Designable Sports Field: Sport Design by a Human in Accordance with the Physical Status of the Player

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ABSTRACT
We present the Designable Sports Field (DSF), an environment where a "designer" designs a sports field in accordance with the physical intensity of the player. Sports motivate players to compete and interact with teammates. However, the rules are fixed; thus, people who lack experience or physical strength often do not enjoy playing. In addition, the levels of the players should preferably match. On the other hand, in coaching, a coach trains players according to their skills. However, to be a coach requires considerable experience and expertise. We present a DSF application system called SportComposer. In this system, the "designer" and "player," roles that can be assumed even by amateur players, participate in the sport to achieve different goals. The designer designs a sports field according to the physical status of the player, such as his/her heart rate, in real time. Thus, the player can play a physical game that matches his/her physical intensity. In experiments conducted under this environment, we tested the system with persons ranging from a small child to adults who are not expert in sports and confirmed that both the roles of the designer and the player are functional and enjoyable. We also report findings from a demonstration conducted with 92 participants in a public museum.

Author Keywords
Digital sports; collaborative; heart rate monitoring; exergames; level adjustment.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Physical sport is not only beneficial for physical health but also brings about feelings of mental satisfaction from communicating and interacting with other players. Competitive sports motivate players with the feeling of winning over their opponents. Collaborative sports also motivate players by giving encouragement and communicating with teammates. These social interactions with others are effective for motivating people to play sports and there are several studies that focus on sociality and motivation in sports [8,9,12,14]. However, playing sports with others is not always enjoyable. If the physical capacities of the players differ significantly, the game is not really fair. Further, a player may feel that he/she is a bother to teammates. These factors may reduce their motivation and prevent them from enjoying sports. To improve sports levels, training and proficiency above a certain level are required. Often, a handicap—such as giving a plus score if the team has female members or special rules for elderly people—is applied if player levels are different, although the handicap is not always appropriate for the physical ability of the players. Further, other players may feel that the handicap is unfair, and may thus become demotivated.

Figure 1: A child and his father experiencing the DSF system. The designer (father) designs the sport field according to the physical status of the player (child).

In contrast, "coaching" between a coach and a player is cooperative rather than competitive, and is motivating because a person directly coaches and he/she has sufficient knowledge about the physical activities. However, coaching requires significant amounts of experience and expertise and the purpose is to upgrade the player's skill in sports, which requires rigorous practice. Therefore, to become a coach or to be coached is arduous.

Physical sports also require space, equipment, and environment for each game, such as court and rackets for tennis or hurdles and track for a hurdle race. These days, exergaming systems such as Nintendo Wii and Microsoft Kinect have become popular. These systems enable people to play different kinds of physical games using small equipment such as gaming machines and controllers or sensors even in their homes. However, the game rules are already fixed, and communication among players is lacking compared with physical team games. In addition, the players can often set the levels of the game, but level adjustments are set according to the fixed algorithms of the game and not according to the physical level of the players.

To address these problems, we propose a different relationship among sports participants using the notion of "Designable Sports Field (DSF)." With this approach, both coach and player roles do not require experience and expertise; thus, anyone can design and play sports in this environment while maintaining an adequate physical level that is not overly easy or difficult. The main idea is to allow humans to adjust the sport level instead of computers, which maintains social communication. We explore whether a human can design adequate sport levels, and whether human design is more motivational than computer design.

In this paper, we describe the key features of DSF and introduce a pilot sport environment that applies DSF for verification (see Figure 1). In experiments conducted in this environment, we tested the system on persons, ranging from a small child to adults, who are not experts at sports. We also report on user experience at a science museum where over 100 visitors participated.

DSF

DSF is a sports environment in which participants can design a sport field according to the physical status of a player. In this paper, we define "sport" as a physical activity with a goal. It combines the elements of competitive sports and coaching, and a participant is not required to have any skills or expertise in sports. Table 1 compares various types of sports. Competitive and collaborative sports without digital technologies, such as tennis and basketball, involve a relationship among players, and preferably, the sports levels among the players are matched. Coaching consists of a relationship between the coach, who must have experience and expertise in coaching, and the players, who are required to endure rigorous training. It is difficult for anyone to play either role. DSF nurtures the relationship between the "designer" and the "player," with both roles playable by anyone without the need for special skills. In general, a "designer" is a person who designs plans or patterns for such things as clothes, architectures, and equipment. In this paper, a designer is a person who designs a sports field according to the physical status or movement of a player, e.g., to maintain the player's heart rate within an appropriate range. The role of the player is to play a physical game in the sports field designed by the designer.

Type	Relationship	Features
competitive / collaborative sports	player ⇄ player (compete / collaborate)	• fixed rules • matching levels preferable
coaching	(advice) coach ⇄ player (respond)	• skill & experience required
DSF	designer ⇄ player (collaborate)	• designable rules • no skill & experience required

Table 1: Comparison of DSF with other types of sports. DSF combines the elements of competitive sports and coaching, and a participant is not required to have any skills or expertise in sports.

Key factors

We describe three key factors to define DSF, which enable participants with different physical levels to enjoy physical activities.

1. Design in accordance with physical status

In DSF systems, the participants play the role of either designer or a player. The designer designs a sports field that fits the physical status of the player, for example, his/her heart rate or total distance covered, to be at a certain target level. On the other hand, the player plays the game in the sports field designed by the designer, which involves physical movement. Although both roles have different goals, the rules are defined for physical activities; thus, a player can play a game with appropriate physical intensity, which is neither very easy nor very hard. This enables players to play without worrying about their sporting levels.

2. Using human power

Instead of a computer, humans assume both designer and player roles. With the use of human power, participants can communicate with and are conscious of each other. As mentioned in the introduction, this social aspect is effective for engagement and motivation in sports. Further, human designers can recognize a player's status whereas a computer cannot. For example, whether the player looks tired, or when unexpected situations occur. In addition, the design patterns change in accordance with the relationship and situations such that playing patterns are likely to vary.

3. Simple and understandable rules

The rules and controls for both player and designer are simple and understandable. Despite this simplicity, a variety of movements can be designed so that player movements are not monotonous, preventing the participants from getting bored. The participants are also not required to have prior knowledge or experience of the game in order to

participate. These elements are especially effective for persons with little sports experience and those who think they are not good at sports.

APPLICATION SYSTEM: SPORTCOMPOSER

In this section, we demonstrate application of a DSF system called "SportComposer." In this system, two persons can participate, with each participant playing the role of either the designer or the player in the first half of the game and then exchanging roles in the second half.

DSF system configuration

Figure 2 shows the configuration of the SportComposer system. The system consists of a short-throw projector (RICOH PJ WX 4141), a depth camera (Kinect for Windows v2), a tablet PC (Surface Pro 3), a heart-rate sensor with built-in low-energy Bluetooth (Polar H7), and a smartphone (iPhone 5).

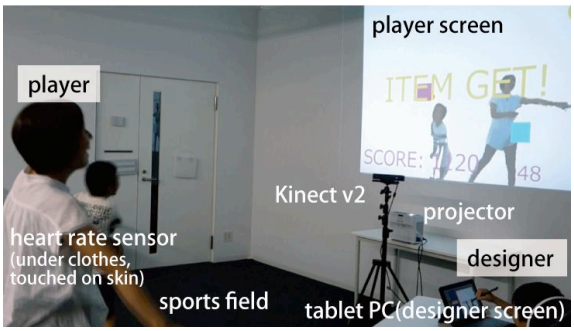

Figure 2: Configuration of the SportComposer DSF system.

Role of the Designer

The designer uses a tablet PC to design the sport field. Figure 3 shows the designer screen. The left part shows the real-time heart rate of the player, and the right part is called the "design canvas," where the designer designs the sport field. The canvas is synchronized to the screen projected in front of the player, except for the heart-rate monitor.

The goal of the designer is to maintain the heart rate of the player within a target heart-rate range. We use the Karvonen formula [5], which calculates the target heart rate as follows:

$$\text{Target HR} = ((\text{HRmax} - \text{HRresting}) \times \text{intensity}) + \text{HRresting}$$

The maximum heart rate is determined according to the age of the player [19]. The upper (Figure 3(a)) and lower (Figure 3(b)) bounds vary according to the age and heart rate of the player at rest. The pink-colored zone on the left (Figure 3(c)) shows the target heart-rate bounds. A heart-shaped icon moves up and down according to the real-time heart rate of the player (Figure 3(d)). When the heart rate is within the pink zone, the background color is green, and when it is outside the zone, the background color changes

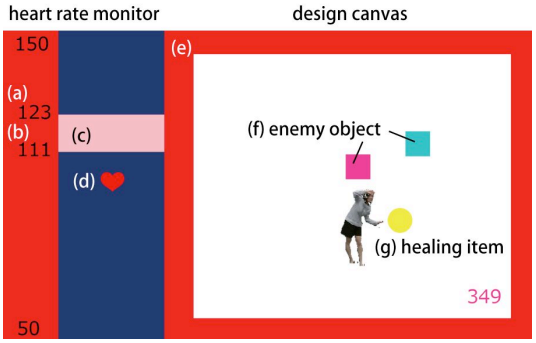

Figure 3: Designer's screen. The left part shows the player's heart rate in real time. The right part is the design canvas where the designer moves the enemy objects and creates healing items.

to red (Figure 3(e)). Thus, the designer can recognize whether the heart rate is within or outside the bounds without looking at the monitor.

To control the heart rate, the designer designs the sport field by controlling two types of objects on the canvas: the enemy object (Figure 3(f)), which has a square shape and reduces the player score; and the healing item (Figure 3(g)), which has a circular shape and increases the player score. Two enemy objects are placed on the field beforehand, and the designer moves the objects by swiping each object with a finger or pen. The swiped enemy object moves to the swiped direction. The designer stops them by tapping on the object and moves them again by swiping. The designer generates healing items by tapping on any place on the screen. The healing item disappears when the player gets it, and the number of healing objects that can be created has no limit.

Role of the player

The player wears a belt-type heart-rate sensor around his/her chest and moves around the sports field while watching the screen in front. A clipped image of the player and the objects designed by the designer are shown on the same field in the screen. The heart-rate monitor is not shown to the player's screen so that the player's movement is controlled not by the player himself/herself, but by the designer. The goal of the game is for the player to obtain as many points as possible. When an enemy object hits the player, a blast sound is played, and the player loses five points. When the player touches the healing item, a chime sounds, and the player gains five points. To escape from the enemy objects and get the healing items, the player moves from side to side, back and forth, jumps, or crawls under the objects (Figure 4).

RELATED WORK

In this section, we review previous sports and exergame systems categorized according to characteristics.

Figure 4: Player screen: (a) Jumping to get a healing item. (b) Jumping to avoid being hit by an enemy object. (c) Crawling to avoid being hit by an enemy object. (d) Stretching to get a healing item. (e) Moving back to avoid being hit by an enemy object. (f) Moving forward to get a healing item

Interactive systems using projection

One major pioneering work on projecting and interacting with a participant's body image is *Videoplace* [7], in which silhouettes of the users are projected on a screen to place them within an interactive environment. The users are motivated to make their movements and actions with the interaction. *HoloWall* [11] allows users to interact with a computerized wall using objects such as fingers and bodies. Following these early systems, many interactive systems with wall projections have been developed. Our system also uses a similar configuration, but we add designable features to motivate physical body motions by the participants.

Social and collaborative exercise systems

Exercising with another person motivates persons through conversation and interaction, which often leads people to participate in physical activities more regularly [3]. *Swan Boat* [1] is a social exergame designed for treadmill running, which is usually a solitary exercise. *"Collaborative Digital Sports"* [17] presents systems that encourage collaboration in sports by changing feedback according to the number of participants. Mueller et al. [13–15] presented social exertion games, games that require physical effort from users, in distant places. *RopePlus* [21] enables players to participate remotely by interacting with ropes that connect physical and virtual spaces.

Exergames according to physical status

People of different physical skill levels can demotivate players in exergames. Previous studies have shown that adjusting levels according to physical status to reduce the performance gap between people of different skill levels helps to motivate players. Heart rate monitoring is a popular method used to scale the physical status of players [2,10,16,18]. *Heart Burn* game [18] uses heart rate information to adjust the pedaling speed of a bicycle. These systems adjust levels by computer calculation. *"Jogging over a distance"* [13] uses heart rate monitoring to create an equitable and balanced experience between distance joggers. Our approach is to use a human to design the sports field according to the player's physical status.

Role-sharing exergames

Sharing the roles of players in exergames is another way of removing the gap between different skill levels. *Age Invaders* [6] is a social-physical game in which players can both attack opponents and join from remote locations. This enables players of different ages to play together. In the cooperative mode of the *Life is a Village* system [22], one player controls an avatar by pedaling a bicycle and another player defends against snowballs thrown by enemies using the Wii Remote. Our system also shares roles with a different approach, the role of "designer" who designs the sports field according to his/her partner's physical status.

Coaching systems

Swimoid [20] allows coaches on the poolside to give instructions to swimmers using an underwater buddy robot. *Flying Eyes* [4] uses an aerial vehicle to capture athletes, which allows the user to see himself from a third person's view and check his form and movements in real time using a head mounted display. These systems are valid for coaches and players who have experience and knowledge. However, it is difficult for amateurs to judge whether their form is right or wrong. Our system aims to enable even amateurs to both play and design sports without practicing.

EVALUATION

We conducted an evaluation using the SportComposer system. Our aims in this evaluation were as follows:

1. Determine whether both designer and player enjoy playing
2. Verify whether the designer can design a sport field in accordance with heart rate
3. Observe the movements of the player, and how participants communicate

Participants

We recruited five pairs of participants, for a total of 10 participants, who were not expert in sports or coaching. Two pairs were parents and children: one pair was a nine-year old girl and her father, and the other pair was an eight-year old boy and his father. The relationship of the

remaining three pairs was friends, and they were all in their twenties. All the participants were playing in the system for the first time.

Experimental method

We employed the same game rules as those explained in the previous section. The designer designed a sport field according to the exercise intensity calculated on the basis of the heart rate of the player. The playing time was three minutes. The lower and upper bounds of the exercise intensity were 30% and 40%, respectively. We set the intensity within a narrow range in order to observe the designer's actions.

Each participant participated in the experiment by changing his/her roles. We provided a tutorial on how to play by demonstrating both roles. Further, we asked the participants to answer a questionnaire after each experiment and conducted interviews after all experiments.

We recorded the information below for each frame:

- Positions of enemies
- Collision detection of enemy object (True/False), player, and position
- Position of healing item when added
- Collision detection of healing item (True/False), player, and position
- Player heart rate
- 3D positions of the head, legs, and arms of the player

The space within which the player moved, which we call "sports field," was 4.5×5 m^2.

Results

Results of the Likert scale

We asked the designer and player different questions in each experiment. Figure 5 shows the rates of enjoyability on a seven-point Likert scale, which was asked for both

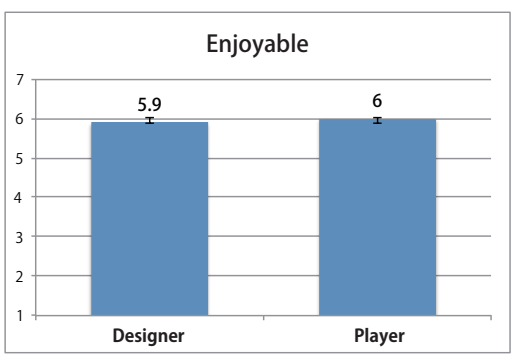

Figure 5: On a seven-point Likert scale (1 = strongly disagree, 7 = strongly agree), both the player and designer clearly rated that the system as enjoyable.

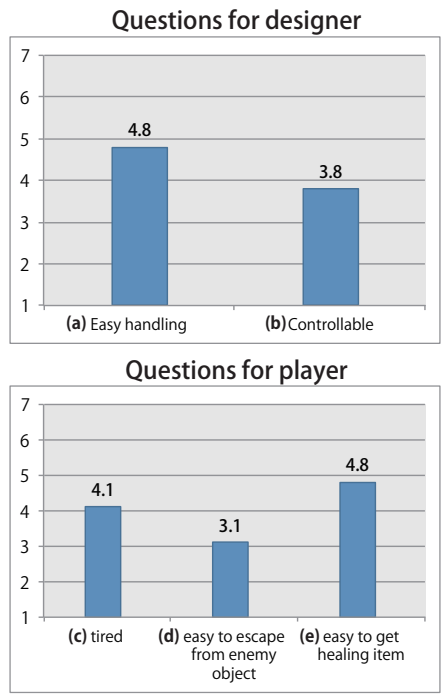

Figure 6: Seven-point Likert scale (1 = strongly disagree, 7 = strongly agree) for the designer and player. The results show that designers felt that controlling the player was difficult, but the players did not feel tired or bored.

roles. On average, both the designer and player rated this at around six, which indicates that both roles were clearly enjoyable. Two participants rated the designer score higher, three rated player higher, and five rated both as the same.

Figure 6 shows the seven-point Likert scale for each role. The designer rated the handling of the design screen as slightly easy (Figure 6(a)). Figure 6(b) shows whether the designer felt he/she managed to control the player. The average rate was 3.8, which is neither easy nor difficult. There was no relativity between questions (a) and (b), in which even participants who rated "controllable" lower than three rated "enjoyable" high. In the interview, participants who rated designer as more enjoyable said, *"I felt like I was controlling the player, which excited me. It was interesting that the player sometimes did unintentional movements."* These "unintentional movements" were, for example, when the designer placed an object at the top of the screen with the intention to jump, the player moved forward so that the size of the body increased in the screen, and gained the item. Figure 6(c) shows the degree of player tiredness after playing. The result was approximately average, which indicates that the physical intensity was neither high nor low. Figures 6(d) and (e) show that escaping from the enemy objects for the player was somewhat difficult, and reaching for the healing objects was easier. The enemy objects move automatically, no

matter where the player is. Consequently, it sometimes moves to the place where players cannot escape, which is a possible reason why the players felt it was difficult to escape from the enemy objects.

Heart rate results

Figure 7 shows the heart rate shift on each player (1 to 10). The cuts in lines are where heart rate was not recorded properly. The ratio that was within the pink area was 34%, which was lower than our expectation. However, 70% (seven players) of the average heart rate for each player through three minutes of game time was within the pink area. This includes the players with the eight-year-old boy and nine-year-old girl as designers. We also observed that designers tried to keep the heart rate within the range from the graphs. The most remarkable case is player 7. These results indicate that heart rate is not finely controllable, but loosely controllable by DSF, even by children. We believe that if the range of the pink area is larger, the rates within the pink area will rise.

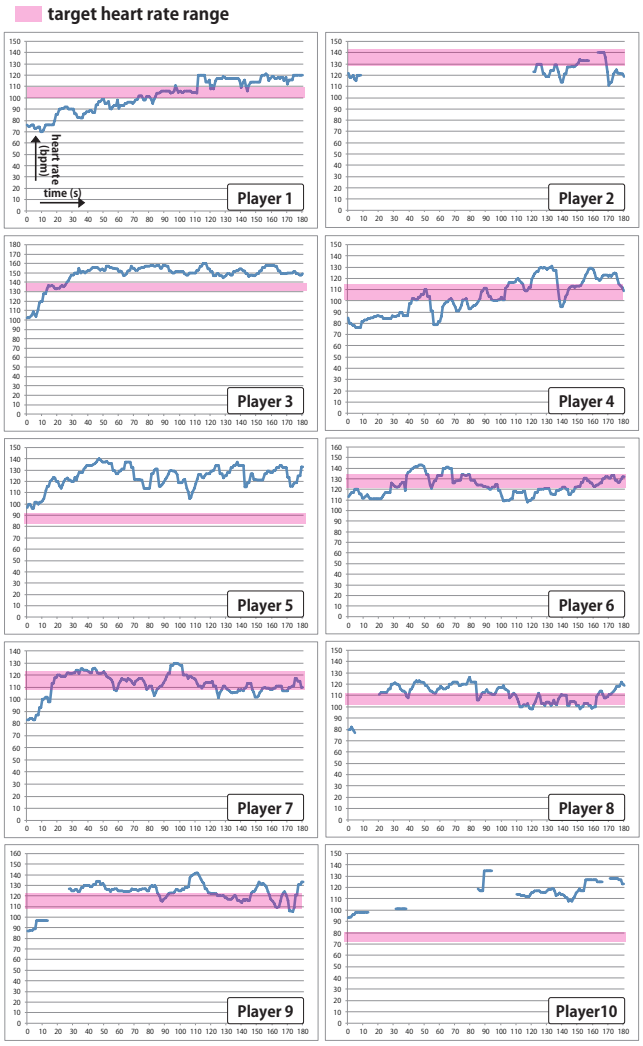

Figure 7: Heart rate shift on player. Although the heart rate is not within the target range, 70% of the players were within the target range for the average value of heart rate

In summary, the results show that our system is enjoyable for both children and adults. Heart rate was roughly controllable and tiredness rate was neither low nor high, which suggests that fitness level was right. We found that some adjustment in the rules, such as movement of enemy objects and heart rate range were required.

DEMONSTRATION AT A PUBLIC PLACE

Figure 8: Demonstration at a national museum.

From the results, we adjusted some rules and decided to demonstrate the system to a large audience at a public place (Figure 8). We also aimed to observe communications between the designer and the player to learn more about the sociality in this system. The demonstration was held at a national museum in Tokyo [1]. There were four other demonstrations taking place in the same hall. We demonstrated the system for one day (five hours, between 1 PM and 6 PM).

The changes we made in this demonstration were as follows:

- The directions of the enemy objects were made controllable by dragging on the designer's screen
- The points awarded for healing items were doubled if the player' s heart rate was within the target range
- Heart rate changes ranged from 30%–40% to 30%–50%

To operate the demonstration smoothly so that more participants could participate, we used wristwatch-type heart rate sensors (MIO alpha, Mio global). The connection method was the same as the belt-type heart-rate sensor. We used an 80 inches display (BIG PAD, SHARP) instead of a projector because the demonstration space was bright. Visitors who were interested in our system lined up and we asked them to write their name, age, sex, and desired role (either designer or player) on a prepared sheet. The playtime was three minutes per pair, which is the same as in the previous experiment, and so that as many people as possible could participate, roles were not exchanged. We set a display that showed the highest score of the day to encourage participants.

[1] Miraikan, http://www.miraikan.jst.go.jp/en/

Participants

Ninety-two visitors (46 pairs) aged from three to 50 years (average 24 years) experienced our system. The relationships of the participants were as follows: 85% were father or mother and child, 4% were among children (friends or siblings), and 11% were among adults (friends or couples). The average age of the player role was 11 and designer role was 37. All the parents, except for one pair, let their children play the role of the player.

Observations

Throughout the demonstration, visitors were lining up to play our system. We observed that many child visitors who walked across our demonstration asked their parents to play, (e.g., *"Mom, I want to play this"*).

Some of the communications observed were as follows. The most popular utterances from the designer role was cheering, such as *"You can do it!"* or *"Come on!"* The second most popular was advice for the player, such as *"Left, left!"* or *"Jump!"* In addition, there were reactions such as *"Oh ..."* with a regretful tone when a player was hit by enemies, or *"Wow!"* with a joyful tone when they managed to obtain healing items. The voices were especially loud when they managed to escape or gain in difficult situations, which seemed to encourage players. We also heard participants in the player role say to the designer role, *"You were not gentle. It was so hard to play (while laughing),"* and another pair say, *"I felt your kindness."* It seemed that some player role participants were conscious of the designer while playing.

Some cases that were not seen in the previous experiment were as follows. Eight children below elementary school age (six years old) joined our game as players. We observed that children below four years old appeared not to understand what to do, and the designer (child's parent) helped him/her to move by holding up his/her child (Figure 9(a)). Children over five years old managed to play by themselves and we observed that they were trying to get healing items. We also observed that some families played the designer role together with other family members and strategized about how to get more points.

One participant in an electric wheelchair participated in our system as a player (Figure 9(b)). She managed to play the game and achieved an above-average score. When we interviewed her after the game, she said, *"It was very intuitive. At the beginning, I was irritated that I could not turn or go back with the speed I wanted because this is an electric wheelchair. However, I felt that the designer became accustomed to my movements and I felt that I was communicating though there was no conversation. I want to try again with a manual wheelchair."* This comment indicates that because the game is designed by a human, he managed to handle unexpected situations, which is difficult for a computer with fixed algorithms.

(a) **(b)**

Figure 9: (a) Mother holding four-year-old son to help him play. (b) A player on a wheelchair playing the SportComposer system.

DISCUSSIONS

Maintaining the strength of the play with the heart rate

In the experiment, the designers tried to elevate, lower, or maintain the heart rate of the players. To elevate the heart rate, the players were made to perform movements such as jumping and crawling; however, this sometimes elevated the heart rate very much and took time to calm down. The designers appeared to have difficulty designing within the target range. However, they tried to calm the players' heart rates when they were over the range, and elevate them when they were lower than the range. Thus, a good balance in the physical intensity for the players appeared to have been realized.

Benefits for human design

Our system uses a human to control heart rate, and is not automatic. We believe that there are two main benefits for this design. One is a social aspect, which is generated from communications between the player and the designer. The communication is not only about utterances (e.g., *"You can do it!"*) and voice reactions (e.g., *"Wow!"*), but also consciousness in the mind. It is likely that conversations and voice reactions encourage and motivate players directly. We expect that the consciousness of the partner is also another factor in the encouragement. If the designer were a computer, the player would not feel meanness or kindness.

Another benefit is flexibility. A computer is good at calculating and detecting specific things faster than a human, but they cannot detect feelings from face expressions or voice. Further, a human is unique in that the patterns of design differ on each person, which produces diversity in game levels and patterns. In addition, a human has the ability to react to unexpected situations such as the cases in the previous section. We believe that human design generates sociality, motivations, and diversity that make sports enjoyable.

Limitations

However, in addition to the benefits for sociality, we feel that the communication depends on the relationship between the designer and the player. For example, we found that in plays among families, especially when the player is a child and the designer is a parent, the designer tends to encourage the child directly with words. As

mentioned above, a computer can detect specific things faster and more accurately than a human and response to specific movement, such as detecting the height of the player and moving enemies automatically, can be better than that of a human designer.

CONCLUSION

In this paper, we presented the notion of DSF, a sport environment that comprises a designer, who designs the sports field according to the player's physical status, and a player, who plays the physical game in the designed sports field. We implemented an application system called SportComposer according to DSF factors. The evaluation results reveal that both designers and players feel that our system is enjoyable. The simple rules allowed eight- and nine-year-old children to both design and play with our system. In a demonstration at a public museum, we found that participants were communicating actively or were conscious of their partner even without conversations, which seemed to have an effect on motivations.

As future work, we plan to apply DSF to various applications in which various activities/movements can be designed. In addition, we further aim to control movements such as jumping, posing, and stretching with various user interfaces.

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