a game in a bar, allowing him to play with friends who could not be there. Almost all the players in the exertion group were very exhausted after the game. Most of them said that it was much more exhausting than they thought it would be. Indeed, the game can be very demanding and fatiguing. Some players were getting so involved that they were seriously out of breath and their shirts heavily sweaty. We had to put a water-cooler close by, because we got concerned that some participants might become dehydrated.

In addition to what we reported in [14], we have further analyzed the videotapes of the players' interviews after the game, when they met for the first time and were interviewed together. We were interested in seeing if the increased bonding between the participants, which was self-assessed, was also visible to outside viewers. When people communicate, they not only use words, but also body language and facial expressions [20]. We believed that this display of affection would be visible in the interviews conducted with the participants after they played the game, and we expected to see similar results to the self-assessment: that the pairs who played the exertion game would show a closer bond throughout the interview than those who participated in the non-exertion game. In the videos of the interviews with the two players, we observed differences between the exertion and non-exertion groups in the way participants talked to each other and answered the questions. We observed that participants in the exertion group talked more freely with one another, seemed more at ease with the experiment situation, laughed together more often and answered the questions together, whereas in the non-exertion group, participants followed a more turn-taking approach.

To verify the objectivity of this finding, seven volunteers were asked to watch the interviews on videotape and rank them in order of how well the interviewees seemed to know each other or were familiar with each other. These volunteers did not participate in the previous experiment, nor did they have any knowledge about it or its scope. Eleven videos were randomly selected from the pool of interviews, six from the exertion, and five from the non-exertion group. These videos were edited and obvious comments of the interviewees that could lead to determining their relationships were edited out, such as “because I don’t know you”, or “if we had met before”. The editing was performed as objectively as possible; however, we are aware that the shortening of the footage could have influenced the results. The participants watched the videos on a computer in broadcast format with a standard software video player, with which all of them were familiar. The independent observers were asked to rank the eleven pieces of footage in terms of how much they thought the people in the video knew each other, on a scale with labels from “know each other more” to “know each other less”. The observers needed to put the videos in an order on that scale, and no duplicates were allowed. The independent observers did not rank the videos consistently. However, when ranking the teams on the ‘team that seems to know each other best’ scale, the observers’ first choice was always a pair from the exertion group. Six out of the seven observers chose the same team, and the seventh observer put that particular team in second place. They all agreed that these two players knew each other well. When asked how they came to this conclusion, they explained that this team laughed together a lot, seemed to share the same sense of humor, showed a lot of eye-contact, and generally demonstrated how much they got along through body-language. All observers were surprised when we told them that this pair had only met for the first time just before the interview. The Exertion Interface seemed to have had an influence on this team’s behavior, facilitating the development of a bond between them so that it was detectable to outside observers. However, we are aware that the results for this experiment are too limited to draw further conclusions, but, in combination with our results from the questionnaires and the interviews, we conclude that Exertion Interfaces more strongly support inter-personal connectedness than the traditional keyboard interface.

Breakout for Two showed that if an interactive game requires intense physical activity, it can foster bonding better than a non-physical game. Based on this, we conclude the recommendation for future Exertion Interfaces to actively support social interactions between players and to allow for follow-up meetings of participants. Physical activity encourages social interaction and affects one's overall well-being, and *Breakout for Two* demonstrated that this can be possible over a distance.

FlyGuy

FlyGuy was designed to combine a collaborative, social environment with a unique physical experience: flying. We identified flying as an interesting sport activity with room for improvement since it could only be experienced in a simulated, computer augmented environment or through means of avionic devices such as hang gliders, which are not accessible by everyone.

The concept behind *FlyGuy* is simple: allow remote people to fly together in a shared, virtual environment. In this virtual space, each player has the opportunity to solve different flying tasks. They can meet other people and fly and exercise with them. The different *FlyGuy* devices are connected via a local network or the Internet. Whenever players fly close to each other in the virtual space, an audio channel is opened.

Our design concept immerses the user into a 3D virtual environment. The player controls a flight simulation through body motion. Beyond the question of how a person can immerse into this simulation, we primarily addressed the problem of how an Exertion Interface could create the physical feeling of flying (Figure 8, Figure 10).

Figure 8 Experimenting with early prototypes of the *FlyGuy*

Figure 10 User applying force to control flying motion (shown without head-mounted display)

Flight Control Concepts

Several concepts for flight navigation were developed. Our first idea was to direct the flight with bird-like wing movements, the second idea was to allow for diving actions (twisting and flipping the body, as well as moving arms and legs), and the last was to guide the flight through physical control of a steering rod, similar to hang-gliding.

Technical Implementation

In order to evaluate our ideas for flight control, we designed and built a prototype consisting of an aluminum frame and computer flight simulator. To use, a player climbs into a hanging aluminum frame, similar to a hang glider, and navigates an avatar in the flight simulator, which is perceived via a head-mounted display.

Some technical aspects, such as control of the avatar, were not implemented but were mediated by us. With this prototype, we were able to evaluate which of our flight control concepts provided an experience similar to flying and was intuitive to use.

First Evaluation

In order to evaluate the prototype and control concepts, we chose to conduct a Think Aloud [21] study that incorporated the Wizard of Oz method to assist with technical challenges. This combination of methods allowed us to quickly and easily obtain participant feedback.

Traditionally in a Wizard of Oz evaluation, a human actor, a hidden wizard, simulates the system's behavior by interpreting the user's input and creating a suitable output behavior [22]. We applied this main feature of the Wizard of Oz concept (Figure 12) but extended the method by introducing two additional wizards to meet the specific physical requirements of force feedback. The first wizard simulated visual feedback by translating the movements of the participant into corresponding commands to steer the avatar. The second wizard simulated the passive components to provide extra counter feedback during steering. The third wizard simulated toughing a fixed object or crashing into another player by pushing the participant when he/she collided in the virtual game (Figure 14).

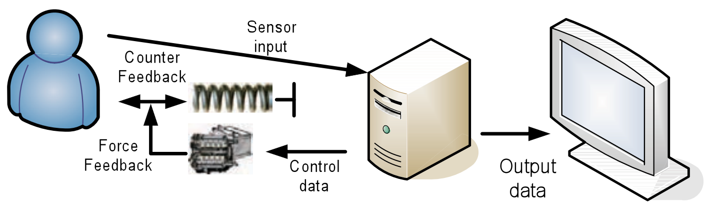

Figure 12 A hybrid counter and force-feedback architecture for the Exertion Interface

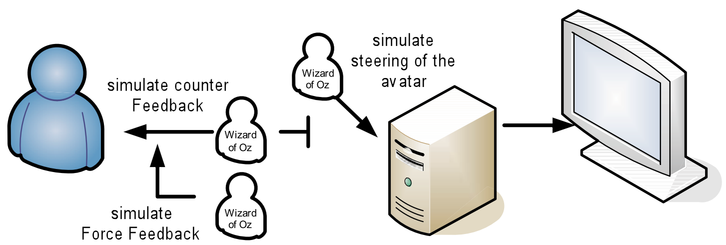

Figure 14 Wizard of Oz: Simulating the hybrid architecture for the Exertion Interface

In our initial evaluation, each participant experimented with the three tasks of controlling the avatar in the flight simulator while using one of our three control concepts: arm ‘wing’ movements, full body ‘dive’ movements, and by maneuvering a metal bar. During the evaluation, in Think Aloud fashion, participants stated where she/he wanted to fly and whether or not the flight control was intuitive. In addition, users described how they physically felt while completing the task. Afterwards, we interviewed the participants on their overall impression of the system and asked them to assess steering solutions.

Results of the evaluation were somewhat surprising; they showed that the participant expected and desired force feedback as they flew. We had predicted that the bird-like motion of flapping one’s arms would result in a flying sensation; however, participants commented that the bird-like control solely felt like signals to the avatar and did not give them the physical sensation of flying since, other than their moving arms, their bodies were stationary. Steering with the metal bar was an improvement- when the participants pushed the bar, the force caused their bodies to rock back and forth in a gliding motion. Our control concept of full body, dive-like movements was determined the best in that it created a more physical experience. As participants twisted around, flipped upside down, and moved both their legs and arms, gravity came into play as a desired counter force. Participants commented that the physical feelings from their actions made them believe like they were doing more than just controlling the avatar on the screen. However, there is room for improvement in this prototype, mainly in allowing for an easier way to change body-position. We observed participants grasping for something to assist them when moving.

Second Evaluation

In order to further determine whether a concept resulting in counter-action motion is successful in providing a desirable experience, we tested a fourth design idea. In this concept, we extended the use of a steering rod to consist of two handles to control flight path and a lever to control flight height. When holding onto the handles, the user changes their flight direction by rotating their torso and pushes or pulls the lever horizontally to change flight height. The effect is intensified by resistance for both concentric and eccentric movements (implemented with the help of the human wizards); thus it was possible to provide for extreme intensity between player and interface.

Although the two-handle-concept does not allow for free flight motions, the evaluation demonstrated some advantages in the design. We observed that this solution reduced the complexity of steering the avatar. After an initial phase where the human wizard misinterpreted the grabbing of handles and drove the avatar in the wrong direction, the interpretation of the grabbing activities became stable. Another positive aspect of this design is that the resistance felt during both concentric and eccentric movement provided an intense, physical experience. The handles were able to introduce an element of resistance feedback. In this case, the counter force wizard was helpful in providing a sufficient amount of resistance when the participant interacted with the handles. In this implementation, we found that the horizontal flight posture and the steering techniques were considered to be rather intuitive; however, the usage of a fixed and stiff lever to adjust flying height was regarded suboptimal because it did not match our participants' idea of graceful flight motions. Other aspects which need to be improved are the overly complicated process of positioning one's body into the device and the device's lacking adaptability for different user anthropometries.

In our evaluation, the Wizard of Oz method did not only provide valuable information whether a specific design approach worked in principle, but it also indicated how to build an algorithm to interpret the sensor data in order to offer a suitable steering experience. The main outcome from the evaluations was the importance for players to go beyond the feeling of simply controlling an avatar on a screen to more fully experience flight navigation in a virtual world. Feedback shows that in order to obtain a positive flying experience, a flying device needs to not only allow for physical actions but physical feedback as well. One way to provide this physical feedback is through a counter-force, such as gravity.

Push'N'Pull

Push'N'Pull was designed to evaluate whether different levels of physical exertion result in different feelings of connectedness, the intangible bond between human beings that contributes to both psychological and physical wellbeing [23]. The *Push'N'Pull* system requires two users supported by a high quality videoconferencing software to exert synchronized actions at varying physical intensity to complete a cooperative game (Figure 16).

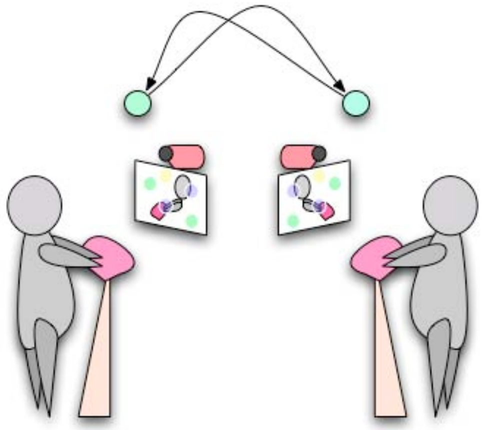

Figure 16 Concept Diagram of *Push'N'Pull*

Implementation

To play the game, the two players stand at a controller station that is connected to each other via an IP network. Each of these controller stations contains a "Power Grid" [24] exercise machine (a metal isometric device designed for exercising), a video camera and an LCD screen positioned at eye-level (Figure 18). The Power Grid is used as the controller of a cooperative game in which the two participants command a shared virtual object on the screen in front of them. The task is to use the shared object to chase and capture particles that have an avoidance behavior before time runs out. These particles are harder to catch if only one player engages, which is implemented to encourage the cooperation and communication of both parties to complete the task. If both players push and pull in the same direction, their combined applied force makes it easier to win the game. The LCD screen displays not only the game, but a real-time video of the other player, allowing the two players to visually and audibly communicate (Figure 20).

Figure 18 Setup of *Push'N'Pull*

Figure 20 The view of the player

Evaluation

The system was presented to an internal conference with about 200 people. Around 50 participants of the system were videotaped and comments were noted. This informal evaluation of the force-input device provided both constructive and supportive user feedback. The demonstration showed that the interface of the game needs to have few instructions, allowing the participants to easily interact. We were encouraged to see that players interacted with the device with a wide-range of forces. Some applied gentle pressure (Figure 22), others a steady force and yet others applied full-body movement into pulling and tugging the device (Figure 24). Participants communicated with their team-mate via multiple ways of communication, including hand gestures and facial expressions. Participants also expressed an expectation of haptic feedback, perhaps because of the physical aspect of the input.

Figure 22 Participant using gentle pressure

Figure 24 Participant using full body input

Design Lessons Learned

Comparison

We have compiled the major differences between our three applications in a table outline (Figure 26), and we draw design recommendations from that in the following paragraphs.

	Breakout for Two	***FlyGuy***	***Push'N'Pull***
Number of players	2 or 4	Unlimited	2
Exertive	Very	Fairly	Very
Shared environment between players	Yes	Yes	Yes
Playable across distances	Yes	Yes	Yes
Focus	Soccer-like interaction through virtual shared blocks, socialization	Flying sensation, socialization	Exercise and cooperation, socialization
Similar to	Soccer	Hang-gliding	Weights
Technology worn/operated by the user	None	Head-mounted display, body harness	Exercise equipment
Visual representation of other player	Life-size video-conference	Avatar	Screen-size video-conference
Audio connection	Constant	When near-by	Constant

Exertion Interface	Throwing and kicking a ball	Twisting body and pushing / pulling set of handles	Pushing and pulling bars

Figure 26 Comparison between *Breakout for Two*, *FlyGuy* and *Push'N'Pull*

Implications for Future Computer Supported Collaborative Sports

Our observations, formally and informally, revealed practical findings for future implementations, and some of them were rather unexpected. These outcomes form the basis for the following implications for the design of CSCS:

- Force Feedback
- Range of Movement
- Social Aspect

Force Feedback

If an application simulates a sport, it needs to be physical like a sport. Current attempts in force-feedback technology such as the use of vibration to indicate a hit, however, do not pay justice to the rich interaction of real and sometimes painful contact exhibited in sports. We partially credit the positive response to our three implementations of *Sports Over a Distance* to the force feedback each participant received during their interaction, which greatly enhanced his/her enjoyment. In order to provide effective and efficient force feedback, we reverted back to what has been used in many mechanical devices to balance a load: a counter force. Each application uses physical counter force to provide feedback to the player. *Breakout for Two* utilizes the natural feedback one receives by kicking a ball against a wall. The feedback is instant, forceful, and proportional to the strength of the player, all without complicated mechanical devices - just a simple wall. *FlyGuy* relies on the gravity of the player hanging in mid-air that: once the player is pulled in a horizontal direction to steer the flight, gravity pulls him/her back into the starting position. The player's own weight provides this physical feedback to the flight movements. In *Push N' Pull*, as the player pushes and pulls the game piece, the resistance of the device provides force feedback to the player.

Modern computing technology can be very fragile. We encountered that this preconception initially hindered volunteers to forcefully interact with our prototypes. They seemed to have a healthy fear of breaking our equipment, however, once demonstrated that fierce force could be applied, they were not shy of throwing their whole body weight in. We recommend reinforcing the equipment for robust use. Physical interfaces require strength, and common prototyping material may not withstand such force.

Range of Movement

Allowing the players to be creative in their movements is desirable. During our experiments, we were surprised of the novel ways of interacting and physically moving the players introduced. For example, in *Breakout for Two*, players decided to allow themselves to only throw the ball through their legs, which they greatly enjoyed. In *FlyGuy*, participants were happy to demonstrate interesting mid-air motions to simulate flying, such as twisting and flipping. In Push N' Pull, while the equipment was rather restrictive since it only allowed for pushing and pulling movements, players became more creative in the way they communicated with their partner in the forms of hand gestures and facial expressions.

While a balanced exercising component in an Exertion Interface can contribute to physical well-being, we observed that some participants became highly physical to the extent of undesired physical exhaustion. In *Breakout for Two,* some participants became so engaged that we were afraid they might get hurt from tripping or falling. Because players may be unaware that computer supported interfaces can provide extensive exercise, proper instructions should be provided in order to avoid injury.

Social Aspect

Social interactions are not only a by-product, but often the reason to exercise, which should be considered in the design process. Of important social aspect are breaks during physical activities. Whether it is a small break for catching breath, a pause for rethinking strategy, or the mutual review of the experience after the game: these are the main opportunities for social interaction and form an essential part of the experience. Our implementations allowed for these social breaks by having an always-on videoconference. In our evaluation of Breakout for Two, people outside the experiment who were casually walking past asked if they could play the game. We left the project up and running for an extra hour, which was greatly appreciated by those occupying the building. In our evaluation of *Push N' Pull*, the always-on system made it possible for the conference attendees to easily engage in a game. We recommend designing systems that allow for casual games to be initiated by everyone, which might facilitate social contact between people who otherwise might never meet.

Interestingly, perceived audio and video quality of Exertion Interfaces depends on the experience. In *Breakout for Two*, participants who played the version with the Exertion Interface ranked the quality of the video conference significantly higher than the ranking given to the same video conference in the non-exertive game. The audio quality, however, needs to be sufficient for conversational speech.

Future Work

An apparent extension of *Breakout for Two* is to support multiple courts, extending the current approach of team sports by allowing several distributed players (or even teams) to play with each other (Figure 28).

Figure 28 Multiple game stations

An interesting avenue for research would be to investigate how supporting remote teams differs from supporting local teams. Imagine playing a game with your teammate situated far away, perhaps in a different country, while your opponent plays right next to you (Figure 30).

Figure 30 Remote teams

Our next step with *Push'N'Pull* is to conduct a more formal analysis of participants' various interaction techniques to discover if our initial question of whether or not the intensity of physical activity and remote interpersonal connectedness are positively correlated. We plan to conduct an experiment where the force-requirements vary during the experience. This adjustment of parameters will require participants to use varying amounts of physicality to interact with the game. Data from observations and questionnaires will be collected for analysis on the levels of connectedness participants felt towards each other after having used the Exertion Interface.

Ubiquitous Computing in Sports over a Distance

Ubiquitous computing helps bring the vision of *Sports over a Distance* into practice. The ubiquitous computing research community can learn from the sports discipline how to design systems that provide unique experiences that facilitate, maintain, and utilize social relationships between users. We have yet to design a personal sports interface that can be used in a mobile context, but we believe devices such as the *Handgrip* [25] could be a starting point for investigations. If the ubiquitous computing artifacts are networked, spanning from sensor networks to being components of a larger network, we can imagine an environment that supports a sports interaction between remote teams. Designing an enjoyable *Sports over a Distance* experience is a challenge that lies within this community.

Related Work

There are quite a few past projects that present physical computer interfaces to provide new ways of interacting with computers through real objects and spaces. However, most fall short in terms of social interaction, or require the co-player to be present in the same physical location and do not support the creation of teams, which are unique aspects to our projects. The following gives a brief description of related work.

Dance Dance Revolution is a physical dance game, which can be played in teams of two. The players step on lighted platforms in time with the music as they try to match the dancing instructions on the screen. Both players have to be in the same physical location. However, a new home version [26] released for Playstation 2 offers not only online support, but utilizes the vision-tracking features of *EyeToy* [27], which reinforces interacting with the hands [28]. Research has been investigating the applicability of two different frameworks ([29] and [30]) regarding the interaction that the Eyetoy affords [31].

Virtual Arena [32] is a multi-player arcade game, where the body movements of players are tracked and mapped onto fighting avatars so players are able to hit one another without getting hurt. Two players stand next to each other, looking at a screen with their avatars in front of them. Although there is currently only support for local play, it seems plausible that this system could easily be expanded to work across remote locations. The social aspect of such a game, where the aim is to knock the other player unconscious, however, is questionable.

AirKanoid is a networked version of the arcade classic *Arkanoid*, however, players do not control their bats with a joystick, but with a physical wand, tracked via a vision-based camera. The inventors conducted tests with 2 and 4 players; in the 4-player game, two players shared the same physical space. Their study revealed that the physical proximity of fellow players is important, and has a positive effect on the game experience [33]. An arcade soccer game is *Kick and*

Kick [34], where one kicks a real ball on a screen. Sensors in the frame detect the trajectory, while the plastic screen measures the velocity of the shot. Due to its limited size, it supports practicing penalty shots or corner kicks rather than replicating the soccer experience of running around with teammates.

KiRo [35] is a robotic foosball table, where robotic arms control one set of handlebars, replacing the other player. Such a system could be extended to allow playing over a distance: two coupled versions of the table would be networked, and the sensors on the human player's handles could measure the movements and transmit them as input for a distant robot.

Telephonic Arm Wrestling [36] is an early attempt at a networked sport, in which the player arm-wrestles the opponent over a phone line. *Virtual Tug-of-War* [37] 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. *Snowwars* [38] is a networked physical game, which simulates a snowball fight using virtual reality technology and guns that shoot tennis balls at the remote player. *Virtual Hang-gliding* [39] is a virtual reality hang-glider simulation, which only supports single players.

The *Virtual Fitness Center* (Virku) uses physical movements conducted on exercise bicycles as input to modify the representation of a 3D virtual environment from map information. Reversely, the map information affects the pedaling efforts [40]. Similar commercial products exist: a fitness training program called *NetAthlon* from *FitCentric Technologies* [41] offers competitive racing from seats of exercise bicycles connected by a digital network. *Sportwall International Technologies* [42] offers sports training equipment that incorporates digital sensors and microprocessors into walls and mounted targets to help tennis players improve their game; they are thinking of supporting long-distance versions [43].

Conclusion

Computer Supported Collaborative Sports (CSCS) with Exertion Interfaces support people connecting with one another, while simultaneously encouraging a healthy lifestyle, whether playing soccer together via a video-conference, flying together in a virtual environment or exercising cooperatively. Players can use the universal language of sport to connect with one another, and we described examples where this is possible with people situated on the other side of the world.

We demonstrated that movement-based interaction offers new opportunities for the design of CSCS. Movement-based techniques of interaction should be designed to be enjoyable and fun, to encourage physical activity, and to convey social bonding. Our prototypes show alternatives to conventional approaches of force feedback. While we have conducted some early evaluation studies, further investigations are needed to better understand the appropriation of these types of sport devices. For instance, it is an open question to how much the lack of transmitted body contact limits CSCS interactions.

On a methodological level, the Wizard of Oz evaluation method seems to be well suited to support the design of Exertion Interfaces. It allows gaining feedback in early phases of the design process. Moreover, it generated valuable ideas on how to build force-based input and output solutions. We have also shown the use of observations, questionnaires, interviews and video footage for evaluation, which resulted in evidence that Exertion Interfaces can support social bonding better than mouse and keyboard interfaces.

While we are just at the beginning of our exploration, we believe that research into embodied activities in the CSCS domain carries considerable potential. It opens up a new field of computer applications, and its concepts and technologies may lead to new paradigms in how people interact through body movement.

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