Enhancing Physical Education with Exergames and Wearable Technology

Renny Lindberg, Jungryul Seo, and Teemu H. Laine

Abstract—Increases in the numbers of obese and overweight children are a major issue in post-industrial societies because obesity can lead to severe health-related problems. In addition, many challenges affect the quantity and quality of physical education (PE) provided by schools. Exergames that combine exercise with gaming have been recognized as a possible method for motivating children to become physically active and to make PE more fun. Furthermore, exergames that utilize wearable sensors devices allow players' movements to be tracked for estimating the efficiency of exercise. In this study, we developed the Running Othello 2 (RO2) exergame, where players wear a smartphone and a smart wrist band to compete in a board game enhanced with physical and pedagogical missions. In physical missions, the game uses inertial sensors and a heart rate meter to detect the physical activities of players. The pedagogical part of the game is based on the South Korean PE curriculum. We evaluated RO2 with 61 South Korean third grade elementary school students, 32 of whom learned curriculum topics by playing the game. The other 29 students comprised a control group who studied the pedagogical content using handouts. The results indicated that learning with RO2 was more efficient, the players were engaged, and their heart rates increased. Based on the evaluation, we identified several issues to be addressed in future research. Finally, we discussed how RO2 supports the educational affordances of wearables and we explained how exergames using wearables can overcome some of the challenges faced by PE.

Index Terms—Exercise, game, physical activity recognition, physical education, wearable technology

1 Introduction

Child obesity is a growing concern in post-industrial countries. According to the Organisation for Economic Co-operation and Development (OECD), the overweight/obesity rates were 30–40 percent among children aged 5–17 years in countries such as Greece, Italy, New Zealand, the USA, and Mexico in 2014 [1]. Research has shown that overweight children are likely to become overweight adults [2] and that child obesity can lead to lifelong health problems [3]. There are many reasons for child obesity, where bad eating habits and a sedentary lifestyle are part of the problem, but poor knowledge of a healthy lifestyle is also a possible contributor.

A combination of physical exercise and healthy nutrition is essential for decreasing obesity. Scientific studies have shown that regular physical exercise has positive effects on health and academic performance [4]. However, despite the well-known benefits of physical exercise, physical education (PE), which can also include health education topics, is often given less importance than sedentary subjects, such as mathematics and reading [4]. Furthermore, the effectiveness and equality of PE can be undermined by various challenges such as a lack of knowledgeable teachers, lack of personalized instruction for obese and overweight children, lack of resources, safety issues, and policy pressures [4], [5].

A possible solution to the child obesity epidemic is the use of exercise games commonly known as *exergames*, which allow children to exercise while playing. Previous research indicates that exergames may improve the fitness and motivation of players [6], [7], [8], [9], [10], as well as their cognitive and academic performance [7], [10]. Furthermore, several studies have reported the benefits of exergames in PE [7], [10], [11], [12], [13]. Thus, if exergames can be coupled with curriculum content relayed to physical and health education, they may help to solve some of the current challenges faced by PE.

In this study, we investigated the use of mobile exergames in PE. In particular, we established the theoretical and technical foundations of Running Othello 2 (RO2), which utilizes near-field communication (NFC) tags and wearable sensors to transform the Othello board game into a stimulating exergame, where players are required to think tactically as well as perform physical exercise and solve pedagogical challenges. The game's pedagogical component comprises content and tasks related to the third grade PE curriculum in South Korea.

We used a mixed method approach to evaluate RO2 with 61 South Korean third grade primary school students, 32 of whom played the game and 29 comprised the control group. A teacher was also interviewed to understand an educator's perspective. The aim of this evaluation was to investigate whether exergames with wearable technology can effectively enhance learning, exercise, and motivation in South Korean PE classes. Based on this evaluation, we discuss how the current challenges faced by PE could be addressed by exergames.

2 Background

2.1 Challenges of PE

PE is considered to be an essential part of primary school curricula around the world. PE curricula typically include

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both physical activities and related educational content. In addition, many primary school PE curricula, including that in South Korea, incorporate health education on topics such as personal health, safety, alcohol and drugs, sexuality, and nutrition. Given the growing concern about childhood obesity, it is imperative to ensure the provision of high quality PE at sufficient frequency so the World Health Organization's recommendation of 60 minutes of moderate or vigorous physical activity per day can be met for children [14]. Unfortunately, many challenges affect the implementation of these ideals in school curricula.

One of the critical challenges is the pressure to reduce the amount of time allocated to PE. This pressure can be exacerbated by various other problems such as a lack of staff and space, lack of equipment, or a preference for other subjects rather than PE. It is clear that the quality of PE can also be affected by these challenges [15]. According to a report published by the Institute of Medicine, the National Academies, USA, almost half of the surveyed school administrators mentioned cutting PE class time to allocate more time to sedentary subjects such as reading and mathematics following the passing of the "No Child Left Behind Act" in 2001 [4], which excludes PE from a list of core academic subjects. The following list summarizes the problems that may reduce the quality and quantity of PE education.

- Lack of time or reduced time for PE [4], [16], [17].
- Lack of skilled PE teachers [4], [5], [16], [17].
- Overburdened PE teachers [16].
- Lack of extracurricular PE activities [16].
- Lack of support from home [17].
- Lack of financial resources [4], [15], [16].
- Lack of or poor quality PE facilities [4], [5], [16], [17].
- Lack of or poor quality PE equipment [4], [15], [17].
- Violence and safety issues [4], [15].
- Lack of contextualized instruction (e.g., for different cultures) [15], [17].
- Lack of personalized instruction (e.g., for different skill levels) [5], [10].
- Lack of (digital or non-digital) games in the curriculum [15].
- Lack of PE policy [16].
- Lack of interest among students [10].

Lee and Cho studied the history and the current state of the national PE curriculum in South Korea [17], where they found that the current state of PE is precarious due to various problems, such as its low status compared with academic subjects, generally poor quality, lack of investment in facilities, little support from parents, and a strong preference for Western approaches. In South Korea, PE studies are compulsory from the first to tenth grades, and optional from the eleventh grade onwards. However, the time allocated to PE has been reduced across schooling and only 2 to 8 percent of students receive their recommended daily PE class. Indeed, although PE is a part of the national curriculum, teachers at many schools use the class time assigned to PE to conduct academic lessons.

2.2 Exergames

Exergames aim to combine exercise and digital gaming in an engaging manner. Their informal nature makes them usable both within and beyond school environments. Typical exergames rely on tracking the movements of players with wearable or remote sensors, such as accelerometers, heart rate meters, and cameras. In this section, we review some of the previously developed mobile exergames for motivating young players to perform exercise and we discuss their benefits according to other researchers. Therefore, we do not consider non-mobile exergames such as rehabilitation exergames and those based on stationary sports equipment.

Due to the popularity of location-aware smartphones, many commercial location-based games have been developed to promote movement. In some of these games, such as Turf Wars [18], Ingress [19], and Foursquare Turf [20], exercise is merely consequential because it is motivated by the game's requirement that players move around in the real world. By contrast, other commercial mobile games, such as Zombies, Run! [21], and Tourality [22], are built on the idea of exercise.

In the last 10 years, researchers have invested substantial efforts in the development and evaluation of mobile exergames. The first mobile exergames typically used the global positioning system (GPS) or an accelerometer to detect the movements of players. In particular, Freegaming [23] is an outdoor exergaming concept, which promotes play within mobile contexts and social environments. A prototype of this game was described where the players must take pictures of certain objects at given locations. In addition, Lin et al. [24] described a game that links a player's daily foot step count to the growth and activity of an animated virtual fish in a fish tank. An evaluation suggested that this game acts as a catalyst to promote exercise, but the enthusiasm of the players for the game decreased after a couple of weeks.

More recently, researchers have proposed mobile exergames based on advanced technology such as augmented reality (AR) and physical activity recognition (PAR) using wearable technology. GeoBoids is an exergame based on AR where the player searches for and captures virtual GeoBoid creatures using a map on a mobile device [25]. The GeoBoids move so the players must run in order to catch them. Calory Battle AR [26] is another location-based game where the player must run against time to find and defuse virtual bombs visualized by AR. The game can also present other types of tasks, such as educational quizzes or movement-based tasks. Mortazavi et al. [27] proposed an exergame that uses wearable sensors to detect soccer moves. The accuracy of their PAR algorithm is satisfactory (70 percent), but the game implementation is still at the prototype stage and it requires a special sensor device attached to the player's shoe. Finally, more examples of location-aware exergames and exercise applications were described in a survey by Boulos and Yang [20], who found that many of these systems included a social component. Table 1 summarizes the features of the exergames reviewed in our study and the proposed RO2. Among these games, only RO2 provides pedagogical content to the player.

Researchers have reported various benefits of exergames. Douglass-Bonner and Potts [6] surveyed previous studies to determine the health effects of exergames, which showed that exergames may improve fitness and adherence to exercise. Another survey [28] found positive health effects of

TABLE 1
Review of Mobile Exergames

Name	Genre	Exercise focus	Sensors	Social	Physical activity recognition
GeoBoids [25]	Location-aware AR shooter	Running	Camera, microphone, GPS	No	Movement tracking using GPS
Calory Battle AR [26]	Location-aware AR puzzle	Running	Camera, GPS	No	Movement tracking using GPS
Exergame [27]	Sports	Soccer	Accelerometer, gyroscope, magnetometer	Yes	Various soccer activities
Dokobots [20]	Location-aware AR geocaching	Walking	Camera, GPS	Yes	Movement tracking using GPS
CodeRunner [20]	Immersion, location-aware	Walking	Camera, GPS	Yes	Movement tracking using GPS
Coke Zero LiveCycle [20]	Location-aware racing	Walking, running	Accelerometer, GPS, compass	Yes	Movement tracking using GPS
Degree Confluence Project [20]	Location-aware	Walking	Camera, GPS	Yes	n/a
GeoDashing [20]	Location-aware racing	Walking	GPS	Yes	n/a
Ingress [20]	Immersion, location-aware	Walking	Camera, GPS	Yes	Movement tracking using GPS
Zombie, Run! [20]	Immersion, location-aware, exercise	Running	GPS	No	Movement tracking using GPS
Foursquare Turf [20]	Location-aware board game	Walking	GPS	Yes	Movement tracking using GPS
Tourality [20]	Location-aware, treasure hunt, racing	Running	GPS	Yes	Movement tracking using GPS
Turf Wars [18]	Location-aware, capture the flag	Walking	GPS	Yes	Movement tracking using GPS
Fish'n'Steps [24]	Step counting, digital pet	Walking	Pedometer	Yes	Step counting using pedometers
Can You see Me now? [23]	Location-aware, tag	Running	GPS, PDA	Yes	Movement tracking using GPS
Running Othello 2	Board game, quiz	Running, jumping, spinning, shaking	NFC, accelerometer, magnetometer, heart rate monitor	Yes	Accelerometer and magnetometer detect the movements of players in some missions

exergames in elderly individuals. Exergames have also been shown to boost motivation [29]. Osorio and Sykes [8] compared the motivational aspects of exercise, computer games, and exergames, where they identified several key motivators, including perceptions of enjoyment and a euphoric feeling after a session, as well as social participation. The social dimension of exergames was also explored by Feltz et al. [9], who found that playing an exergame with a real or virtual partner can result in a Köhler motivation gain effect. Finally, literature surveys by Ennis [10] and Staiano and Calvert [7] identified several physical, psychological, cognitive, and academic benefits of exergames.

In addition to demonstrating the many benefits of exergames, researchers have identified challenges that may undermine the required effectiveness of exergames for use in PE. Sun [29], [30] found that exergames are motivational in the short term, but this might not be sustained in the long term to obtain the desired health benefits of PE. Furthermore, Gao et al. [31] noted that the complexity of equipping a group of students with body-mounted sensors can be challenging when deploying sensor-driven exergames in schools. We considered these challenges when designing RO2 by allowing the game to be extended with new content to support the goals of a PE curriculum and by utilizing simple control devices that are easy and comfortable to use. We conducted a systematic, in-depth literature review to identify all of the challenges of exergames and appropriate solutions, as follows.

2.3 Exergames and PE

Most of the studies shown in Table 1 focus on the gamification of casual exercise but without considering the potential of exergames in the context of PE. As shown by the following examples, the combination of PE and exergames has received some attention from researchers. Vernadakis et al. [11] reviewed studies that used exergames in PE and training with Nintendo Wii Fit and its balance board, where they concluded that exergames can be used efficiently in health and PE programs. Furthermore, they conducted a comparative study of the use of Nintendo Wii exergames and a traditional balance training method among PE students at a university. They found that the exergame approach did not differ greatly from the traditional approach. Sun [30] investigated the effects of exergames on physical activity and motivation in PE classes at an elementary school; their results indicated that the situational interest of students declined over time, but their exercise intensity increased. The positive effect of exergames on increased physical activity was also reported in a study that compared exergaming with a standard PE class among inactive children [13]. Finally, Staiano and Calvert reported several cases where the use of exergames in PE classes increased the physical, social, and cognitive skills of children [7]. These games were mostly console-based (e.g., dancing games) or they required a special device (e.g., rowing and cycling games).

Ennis [10] reviewed previous studies and identified three categories of PE curricula that can be complemented by exergames. The first category comprises *recreational* or traditional PE curricula that focus on limited skill and tactical development with light-to-moderate intensity. Exergames can enhance these curricula by providing alternative fun options that can mainly benefit low-skilled or reluctant students. The second category comprises *public health* curricula that focus primarily on moderate-to-intensive physical activity, which possibly include making the students' heart rates reach a target level. According to Ennis' findings, exergames can improve these curricula by preventing boredom, increasing the students' ability to play effectively, providing appropriate challenges based on the students' levels, and providing exciting novel experiences. The third category comprises *educational curricula* that aim to facilitate the learning of various physical and mental skills related to PE. Ennis discovered that very few studies have addressed the educational affordances of exergames in PE, but suggested that exergames may be "the perfect site to integrate the physical, affective, and cognitive outcomes central to educational PE." In addition to teaching PE topics, exergames and electronic games may also be used as general pedagogical platforms for health education, as suggested by the results of Papastergiou's survey [12].

Many of the exergames described in previous studies were based on stationary exergame devices (e.g., game bicycles) or game consoles (e.g., Nintendo Wii), and they focused solely on physical exercise. To the best of our knowledge, there has been little research into the use of mobile exergames and wearables to support PE in terms of physical exercise and knowledge acquisition. Thus, in the present study, we investigated how our proposed mobile exergame RO2 can support the academic goals of the South Korean elementary school PE curriculum.

3 RO2

Othello, also known as Reversi, is a strategic turn-based board game where two players compete on an 8×8 board using black and white pawns. All of the pawns have equal properties, but the available moves depend on the pawn's position on the board. Players capture an opponent's pawn by moving their own pawn over it in a straight line horizontally, vertically, or diagonally (Fig. 1). The game ends when the board is full, when there is only one color left, or when no further moves are possible. In this section, we describe our exergame version of Othello called RO2.

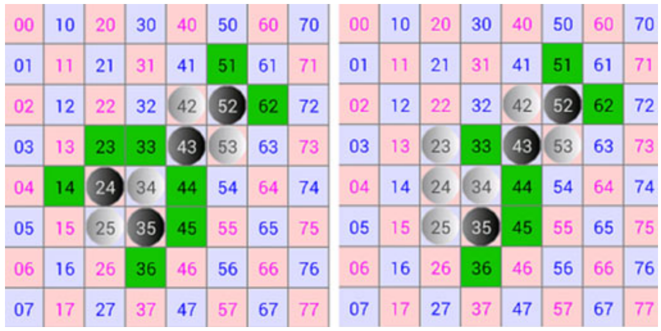

Fig. 1. Running othello 2 game board where the white player makes a move from 42 to 44.

3.1 The Game Concept

RO2 is an Android-based mobile game that utilizes NFC tags and wearable technology to transform the Othello game into a stimulating exergame, which requires that players think tactically, as well as performing physical exercise and solving pedagogical challenges. The game's pedagogical component comprises content and tasks related to the elementary school PE curriculum in South Korea. The first version of Running Othello focused mainly on physical exercise, but it did not utilize wearables other than a smartphone and it was not evaluated in the context of PE [32].

Unlike the classic board game version of Othello, RO2 has no turns, so a fast player can make multiple consecutive moves by running from one NFC tag to another without waiting, which explains the name of our game. The player initiates a move by reading a tag with a smartphone, which can then trigger one of the following three events (see Fig. 2). First, an error message is shown if the move is against the rules. Second, if the move is odd (i.e., first, third, fifth, etc.), a physical mission is presented, such as jump N times, spin N times, or shake the phone. After finishing the physical mission, the player is shown learning material on topic X. Third, if the move is even (i.e., second, fourth, sixth, etc.), a pedagogical mission is launched related to a previously presented topic X. The game ending is determined according to the aforementioned Othello rules. If the game finishes before all of the pedagogical contents have been presented, the player must go through the remaining learning materials and pedagogical missions before the final points are shown. These points represent the amount of tags captured, the summed points from physical missions, and the summed points from pedagogical missions.

The game utilizes sensor data to recognize the physical activities of players during physical missions. We selected jumping, spinning, and shaking as physical missions because they are easy to learn, require little space, and they are relatively simple to detect via sensors. More complex movement patterns would require sophisticated algorithms for their detection. In our future research, we will consider creating physical missions that target the different body parts used in different sports in an efficient and balanced manner.

3.2 Pedagogical Content

The pedagogical content of RO2 is based on the national third grade PE curriculum in South Korean elementary schools. First, the curriculum comprises information and

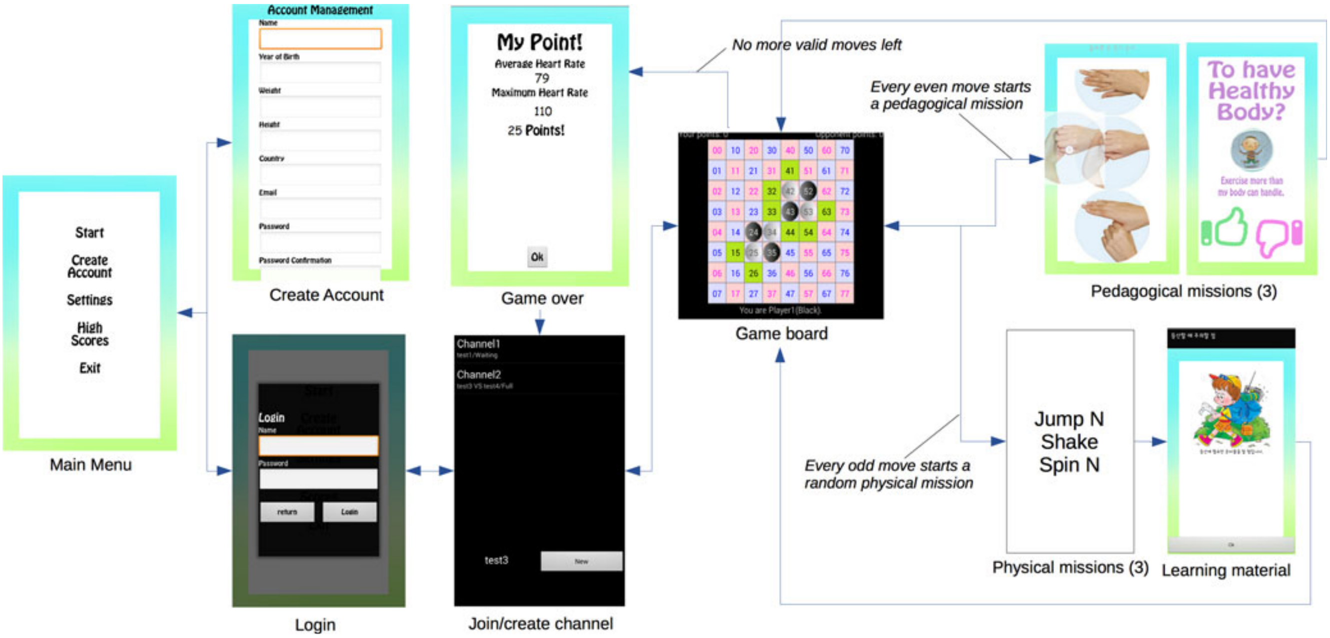

Fig. 2. Game flow in running othello 2.

instructions about various sports, such as swimming, tennis, and dodgeball. Second, the curriculum includes information related to health education, such as personal hygiene, emergency procedures, first aid, and safety. RO2 is not related directly to any of the sports described by the curriculum, so we prepared the pedagogical content regarding the health education topics listed below. This content was analyzed by a teacher at the target school who provided constructive feedback to ensure the suitability of the content for the students.

- Calling an emergency service,
- Taking a shower,
- Brushing teeth,
- Washing hands,
- First aid (fractured arm, burn, foreign object in the eye, or a nose bleed),
- Swimming safety,
- Outdoor activities (e.g., hiking).

The game employs four methods for conveying pedagogical content to the player, as shown in Fig. 2. The first method presents a screen with pictures, explanatory text, audio, or video, which function as static learning materials. These materials are shown immediately after a physical mission has been completed successfully. The other three methods comprise pedagogical missions where the player solves simple challenges, as follows: (1) swiping right or left to confirm or deny a statement, (2) answering a multiple choice quiz, and (3) arranging a sequence of images in the correct order. A pedagogical mission is shown only after the corresponding learning material has been presented. Each mission has a hint button to provide a helpful tip.

3.3 Technical Implementation

RO2 is a client-server system where the server implemented using the Spring Framework manages multiple game sessions through game channels (Fig. 3). A match can commence when two Android-based clients log in to the server and join the same channel. The server sets up a virtual game board and manages it throughout the game. After a client reads a tag, the server checks whether the move is valid and returns an appropriate response (e.g., a mission ID and optional content). Consequently, the client launches the corresponding mission and reports the results back to the server after the mission has been completed. The clients also poll the server frequently for game board updates, and thus any moves made by the opponent are updated on the virtual game board in a timely manner.

One of the advantages of the client-system architecture is that RO2 can be played in local and distributed settings. For example, a player in South Korea could play against a player in the USA provided that they both have a physical game board set. This is illustrated in Fig. 3 where the server manages two ongoing matches: one local match and another played by two remote players. In this study, we only evaluated the game in a local setting.

The physical game board is implemented with 64 NFC tags arranged in a grid. Due to the portability of the NFC tags, the physical game board can be set up anywhere with sufficient space, such as a school gymnasium or a park. The distance between the tags can be any length. Each tag is labeled with an ID number, which represents a row and a column on the game board. These ID numbers are also shown on the virtual game board on the smartphone (Fig. 1). The virtual game board also shows hints about the moves that are currently possible. This feature is aimed mainly at novice players who might not be familiar with the rules of Othello.

The PAR algorithms in RO2 can utilize the sensors in a smartphone and in a Microsoft Band smart wrist band to detect physical activities, such as shaking, jumping, and spinning (see Fig. 4). To detect a spin of 360 degrees, we track the orientation of the smartphone and estimate when it has completed a full circle. To detect shaking and jumping, we use a thresholding technique based on the smartphone accelerometer data to estimate when the activity has been performed. Finally, the optical heart rate sensor in the

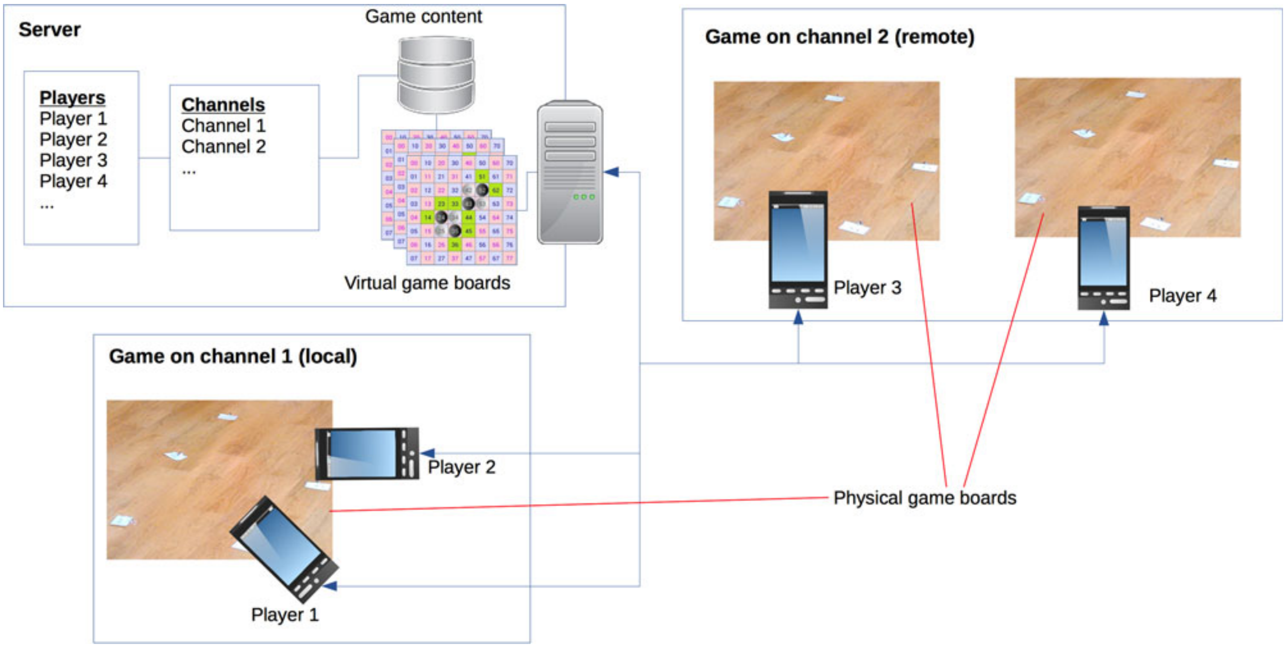

Fig. 3. Distributed architecture of running othello 2.

Microsoft Band is used to collect heart rate data during game play. The game client automatically writes the player's heart rate data in a file if the sensor device is detected. The heart rate data could be used to personalize the level of physical difficulty for each user but this is not implemented in the current version of the game.

4 Evaluation

In this evaluation, we investigated the effectiveness of exergames using wearable technology in terms of learning, exercise, and motivation in South Korean PE classes. In the following sections, we present the design and the results of the evaluation.

4.1 Evaluation Setting

We evaluated RO2 in two classes of South Korean third grade elementary school students. All of the participants were 10 years old according to the Korean age reckoning system, where a child is one year old at birth and years accumulate at the Lunar New Year. We divided the participants into a game group (32) and control group (29), with gender distributions of 18 males/14 females and 14 males/14 females/1 unspecified, respectively. The teacher (female, 29 years) of the game group was also interviewed.

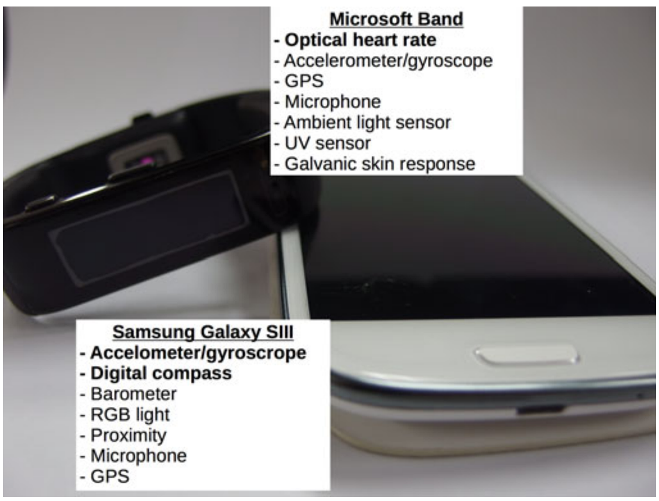

Fig. 4. Sensor devices: Microsoft band and samsung galaxy SIII.

The control group was used to measure the learning and retention of the pedagogical content when studying the content in handouts (control group) compared with studying it via the game (Section 3.2). In addition to exploring the effectiveness of RO2 as a learning tool, we aimed to determine how the game worked as an exercise tool and how engaging it was for the players. We were also interested in the players' perceptions of the game's features (e.g., different missions) and the difficulties they experienced. These data would be useful for improving the game as well as for understanding the benefits and challenges presented by exergames and wearables for PE.

Several data collection instruments were developed as follows. First, we devised a mixed method questionnaire for the game group, which comprised open questions and statements assessed by a four-point Likert scale (1 = strongly disagree, 4 = strongly agree). The questionnaire was designed to obtain answers to questions such as what the player liked/disliked about the game, what game features they found interesting/boring, whether anything disturbed them while playing, how they rated the game relative to ordinary PE classes, what new things they learned from the game, and how they felt about the game as a learning tool. Second, we prepared a set of semi-structured interview questions for the players in order to build on the questionnaire data and to obtain a better understanding of the players' thoughts about the game play and learning. Third, we also prepared semi-structured interview questions for the teacher in order to collect her perceptions of the Korean PE curriculum, exergames, wearables, and the game play in RO2. Finally, we prepared a

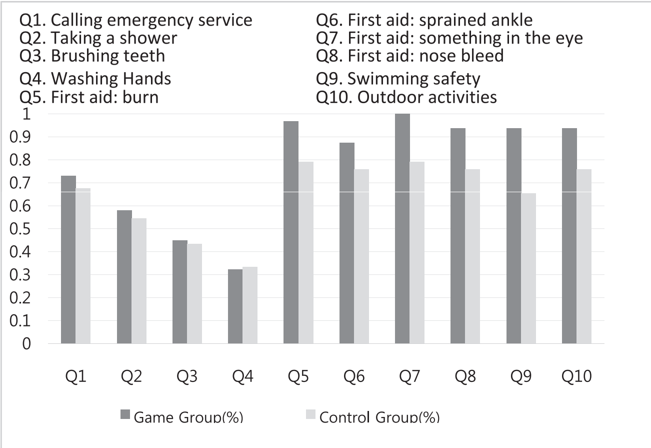

Fig. 5. Post-quiz comparison: Mean correct answer rates between the game group and the control group.

post-quiz that comprised multiple choice questions and ordering tasks to measure the learning and retention of the pedagogical content in the game group and the control group. All of the instruments were translated into Korean and the collected data were later translated into English by a Korean American researcher. The teacher also validated the translated questionnaire and student interview questions in order to ensure that appropriate vocabulary was employed.

The data were collected for several days over a period of one week at the target school. After obtaining permission to conduct the experiment, the researchers prepared the game infrastructure at a school gymnasium and introduced the game concept and rules to the game group. The children were asked not to discuss the experiment with anyone during this week. Next, during recesses over two days, the researchers invited four players at a time to play two simultaneous matches. The players wore Microsoft Band devices and Samsung Galaxy SIII smartphones, and they were given approximately 15 minutes to play. If the game ended early, the remaining learning content was displayed to the player together with related pedagogical missions. Heart rate data were recorded throughout the game sessions. Researchers and the homeroom teacher of the students made observations during the playing to the game and assisted the players in case of technical and usability issues. These observations were later expanded into short essays by each of the four participating researchers. After all 32 players had played the game, they were asked to complete the questionnaire. The students in the control group were asked to study the learning material handouts for 15 minutes. The teacher selected eight volunteers from the game group for one-to-one interviews in Korean. The interviews with the players each lasted approximately 10–15 minutes. The teacher, who was fluent in English, was interviewed in English for 35 minutes. One week after playing the game, the control group and game group were asked to complete the post-quiz. All of the data were collected in Korean, except for the teacher interview.

During the data analysis, the quantitative questionnaire data were complemented with relevant insights captured from the qualitative data. In particular, when analyzing the qualitative data, we aimed to understand various aspects of the use of exergames and wearables in the context of the South Korean elementary school PE curriculum. In the

TABLE 2
Post-Quiz Comparison: Maximum Available Points, Means (μ), Standard Deviations (σ), and T-Test Results ($df = 59$, $p <= 0.05$) for the Control Group (CG) and the Game Group (GG)

Ques.	Max	CG μ	GG μ	CG σ	GG σ	t	p
Q1	5	3.38	3.66	1.50	1.16	0.798	0.428
Q2	5	2.72	2.91	1.68	1.42	0.451	0.654
Q3	5	2.17	2.25	1.53	1.58	0.191	0.849
Q4	6	2.00	1.94	1.23	1.17	-0.200	0.842
Q5	1	0.79	0.97	0.41	0.17	2.199	0.032*
Q6	1	0.76	0.88	0.43	0.33	1.175	0.245
Q7	1	0.79	1.00	0.41	0.00	2.842	0.006*
Q8	1	0.76	0.94	0.43	0.24	1.999	0.050*
Q9	1	0.66	0.94	0.48	0.24	2.914	0.005*
Q10	1	0.76	0.94	0.43	0.24	1.999	0.050*
Q1-4	21	10.28	10.75	3.89	2.99	0.53	0.60
Q5-10	6	4.52	5.66	2.13	0.54	2.88	0.006*
ALL	27	14.79	16.41	4.79	2.89	1.58	0.12

quantitative analysis, we calculated the means and standard deviation, and performed t-tests between the game group and the control group. The qualitative data were first transcribed and then transformed into concepts according to predefined categories.

4.2 Results

In this section, we present the results according to the following categories: (1) learning, (2) exercise, (3) motivation and engagement, and (4) issues. The quantitative data obtained from the questionnaires are presented as bar charts with the mean (μ) and standard deviation (σ) values. Relevant data samples from the open questions and interviews are presented in quotes.

4.2.1 *Learning*

To determine the effects of RO2 on learning during a short-term intervention, we compared the post-quiz results for the game group with those for the control group. Our hypothesis was that the game group would learn the pedagogical content better using a game-based learning approach, thereby exhibiting a higher level of retention. The post-quiz comprised four ordering (Q1–Q4) and six multiple choice (Q5–Q10) questions on different topics.

Fig. 5 shows the mean correct answer rates in the post-quiz for the game and control groups. Table 2 shows the maximum available points for each question, the means and standard deviations for the control group and the game group, as well as the t- and p-values (two-tailed) obtained from t-tests ($df = 59$, $p <= 0.05$). Significant results are marked with an asterisk. The last three rows of Table 2 show the combined results for ordering questions, multiple-choice questions, and all questions, respectively.

The average correct answer rates for the game group and control group were 77 and 65 percent, respectively. Based on a visual analysis of Fig. 5, it can be seen that the game group outperformed the control group for nearly all of the questions, but only questions Q5 and Q7–Q10 differed significantly between the groups. The ordering tasks (Q1–Q4) were particularly difficult and some students reported that the images for ordering were too similar, thereby making it

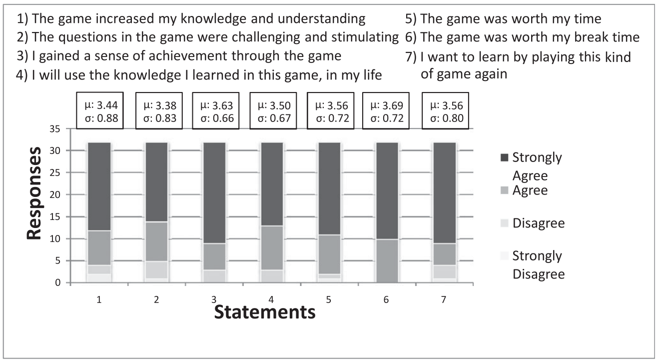

Fig. 6. Learning experience.

difficult to determine the correct order. This was particularly true for Q4, which presented six images of different phases of hand washing. None of the students answered this question correctly.

The game content was based on the South Korean PE curriculum, so it is possible that the players were familiar with some of the topics before the experiment. However, the differences in the quiz-post performance by the game group and control group indicated that RO2 facilitated the learning and retention of the selected PE curriculum topics by the players.

It should be noted that the features of the game forced the player to complete all of the remaining pedagogical content and pedagogical missions in this version to ensure that both the game group and control group were presented with the same learning content. According to our observations during the evaluation process, few pedagogical missions remained after the actual RO2 part was completed in most cases. All of the students finished the remaining pedagogical missions, but we obtained no evidence of the extent to which they focused on these missions. It would be useful to investigate the depth of the player's focus on the pedagogical content in future research.

In the questionnaire, we asked the players to evaluate their learning experiences based on statements scored using a Likert scale. Fig. 6 shows the results obtained for the game group, which were mostly positive. Statements 1–3 measured the players' perceptions of the game's efficiency as a learning tool. Statements 4 and 7 investigated the game's potential for having pedagogical implications beyond the experiment. Finally, statements 5 and 6 explored whether the game provided a suitable learning experience in terms of the time and effort invested.

All eight interviewees told us that they would prefer playing games such as RO2 during ordinary PE classes, where their reasons ranged from gamification to technology, and from playing with friends to learning without a book. The following comments by the players explain the reasons why learning in an exergame could be a suitable method for PE classes.

> *Male player:* Learning facts about safety precautions while playing a game was worth it. Because learning them during class time is boring, but studying while playing a game is fun.
> *Female player:* PE is boring because I study from a textbook. But studying with this game was much fun.
> *Male player:* Learning PE by Running Othello was great. It also felt good to sweat a lot.
> *Male player:* I thought smartphone is bad for your health and posture, but this game is very because it makes me move to improve my knowledge and health. The content of the game is also similar to a textbook,
> *Female player:* It was interesting to tag the number and receive a mission. The greatest thing was that I had a chance to learn safety precautions and more useful facts while I played with the phone.

The comments above refer to one of the pedagogical affordances of RO2, i.e., its ability to seamlessly combine physical exercise with physical and health education topics. In a typical South Korean PE class, the students are either exercising or learning theory, but these two are never mixed in a single session. This was confirmed by the teacher who noted the game's ability to embed both exercise and reading in one package, although she suggested that the game instructions could be clearer, as follows:

> *Teacher:* In a normal PE class, you are either learning in the classroom with a textbook, or you go to playground or a room to actually move your body. It is hard for me to imagine that [in a PE class] they would be doing some sports and I would make them read something in between sports. That would be really silly. But with the game they were moving their bodies and reading the text at the same time without any obstacles or discomfort, which was good.
> *Interviewer:* Do you think they could actually focus on learning while they were playing and performing physical activity?
> *Teacher:* Well, that is the problem. If there were more instructions, then they would obviously have been more focused on the text.

Some players reported that they already knew some of the learning material, but most of them found that the game taught them something new. This shows the importance of personalizing learning content according to the learner's skills and previous knowledge. In some cases, such as the following interview excerpt containing the responses of a female player, the game helped the players to deepen their knowledge of certain familiar topics.

> *Interviewer:* Was there anything that you learned from the game?
> *Female player:* Well...what I need to do when someone gets burned, how to call 911, and how to brush your teeth properly.
> *Interviewer:* Did you know them before?
> *Female player:* I knew them but not this well.

Based on her observations of students playing the RO2 game, the teacher recognized the potential uses of wearable technology in two PE scenarios. First, wearables can help to demonstrate the importance of exercise for one's body by quantifying the outcomes of exercise. Second, the sensors embedded in wearables can be used to identify physical postures for pedagogical purposes. The following comments reflect these ideas, which are linked to the motivation of students.

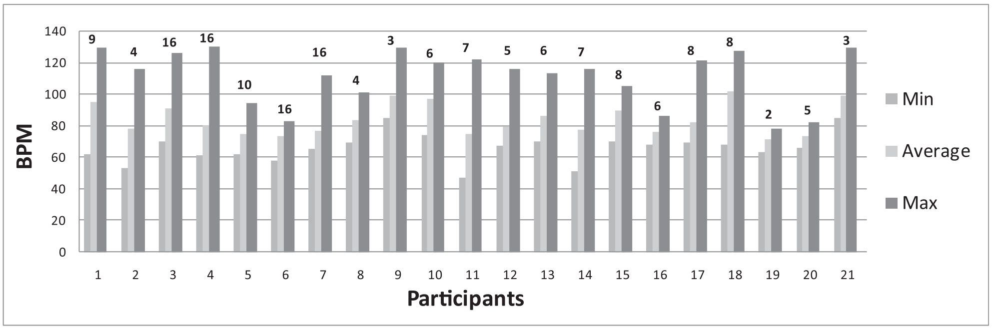

Fig. 7. Minimum, average, and maximum heart rates of the players (the game session lengths in minutes are shown at the tops of the bars).

> *Teacher:* It is good for your body when you are doing exercise, but young kids do not understand this. Wearable technology allows you to actually see that your body is changing, which would definitely motivate them. I guess they would like to compete with each other by numbers.
>
> *Interviewer:* Can you think of any ways in which wearables could be used in your PE classes?
>
> *Teacher:* Calculating the accuracy of my movements could be one way if it is possible. For example, it we are learning about playing ball and a certain position is required for throwing or catching. It would be excellent if the device could detect this position and explain how you can improve your body position.

In addition to using RO2 in PE classes, the teacher saw the potential of RO2 as a reviewing tool for other subjects at the end of each study unit.

> *Teacher:* After we learn each unit, I try to play a game to make sure that the kids understand what we have learned. I usually check what the others have prepared already and shared, or I may need to prepare it myself using a PowerPoint or a normal old-school quiz. But if someone makes this mobile game work for us, then I would be very happy to use it and my kids would also love it. [...] It could be used in almost every subject for checking and reviewing.

One of the problems with the South Korean PE education that could addressed by RO2 is the lack of daily physical activity among students [17]. The following comment from the teacher suggests that the students lacked both exercise equipment and time to perform exercise at home, which could be alleviated by installing RO2 game boards in parks and playgrounds so children could play with them on a casual basis. Furthermore, RO2 is a suitable option for use as a recess activity to increase physical activity on school days.

> *Teacher:* Young kids such as my 10 year olds really like to play and exercise. However, after school, they do not have the equipment or the time in Korea. They need to go to hagwon [after school study academy].

4.2.2 Exercise Efficiency

We collected the heart rate data from the players in order to estimate the efficiency of exercising using RO2. Two players who competed against each other were equipped with Microsoft Band wearables and 21 heart rate data samples were collected successfully. Fig. 7 shows the maximum, minimum, and average heart rates of the players in beats per minute (bpm) in selected game sessions. The duration of the game session in minutes for each sample is shown at the top of the bar. An average game session lasted for 8 minutes. The overall maximum, minimum, and average heart rates were 111, 65.9, and 83.7 bpm, respectively. Short game sessions were due to technical errors or a rapid victory by one of the players. In both cases, the players were given the opportunity to restart the game.

Fig. 7 shows that the heart rates of the players exceeded 100 bpm, except in six sessions. These increased heart rates indicate the potential benefit of mild or even moderate-to-high intensity exertion. The level of exertion depended mainly on how far the NFC tags were placed from each other on the physical game board and the thresholds set for the physical missions. In the evaluation setting, the tags were located about 70 cm apart.

The tempo of the game was constructed so the exercise routines were interspersed with the educational content to avoid an excess of either activity, i.e., tiring the player out with too much exertion or boring them with a constant flow of learning content. Fig. 8 shows the heart rates of three players in separate game sessions. The missions normally took from several seconds to approximately half a minute, except for the challenging hand washing image puzzle and physical missions where all the moves were not read on the first attempt due to poor sensor sensitivity. The heart rate patterns indicate that the heart rate increased slowly with peaks during the physical missions, before declining again until the player was introduced to the next physical mission.

Calorie expenditure is a useful indicator for evaluating the efficiency of physical exercise. Several studies have

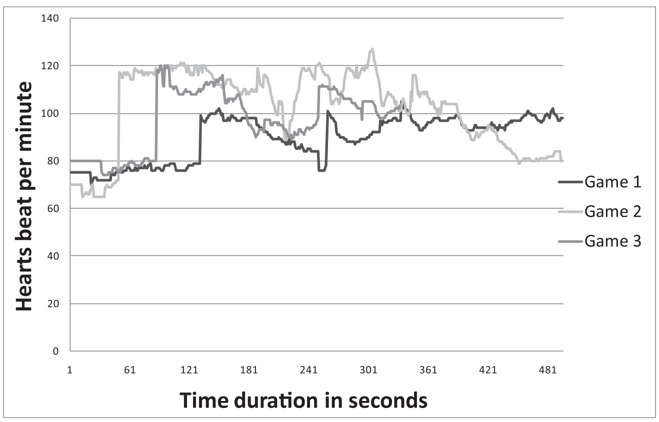

Fig. 8. Heart rates of three players during a full game session.

investigated the calorie expenditure by children based on their heart rates, but these studies were based on commercial products [33], [34], or they used additional measurement equipment [35]. Thus, we were unable to access the proprietary formulae employed to calculate the calorie expenditure by the RO2 players. Keytel et al. reported an openly available formula for estimating the calorie expenditure based on an individual's heart rate [36], but this formula is only for adults and it requires the weight of the individual. Thus, in this study, we only considered that the increased heart rate in children was a positive indicator of the efficiency of RO2 as an exercise tool. Moreover, we observed that many players became out of breath due to intense spinning or jumping during the game play. The teacher also noted the excitement and engagement of her students during the exercise, as shown by the following comment.

> *Teacher:* I was really happy to see that my kids were running, jumping, and turning, and that they were happy. They did not even realize that they were doing some exercise.

The results of this evaluation are encouraging in terms of learning and the exercise efficiency of RO2, but it is still possible to improve the personalization of the game activities and to embed pedagogical content into the game so it would have a minimal effect on the fun factor.

> *Male player:* The greatest thing about Running Othello was that I did not have to sweat while I played, but the worst part was that it was all about safety precautions and the puzzle was difficult.

4.2.3 Motivation and Engagement

Our evaluation confirmed the suggestion of Ennis [10] that exergames can motivate low-skilled students to perform exercise. We observed that all of the players were highly engaged in playing the game, regardless of their physique. Some were engaged up to the point that we had to ask them to slow down to reduce the dizziness caused by fast spinning. This high level of engagement was noted by the teacher who was surprised to see how much the game motivated the players who were normally inactive in PE classes.

> *Teacher:* Some of my children do not like sports or moving their bodies as much as others and they are slightly overweight. However, they were jumping and running everywhere, and they were smiling. They were clearly having fun, and I am sure of that. So that was surprising for me, really, really surprising.
> *Interviewer:* So are these children usually inactive in PE class?
> *Teacher:* Yes, the overweight children.

We also observed that wearable technology could function as a motivator. For example, after being equipped with the Microsoft Band, one male player commented that he felt like a secret agent and demonstrated agent-like moves. The fascination with technology among the young players is further demonstrated by the following interview answers after we asked what was the "coolest" thing about the game. Interestingly, many of the players referred to the NFC technology, which is fairly common in South Korea (e.g., advertising and payments). The smartphone and the heart rate meter were also mentioned by other students.

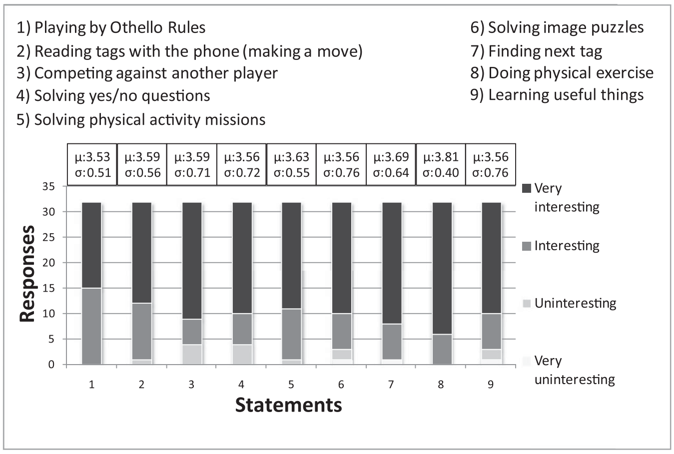

Fig. 9. Game features.

> *Female player:* Recognizing a number when I put the phone on the number. That was cool.
> *Female player:* It was cool to see the phone recognize a number written on paper.

The teacher also noted the increased engagement due to the novel technology, but she was worried that the effect of novelty would decline over time. As a solution, the teacher suggested that the game's content and modes should be varied.

> *Teacher:* The children were also able to enjoy using cool new technology. [...] If we play the same game, such as RO2, quite regularly, then they will lose their interest rapidly. The ultimate aim is to have different games every time. If that is not possible, then I will play individually the first time, then in a group, and I will try to do a survival task the third time.

The questionnaire contained a series of statements rated on a four-point Likert scale to ask the players about the features of the game that they found interesting or uninteresting. The results shown in Fig. 9 demonstrate that the players agreed with most of the statements. However, statements 3 and 4 regarding competing against another players and solving yes/no questions, respectively, were both given negative answers by four players. In an interview, one of them said that she preferred helping her friend rather than competing, thereby suggesting an altruistic mindset.

> *Interviewer:* Did you have fun competing and talking with your friend while playing the game?
> *Female player:* Yes, but rather than competing with my friend, it was more fun to help her after I finished my puzzles.

Indeed, the ability of RO2 to provide a social experience is similar to many other exergames [20]. Although there were a few negative responses, the combination of social game play and technology was identified by several players as a positive aspect of the game, which is illustrated by the following comment from a girl who was keen to follow her friend's reactions while playing with the appealing technology.

> *Female player:* A positive thing about this game was that I got to play it with my friends using my

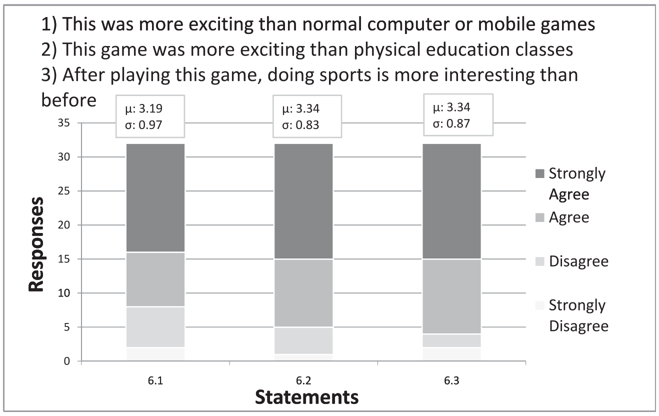

Fig. 10. Motivational impact beyond the experiment.

favorite technology. [...] It was great to see my friend's facial expressions and feel the atmosphere.

In order to measure the motivational impact of RO2 beyond the experiment, we asked the players how they felt about RO2 compared with other digital games and ordinary PE classes. We also asked them whether the game increased their interest in doing sports. The answers to these questions are shown in Fig. 10, which indicates that most of the responses were positive. Given the high popularity of mobile and other digital games among modern children, it is not surprising that several players disagreed with statement 1. In addition, as suggested by the following interview comments, technology and gamification were among the reasons why the game was considered more likeable or interesting than a normal PE class. The last comment reflects the playful mindsets of young pupils. Based on these results, we can conclude that although technology and gamification may be powerful motivators for young pupils, creating games that maintain excitement during the pedagogical content is still a significant challenge for educational game designers.

Female player: We do not use a phone when we are in a PE class but it was interesting to use a phone and learn at the same time.
Male player: The game is more fun. I liked it because it is a searching game and it is not boring.
Male player: Everything becomes interesting if you make it a game.

4.2.4 Issues

During the evaluation, RO2 was affected by a few technical faults, which were solved by restarting the game. Furthermore, the PAR accuracy in some missions was criticized by the players and the teacher, which can be attributed partly to selecting inappropriate threshold values in the algorithms. Our observations also showed that some of the children performed the physical missions without complying with the instructions given in the game. This issue could be addressed by using video clips in the instructions. Some of these issues are evident in Fig. 11, which shows the answers given by the players to the question: "did any of the following things disturb your playing?" The difficulties of picture puzzles, activity recognition, and technical problems when reading tags were often recognized as disturbance factors.

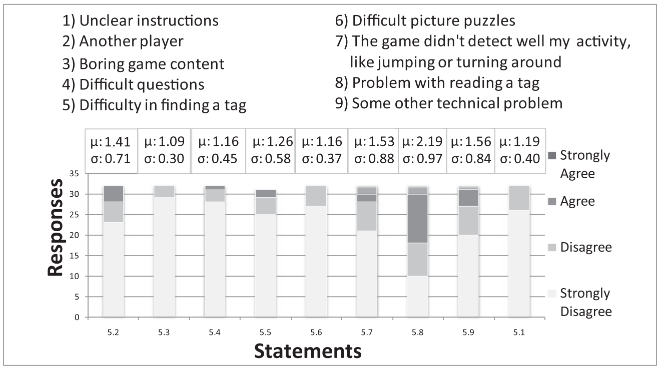

Fig. 11. Disturbances reported by the players.

Thus, we intend to focus on solving these problems in future research.

During the interview with the teacher, we asked about potential issues that might affect using RO2 and wearable technology in PE. She reported several issues such as technology cost, technology maintenance, technology storage, teacher training, material preparation, finding a place for the game, and setting it up before the class. The following comments from the teacher illustrate these concerns.

Teacher: The government or someone else should provide smartphones or devices for all children, although this would cost a lot of money.
Teacher: Storing the [technology] is an issue and whenever it breaks, the children will be sad until I have fixed it. The teachers should study and prepare for the class to use the devices wisely and according to the curriculum. [...] We would have to put those tags somewhere in advance, and we definitely require some space.
Teacher: We do not have the technicians. If we are playing with cool new technology, there will be some technical problems and we have no-one to fix it.

5 Discussion

Wearable technology has advanced tremendously in terms of its quality and features during the past few years, but it is clear that learning environments built on wearables are not yet ready to replace traditional education. In particular, PE is one of the subjects that will require a traditional hands-on approach at some point. Regardless of how many wearable sensors we attach to students and how appealing our exergames might be, it is still necessary to teach children how to physically kick a football or how to swim in real water. However, many challenges in PE (see Section 2.1) could still be addressed by exergames and wearables. Table 3 shows our suggestions regarding how exergames with wearables, such as RO2, could be used to overcome these challenges. We suggest that this technology should complement normal PE education. In particular, exergames could be beneficial for providing extracurricular physical activities outside schools and during recess.

Recently, Bower and Sturman [37] analyzed previous studies and asked educators around the world to identify affordances and issues related to wearable technology in education. They identified 14 affordances and 13 issues, most of which were identified 10 years ago when learning

TABLE 3
How Exergames and Wearables Could Address the Challenges of PE

Challenge	How exergames could help
Lack of time	Exergames cannot increase the time dedicated to PE classes in schools, but they can encourage students to perform exercise during recess and outside of school hours.
Lack of skilled teachers	Well-designed exergames with wearables can provide pedagogical instructions to student on topics that might not be familiar to the teacher (e.g., how to perform a golf swing). However, exergames also require training before they can be used efficiently in PE classes.
Overburdened teachers	If exergames provide appropriate guidance, they can be used independently by the students, which would free the time available for teachers to create content, observe, and make interventions only when necessary.
Lack of extracurricular PE	Mobile exergames such as RO2 can easily be set up in different contexts, such as yards, parks, and sport clubs, thereby extending the reach of PE outside the school environment.
Lack of support from home	If the exergame technology is simple to use and affordable, it could motivate parents to change their yards or living rooms into exergaming environments. For example, the Nintendo Wii game console has brought exergaming to millions of living rooms since it was introduced in 2006.
Lack of financial resources	Exergames require an initial investment on technology. However, following that investment, many sports could be incorporated into an exergaming platform. If the budget is very limited, some exergames such as team-based treasure hunts can also be played with the students' own smartphones.
Lack of PE facilities	Mobile exergames can be played outside the ordinary PE facilities, thereby freeing up space for traditional PE classes.
Lack of equipment	After the required technology (e.g., wearables, smartphones, and sensors) has been purchased, it can be used for many types of exergames. Some exergames could detect moves from sports such as golf, archery, and javelin, which are normally difficult to perform in limited PE facilities.
Violence and safety	Exergames could teach a safe way of doing exercise. Violence cannot be prevented completely but situations that might escalate into violence could be avoided by providing the students with engaging exergaming experiences.
Lack of contextualized instruction	The contents of exergames could be tailored to the target contexts. For example, an exergame played in South Korea could detect taekwondo moves, whereas the same game could ask the player to mimic cross-country skiing postures in Finland.
Lack of personalized instruction	Exergames can utilize the data acquired by wearables (e.g., biosignals) to personalize various elements of game play, such as the difficulty level, type of physical activity, and duration of the activity.
Lack of games	Exergames can integrate various elements from digital and non-digital games into a single environment.
Lack of PE policy	Exergames cannot change PE policies, but their positive outcomes could inspire decision-makers to act. Acquiring exergames without support from appropriate policies may result in sporadic use or even the abandonment of expensive technology.
Lack of interest among students	RO2 and other exergames can increase the motivation of students to engage in physical exercise. Theoretical book-based content can be expressed in a fun manner using exergames.

with mobile phones became a popular research topic in the field of educational technology. For example, issues such as privacy, cost, distraction, technical problems, lack of support, and cheating are quite familiar to mobile-based education researchers. Table 4 shows the affordances identified by Bower and Sturman as well as our discussion of how these affordances may be achieved using RO2. The affordances marked with an asterisk (*) are not yet available in the game, whereas those marked with a plus (+) were identified in the evaluation.

RO2 supports individual gameplay where students have the opportunity to compete against each other by comparing the points obtained. This type of gameplay is particularly suitable for learners who belong to the Achiever or Killer play styles, as categorized by Bartle [38]. For students who prefer other Bartle play styles, i.e., Socializer and Explorer, competing may feel uncomfortable and even stressful. Negative stress due to competition is a known phenomenon in PE [39] and some students may handle it better than others. To avoid inflicting negative stress upon non-competitive students, it is imperative that exergames employed for PE, such as RO2, provide alternative play modes with collaborative multiplayer challenges where students can work together to achieve given goals. Furthermore, these games should have different gameplay options for the whole range of play styles. In order to achieve this goal in this project supported by the National Research Foundation of Korea (NRF-2015R1C1A1A02036469), we are currently developing an adaptive educational game system that personalizes the game content according to the learner's play style as well as their learning style. After it has been completed, this adaptive technology can also be applied to RO2.

In this study, we showed that RO2 is a feasible candidate for providing pedagogical content alongside physical exercise in PE classes. RO2 also has potential as a fun recess activity, which could promote physical exercise between classes and outside school hours. However, it must be noted that presenting pedagogical content during recess or spare time is generally questionable because the purpose of recess

TABLE 4
Affordances of Wearable Technology [37] in Running Othello 2

Affordance	Characteristic in Running Othello 2
In situ contextual information	Players' physical context information (e.g., movement and heart rate) is used in the game
Recording	The game records movement data as well as biosignals
* Simulation	This technology can be used for simulating movements in specific sports
* Communication	In distributed game play, the players can communicate using the technology
Engagement	High engagement comprises the sum of gamification and the use of novel technology
* First-person view	The player can observe a professional athlete's viewpoint when performing a specific movement
* In situ guidance	The teacher could give guidance and make interventions through the centralized server
* Hands-free access	In the future, the game could be played without a handheld device, e.g., using smart goggles
Feedback	Heart rate and calorie expenditure are shown to the user
Efficiency	Efficient PE is achieved by combining exercise and pedagogy
* Presence	Presence could be improved in distributed game play by augmented reality
Distribution	Players can be distributed over the internet
Freeing up space	The game board can be installed anywhere and moved around
Gamification	A real-world setting is turned into a board game
+ Quantification	The game explains the importance of exercise for one's body based on quantified biosignals
+ Augmentation	The game augments physical activity with pedagogical content (and vice versa)

is to give the mind time to relax. Therefore, we suggest that when RO2 is used outside lessons, its pedagogical content should be omitted or changed into content that is more suitable for spare time, such as information related to hobbies.

Our study of combining an exergame with wearables in the context of PE obtained encouraging results, including statistically significant differences in learning outcomes between the game group and control group, but we acknowledge that this study had several limitations that must be considered in follow-up research. First, the evaluation period was short so we do not know the long-term effects of the game. Second, the study population size should be increased to obtain more accurate results. Third, the evaluation was conducted among third grade students in South Korea, thereby excluding other age groups and cultural contexts. Finally, RO2 does not take full advantage of the capabilities of the wearables, e.g., the Microsoft Band device was only used for collecting data but it could also be used to interact with players.

6 Conclusion

RO2 has several elements that make it interesting for demonstrating the educational possibilities of wearable technology and gaming. One of these elements is how hands-on activities (i.e., sensor-driven physical exercise) can be augmented with brains-on content (i.e., pedagogical content) while keeping the players engaged through gamification. This was supported by the evaluation results because the responses were positive among 32 third grade students and their teacher in South Korea. The learning effect was stronger with the game than the traditional studying method, but the longitudinal learning effects of the game still need to be verified. Improvements can be made to the study design and the system employed, but our results may be useful for educational technology researchers and PE experts who are interested in combining wearables, educational content, and gaming.

The RO2 concept can be expanded in the future by including more versatile rules, learning topics, and activities. For example, we could combine chess rules with science or language learning content. Thus, when a move is made while using wearable technology, an activity will appear. The uses of wearables in these activities could vary, but a good starting point would be to consider the affordances described in Table 4.

The next steps in the development of RO2 include improving the PAR accuracy, developing more physical and pedagogical missions based on the affordances of wearables, personalizing the missions based on the player's profile, and adding more curriculum content to cover different age groups. Based on these improvements, we aim to address the challenges of PE and the issues that arise when using wearables in education. Finally, an important future research task is performing an extended evaluation of the game to measure its long-term pedagogical, motivational, and physiological effects in order to verify the benefits of exergames.

Acknowledgments

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