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FUTUREGYM: A gymnasium with interactive floor projection for children with special needs

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ABSTRACT

Interpersonal interaction is one of the fundamental factors for successful inclusion in education for children with special needs, including children suffering from autism spectrum disorders (ASD) and/or intellectual disabilities (ID). In order to increase opportunities for interpersonal interactions among children, an interactive school gymnasium called FUTUREGYM, with a large-scale, interactive floor projection system in a school setting is proposed. As part of this study, high performance projectors (approximately 545-inch of total screen size) and tracking cameras mounted on the ceiling were installed in the gymnasium of a special needs school; these devices facilitated overlaying of individual visual aids for children with special needs. Visual aids help these children to be aware of social cues, a behavior that is considered important for the development of social interaction. Group activities to be conducted in FUTUREGYM were designed through careful consultations with teachers at the school: (1) Group running, called Circle-Run, provides an opportunity to experience a behavior that requires coordination with others, and (2) A group exergame, called Constellation Game, provides a situation to trigger helping behaviors by requiring them to be aware of other players' difficulties. The feasibility of these activities has been confirmed in this study through viability tests with the school's children with ASD and/or ID.

1. Introduction

Neurodevelopmental disorder (ND) defined in DSM-V [1] is characterized by marked language impairment, abnormal behavior, or deficits in communication and social interactions, and it includes conditions such as Autism spectrum disorders (ASD), intellectual disabilities (ID), and communication disorders. Approximately 1 in 68 children has been identified with ASD, which is reported to occur in all racial, ethnic, and socioeconomic groups [2]. Children with ND often exhibit severe problems related to social interactions [3,4], which may prevent their successful inclusion in a general educational environment. The challenge of interaction with others lies in the grasping of social cues such as facial expressions, physical gestures, and eye contact, which are often not understood nor produced by these children, hindering their ability to communicate socially. Enhanced social interaction has been considered one of the most important intervention outcomes [5].

The present study focuses on increasing opportunities for interpersonal interactions among children, which is an important element leading to social interactions. Interpersonal interaction starts with being aware of social cues; however evidence suggests that it is challenging for individuals with ND [6–9]. A practical tool for enabling children with ND to be aware of social cues is a visual aid. Visual aids can enable these children to gain an understanding that result in effective communication and to accommodate the support required by them to develop their capability for daily activities [10]. The varied applications of visual aids utilize low, medium, and high-level technology [11]. High-tech applications include technological devices such as computers and mobile devices. It has been found to be implemented successfully with children with ND; for example, it enhances the attention span of children with ND, reduces their behavioral issues, or facilitates their play and game skills [12]. However, a majority of high-tech assistive technologies exhibit limited flexibility. For instance, they limit children's attention to a device screen, which is not practical for activities that require interpersonal interactions with a large number of children and/or vigorous movements.

Considering this background, the present authors propose a large interactive floor of a school gymnasium, called FUTUREGYM, which is installed with a Spatial Augmented Reality (SAR) system using a projection mapping at the Special Needs School at Otsuka (SNSO) in Tokyo, Japan. SAR provides graphical information on real-world objects [13], and the system scales up naturally to groups of children, thus, allowing for collocated interpersonal

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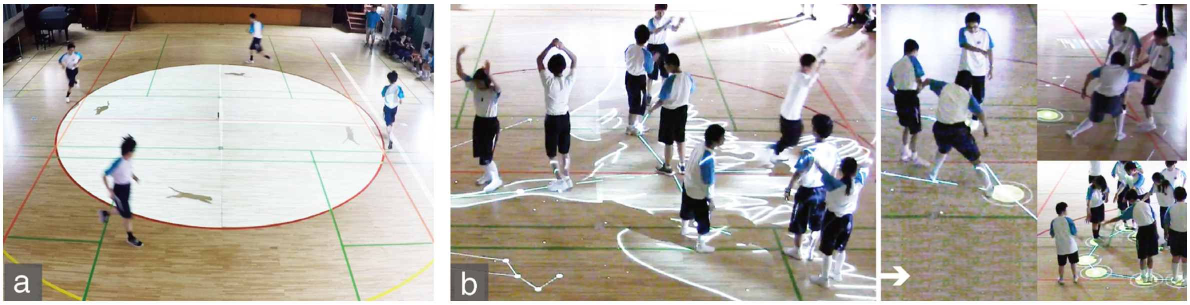

Fig. 1. Two group activities of FUTUREGYM, which increase opportunities for interpersonal interactions among children: (a) Circle-Run helps them to pay attention to running members' pace and positions to achieve cooperative running; (b) Constellation Game promotes positive behavior (left) and helping behavior (right) by requiring them to be aware of other players' difficulties.

interactions among the children. It is considered by the present authors that FUTUREGYM overlays individual visual aids for the children in their environment not only to make rule-guided behavior by following the specified visual guidance, but also to make voluntary behaviors that will result in increased opportunities for experiencing interpersonal interactions including cooperative and helping behaviors. These are regarded as voluntary wayfinding behavior. In this scenario, floor projection is an effective tool for children to understand the visual aids.

This paper describes the concept and configuration of the system developed in the gymnasium as well as two group activities performed following a participatory design approach with teachers at the school. The activities aim to assist children with ND to be aware of social cues, which enables them to experience more interpersonal interactions. The first activity, called Circle-Run (Fig. 1a), provides an opportunity to experience a behavior that stands in need essential actions for practicing social interaction, which is to coordinate with others. It requires children to pay attention to others' running conditions in order to realize cooperative running. Intuitive visual aids assist children's attention to achieve cooperative running behaviors. The second activity, called Constellation Game (Fig. 1b), provides a situation to trigger their social interaction. It requires them to be aware of others' challenges in completing a shared goal. The game stimulates helping behavior and the experience of Positive Behavior. The present authors have confirmed the feasibility of the activities with students at SNSO.

The main contributions of this work can be summarized as follows. First, FUTUREGYM was designed in the school setting, which accommodates a large-scale floor projection system for supporting activities of students with special needs and aimed at increasing their experience of interpersonal interactions. Two group activities, namely, Circle-Run and Constellation Game, were designed in close consultation with teachers to foster interpersonal interactions such as cooperative and helping behavior. The present authors confirmed through a viability test that the individual visual aids of the system enabled children to exhibit cooperative behaviors, and facilitated helping behavior by assisting them in being aware of social cues.

This paper begins by reviewing related works with a focus on interactive technologies for children with ND. Later, the concept, configuration, and design decision-making processes of FUTUREGYM are explained. Then, viability testing of the two group activities conducted, Circle-Run and Constellation Game, is described. The discussion and conclusions are presented that summarize the results obtained from the studies. Lastly, research prospects and future work are mentioned.

2. Related works

Interactive technologies for supporting children with ND have been gaining high attention in recent years. The applications of interactive technologies are diversified, including robotics [14,15], virtual reality [16,17], tabletops [18,19], tablets [20], speech output [21], and computer-mediated communications [22]. The fact that children with ND exhibit a high affinity toward interactive technologies is probably due to the predictable and controllable feature of computer-centered technologies, which efficiently provides immediate and consistent feedback of an application [23]. Although it is widely reported that interactive technologies are successful when they are applied to an individual with ND, there are limitations when they are applied to a small group of individuals. Because the present study aims to increase opportunities for interpersonal interactions among children with ND by assisting their activities at school, it is essential to design solutions that can adapt to a large number of children and facilitate interactions with human partners. Moreover, as the focus is assisting children with ND in attaining more interpersonal interactions at their school, it is preferable to overlay individual visual aids in their environment while ensuring the continuation of the school's regular operations. In addition, although numerous studies have been conducted on social skill training, and there is evidence that the development of social interactions can be triggered under laboratorial or clinical settings, it is critical to be applied in the child's daily life at their home or at school. Considering the requirements, the present authors focused on interactive floor projection, which exhibits the prospective potential for realizing these essential requirements.

Projecting visual aids in a space is a promising support methodology because of the advantage of large space for physical movement as well as the characteristic of visual presentation of information, which is a preferred form of learning and aid for individuals with ND [24]. Furthermore, visual information is more easily processed by such individuals compared to verbal information [25,26]. There is evidence that animated or video aids are more effective in conveying information than static visual aids [27], and large screen displays are more effective than smaller screen displays [28]. Thus, a floor projection can provide intuitive visual aids for children with ND.

One of the first spatially augmented and mixed reality projections for children with ND was "MEDIATE" [29,30]. It was designed to provide children suffering from severe ASD an opportunity to play and discover with fun in a regulated and safe space using interactive rear projection screens (3.0 × 2.3 m). A full-body interactive game called "Lands of Fog" facilitates social interaction among children with ND by using a floor projection [31,32]. It uses a circular floor projection of diameter 6 m, wherein children physically move in the space and within the virtual environment. The facility utilizes interactive virtual elements to foster joint attention of children and engage them to exhibit voluntary wayfinding behavior for exploring novel features in the game as well as collaborating with each other; these contribute to the development of their social interaction. An interactive floor exergame, "SpaceHunters", provides a role-modeling tutorial about eye-foot coordination exercises for children with ASD [33]. The game requires collaboration among the participants to achieve the goal, which facilitates the development of their social interactions as well. An exercise game, "Hunting Relics", also promotes collaborative physical exercise among children (4–6 years old) using an interactive floor [34]. It uses a background story to immerse children into the game dynamics in order to foster their collaborative behavior. A recent study reported that Hunting Relics augments exercise routines, keeps the children engaged, and induces them to seek new collaborative practices to support exercising [35]. "SensoryPaint" uses a large display that allows children with ND to paint with physical objects and full-body interactions. A lab-based study of 15 children demonstrated that it promotes social interactions [36].

Prior studies have demonstrated the prospects for the use of interactive projection for children with ND to learn fundamental social interactions during physical movements.

A number of them attempted to ensure children's attention to virtual elements provided on a screen and deployed an intervention in the context of the virtual environment. In contrast, the present authors' activities aim to assist children in being attentive to people playing with them in order to foster interpersonal interaction among them. Therefore, Circle-Run requires each runner to pay attention to the other runners' pace and position to produce better results, and Constellation Game requires being aware of challenges that other players' face in the achievement of a goal. The visual elements in the activities play the role of aid to children to increase opportunities to experience interpersonal interactions rather than that of main intervention.

Moreover, FUTUREGYM has an interactive screen of a size of approximately 545 inches in total, which has the potential to realize effective visual aids for students with ND in order for them to experience interpersonal interactions during physical movements. It can be applied for activities involving a large number of individuals (up to approximately 25) or for carrying out vigorous exercises such as running, which cannot be realized by interactive floor projections from previous studies. Furthermore, an important feature of FUTUREGYM is that the system is installed in an actual school setting, which provides the following benefits:

- Individual visual aids for supporting students' activities can be overlaid in their familiar environment;
- Long-term interventions can be applied to them in their environment;
- The school setting enables a participatory design approach that adapts the design process to the end user's environment, and takes into consideration the insights of the teachers and students. It also enables their involvement in the design decision-making process.

3. FUTUREGYM

The interactive environment called FUTUREGYM is aimed at the development of interpersonal interactions of children with special needs. The goal is to provide them with the opportunity to learn among their friends to deepen social relationships—irrespective of whether individuals are neuro-typical, and build self-esteem in order to realize successful inclusive education. As inclusion is not a straightforward issue of placement, it requires an individual-need based approach. This study attempts to establish this approach by using interactive technologies, as illustrated in Fig. 2. Certain wearable devices in the figure were developed in previous studies by the present authors [37–40]. Among the key elements of FUTUREGYM, the floor projection is one of the most critical and effective tools for supporting children's activities. The floor projection is used for navigating or guiding them to a certain state as well as for overlaying individual visual aids aimed at voluntary and wayfinding behavior. The goal of the visual aid is to provide children a clue for determining solutions to the problems they encounter. The purpose of using the interactive floor projection is to help them determine a path or target as well as to facilitate individual voluntary behavior. To realize the goal, the study began by installing the floor projection system in the SNSO to develop the environment of FUTUREGYM. SNSO is affiliated with the University of Tsukuba and provides systematic courses of special education, consistent throughout preschool, elementary, junior high, and high schools for children with special needs, mainly ASD and/or ID. The following paragraph describes the configuration of the floor projection system.

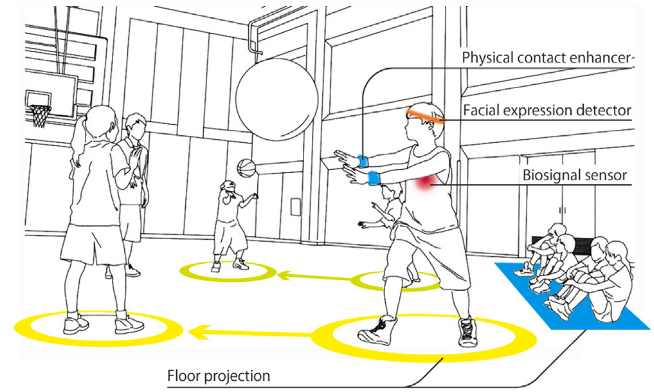

Fig. 2. Concept illustration of FUTUREGYM.

Fig. 3. Digital light processing (DLP) projectors and cameras on the ceiling of the gymnasium.

3.1. Configuration of the system

Eight digital light processing (DLP) projectors (Panasonic, PT-DW100W) and five cameras are installed on the ceiling of the gymnasium (Fig. 3). Two projectors are combined in a cylindrical box (ø780 × h730 mm) to increase light intensity in order to realize a clear projection in a bright environment. Each projector has a resolution of XGA (1024 × 768 pixels), light intensity of 10 klm, and weight of 18 kg, and they are placed at four locations. The maximum size of the projection area on the floor is approximately 8.2 × 11 m, which is approximately equivalent to a screen size of 545 inch in total (Fig. 4a). The distance from the projector lens to the floor is 4.7 m. Four cameras (Point Grey BFLY-PGE-23S6C-C, Lens: HS0619V 6 mm) are fixed on the projector box, and a fish-eye camera (Point Grey BFLY-PGE-13S2M-CS, Lens: M13VM246) is fixed in the center of the ceiling. The images collected from the cameras are used to observe students' behavior and movements.

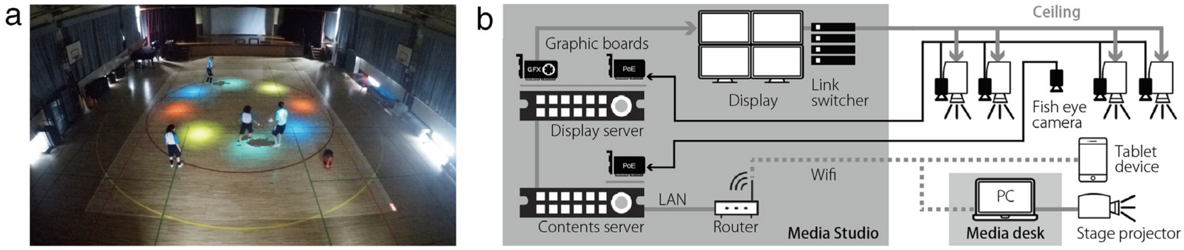

Fig. 4. (a) Floor projection of FUTUREGYM (Projection size: approx. 545 inch). (b) Configuration of the floor projection system.

As the school gymnasium floor is made of wood and particular coat lines are painted on the floor, anti-reflection coating has been applied to the floor in order to project a clear image and simultaneously realize a floor that exhibits friction appropriate for physical exercise in a gymnasium for children with ND. In addition, automatic curtains are installed for illuminance adjustment of the gymnasium space. These considerations are fulfilled in order to ensure the accomplishment of a gymnasium's role in a school.

Fig. 4b illustrates the configuration of the FUTUREGYM system. The system control area is divided into a section beside the stage, called Media Desk, and a small room on the second floor called Media Studio. The projection image generated from the contents server (CPU: 3.30 GHz, RAM: 16 G, OS: Windows 8.1 Pro) is transmitted to the display server and monitored by four jointed displays using a graphic board (NVIDIA, NVS 510). The image on the display is projected by the four projectors on the ceiling through a link switcher (Panasonic, ET-YFB200). The captured images from the ceiling cameras are extracted by the content server through an Ethernet network interface card. A projector (Panasonic, PT-DW100W) is installed on the stage, and an image is projected through the projector from a computer at the Media Desk. A router is connected to the contents server; therefore, the computer at the Media Desk or other mobile devices can communicate wirelessly with the content server. The devices at the Media Desk are mainly intended for the teachers at the school; they were developed with the aim of integrating the system with the school curriculum in the future.

4. Design decision-making process

Five researchers at the University of Tsukuba, sixteen teachers, and sixty-six students from preschool to high school at SNSO participated in the design decision-making process of the study. The design process was organized with the approval of the ethical committee of the Education Bureau of the Laboratory Schools, University of Tsukuba.

There are four feasible roles of end users for a participatory design approach: "Users", "Testers", "Informants", and "Design Partners" [41]. In this study, the teachers and students participated in the design decision-making process in the roles of "Design Partners" and "Informants", respectively. The teachers were entrusted the role of "Design Partners" because they are highly attentive to each student's characteristics and are potentially aware of the problems or requirements for their classes. More critically, they are the main end users of FUTUREGYM. The students were involved as "Informants" at various occasions such as during observation of their behavior in their classrooms or viability testing. Involving children with ND as "Informants" in a design process is adequately demonstrated in [18,42].

Six iterative steps were followed: (1) problem finding, (2) observation, (3) visualization and sense making, (4) ideation, (5) prototyping and testing, and (6) viability testing. Two group activities were designed as the outcome of the steps: Circle-Run and Constellation Game. Over 83 days, two problem finding sessions, three visualization and sense-making studies in the meeting room with the teachers, four occasional ideations, and three prototyping and viability tests were conducted.

Through careful implementation of the repetitive steps, design decision-making was conducted for the activities, Circle-Run and Constellation Game while keeping in mind the aim of assisting the children in being aware of social cues, which is a fundamental behavior that results in social interactions. Although several concepts for FUTUREGYM activity had been developed at the ideation session, these activities were selected for the research purpose as they exhibit high potential for increasing children's opportunities to experience interpersonal interactions. The viabilities of Circle-Run and Constellation Game were tested at the end of the design process.

5. Circle-Run

The initial concept of Circle-Run was obtained from the first session of the design process. The teachers focused on the fact that children with ND exhibit significantly higher odds of being overweight and obese than typically developing children [43]. Adolescents with ND are two to three times more likely to be obese than typically developing adolescents [44]. Moreover, they encounter decreased engagement in physical activities [45]. Accordingly, teachers at SNSO implement a small running activity in physical education (PE) classes to enhance their fitness level and interpersonal interactions simultaneously. The activity aims to enable them to understand that physical activities can provide challenging opportunities for enjoyment and cooperation. During observation of the PE classes, the researchers observed the challenges that the students encountered while they were running around a circle line (ø8 m) on the floor of the gymnasium for 10–15 min. Although the activity itself was neither complicated nor highly physically demanding, it was not easy for the students themselves to maintain the running pace and remain motivated to achieve a health-enhancing level of running. A number of students ran with an irregular pace and disrupted the others' running paces, which collapsed the group running. In addition, they were easily being demotivated and stopped running during the practice. Once a student stopped, other students also slowed down and stopped. To maintain the students' running paces, the researchers and teachers decided to develop a running pacemaker. Animations of animals were used for the pacemaker because they effectively attract children's attention. This idea was a result of the teachers' empirical views. The first prototype was reviewed with twelve teachers from preschool to high school. Pacemakers were placed in four different locations keeping the same distances among each one around the circle line on the floor in order not to hit each other while running. The teachers ran around the circle by following the pacemakers during the session. The important observation here is that the pacemaker is more useful for assisting students' cooperative running. This is because a number of students find it challenging to pay attention to other runners' paces, which is required for achieving cooperative running. For example, when a

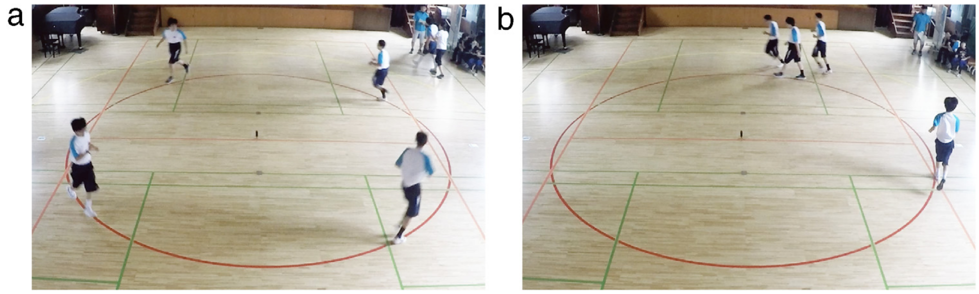

Fig. 5. (a) Running formation 3 s after the start. (b) Running formation 40 s after the start.

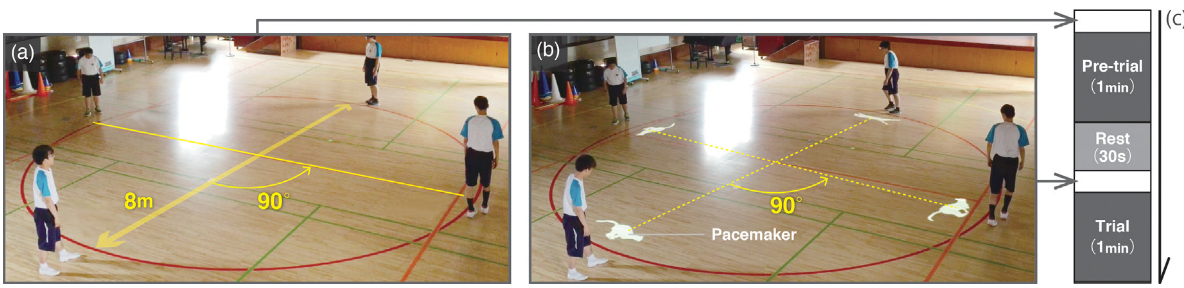

Fig. 6. (a) Starting position of Pre-trial. (b) Starting position of Trial. (c) Procedure of the experiment.

teacher instructed them to stand in four locations, as shown in Fig. 5a, and maintain the formation while running, the formation easily collapsed, as shown in Fig. 5b.

Being aware of their own paces and the other runners' paces plays a critical role in the maintenance of the running formation. It corrects the error detected from the variation between the desired and actual running formation. When children do not pay attention to others' running, the formation results the one as shown in Fig. 5b. Because children with ND find it challenging to pay attention to social cues as mentioned in the literature, the pacemaker has the potential to assist this behavior. The pacemaker simplifies the process of being aware of social cues required for cooperative running and helps children to understand the procedure for developing a desired formation. It reduces eye-tracking points from three runners to one animal and eliminates the need for estimation of running formation based on relative distance among the other runners. This simplification enables them to attain a desired running formation more easily. The visual aid of Circle-Run, the pacemaker, guides them to experience a behavior that requires an essential action for practicing social interaction that is to coordinate with others.

After certain modifications and prototyping tests with sixty-six students from preschool to high school, viability testing was conducted.

5.1. Viability test

To verify the feasibility of the pacemaker of Circle-Run, the following aspects were examined:

(1) Do the students exhibit rule-guided behavior and follow the pacemakers in the required manner?

(2) Does the designed running visual aid exhibit the potential to modify students' running behavior that results in cooperative running?

The first aspect was verified by comparing the running behavior of students with and without the pacemakers in order to confirm that the pacemaker helps them to experience coordination with others. Twenty students (fourteen males and six females), of chronological age ranging 15–18 years (mental age: N/A to 7 years) with mild/moderate ID and/or ASD, participated in the experiment. The experiment was conducted in a PE class. The levels of ID and/or ASD were measured through a five-grade evaluation based on IQ and social maturity scales specified in the identification booklet issued by the Tokyo Metropolitan Government. The mild and moderate levels correspond to IQ50–75 and IQ35–49, respectively. All the students of several classes participated in the study as a part of their class lessons.

Five groups of four students each were created as follows: Group 1 and 5 were all males; each of Groups 3 and 4 included one female; and Group 2 consisted of four females. Two types of running stages were conducted with these five groups: Pre-trial, which involved running without the pacemaker, and the Trial, which involved running with the pacemaker. Fig. 6c illustrates the procedure for these two types of running. Each student stood on his/her position, conducted the Pre-trial for 1 min, and then took rest for 30 s. Subsequently, they stood on the same position and conducted the Trial for 1 min. During the Pre-trial, each student was instructed to run around the circle (ø8 m) and maintain a constant distance between his/her position and that of the peer ahead of him/her (Fig. 6a). They were also instructed to not run either too fast or too slow and to maintain pace with their peers. During the Trial, students were instructed to follow the pacemakers projected before them (Fig. 6b). They were instructed not to overtake or fall behind the pacemaker animals and maintain the same pace as them.

The second aspect was verified by comparing the running behavior of the students before and after running with the pacemakers in order to investigate the effect of experiencing cooperative running brought by the support of the pacemaker. The students of Group 1 (four males) participated in this experiment. The procedure was similar to that of the first experiment, except for additional running without the pacemaker (Post-trial), which was conducted after the Trial. During Post-trial, each student stood on his/her Pre-trial position (Fig. 6a) and ran for 1 min without the pacemaker.

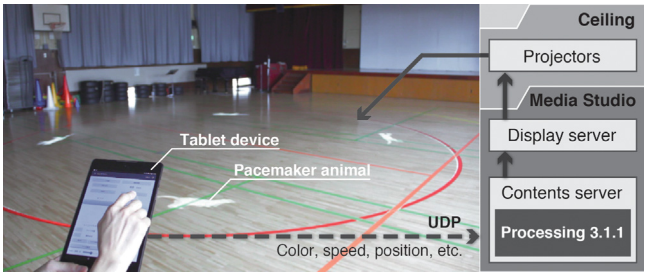

Fig. 7. Tablet device for controlling the color, speed, and position of the pacemaker animals.

The start and stop times of the pacemakers were configured by a tablet-based controller (Nexus 9, Android 5.1.1) shown in Fig. 7. The timing signals were transmitted to the content server using the User Datagram Protocol (UDP). The speed of the pacemaker was fixed to 2.5 m/s, which corresponds to a slow jog [46]. Black and white colors were used for the floor projection in order to maintain the visibility of the projected images in the bright space setting. The projected images were developed using Adobe Illustrator and Photoshop CS5, and the animations were developed using Processing 3.1.1.

5.1.1. Results

Videos of the students' running were obtained from the fish-eye camera on the ceiling with a frame rate of 15 fps. The position of each runner was detected in the videos by using Kinovea, and θ_i represents the angle between a runner and the runner ahead of him/her (Fig. 8d). While running, when the distance between a runner i and the runner ahead of him/her is maintained and is equal to that at the starting point, as shown in Fig. 8b, θ indicates 90°.

Fig. 8c and e exhibit transitions of θ_i among Group 1. All the angles, θ_1 to θ_4, are distributed over a large range during the Pre-trial (Fig. 8c); however, all of them are approximately 90° during the Trial (Fig. 8e). RMSD(i) (Root Mean Square deviation) of the student i was calculated as follows:

$$RMSD(i) = \sqrt{\frac{1}{N}\sum_{S}^{N}(\theta_i(s) - 90)^2} \tag{1}$$

where $\theta_i(s)$ represents the θ_i at the frame s. i and N indicate the number of students and number of frames in the videos (15 fps × 60 s), respectively.

Fig. 9a presents the average of RMSD of each group during Pre-trial and Trial. The bar represents the standard error. This result indicates that the pacemaker effectively stabilized θ_i to approximately 90°, which indicates that each of the runners' positions and running paces were adequately coordinated. It also indicates that looking at the pacemaker and following it from behind is easier than keeping one's eyes on others' running paces and positions. The result indicates the usability of the visual guidance for providing an opportunity to experience the desired outcome.

Fig. 9b presents the RMSD for each student in Group 1 during Pre-trial, Trial, and Post-trial. Although the RMSD of Post-trial is larger than that of the Trial, each runner decreased his RMSD during the Post-trial in comparison with the Pre-trial. This preliminary result indicates that the intervention using the pacemaker (Trial) has the potential to modify students' running behavior. Each student enhanced his cooperative running behavior that requires adjustment of one's own running pace and position in relation to those of the other group members. It insists a potential of improvement of their behavior brought by the practice with the visual guidance. The enhanced results can be anticipated in a long-term intervention.

6. Constellation Game

Play is important for children's physical and cognitive development [47], and it allows children to become part of a group as they interact with others [48]. However, children with ND playing on playgrounds are often unengaged with their peers, making few attempts to interact with others and being less responsive to other's offers for social interaction [49]. Moreover, cooperation on the playground is viewed as one of the major challenges for individuals with ND as it requires shared acts, intentions, and planning, which are all considered to be impaired in ND [50–52]. According to the context, the initial concept of a large group exergame, called Constellation Game (Fig. 10), was proposed in the first session of the design process. The researchers and teachers decided to create the cooperative exergame, which aims to provide opportunities to trigger helping behavior (HB) in order to develop students' cooperative behaviors. Constellations were included in the theme of the game because a number of the children at SNSO are curious about the night sky. This is because they go on a field trip every year as part of summer camping, wherein there is an activity of watching stars at night. The teachers recommended that providing the experience of observing and learning about constellations is preferable for the activity. In order to realize the aim of the game, a contrivance to facilitate Positive Behavior (PB) and HB is required. It has been reported that PB promotes HB; there is a strong positive correlation between them [53]. Prior studies also support the claim that positive emotions enhance learning and performance [54]. Taking this into account, a prototype of the Constellation Game was developed based on Bratman's three features of cooperative activities [55]: 1) Mutual responsiveness, 2) Commitment to joint activity, and 3) Commitment to mutual support. The procedure of the game consists of the following steps:

(i) An image of the sky with stars is projected on the floor with a certain number of players required to form a constellation displayed in the middle of the image (Fig. 10a).
(ii) When the required number of players is set on the field, the players stand outside the circle (ø8 m) and wait.
(iii) When a specific constellation is focused upon and the stars in it start to blink, the players are to reach and stand on the stars as fast as they can (Fig. 10b).
(iv) When all the stars are covered with the players, a picture of the constellation appears on the floor (Fig. 10c) and on the stage screen (Fig. 10d).

As it is required that each participant equally stand on a star projected on the floor, the cooperating partners are mutually responsive to each other, satisfying Bratman's first feature. In addition, each participant is required to share the goal of forming a constellation; it also satisfies the second feature. The third feature required an investigation, i.e., whether they mutually support each other in their roles in order to achieve the shared goal, which corresponds to HB. The viability testing was conducted with high school students at the end of the design process.

The Constellation Game was implemented using Processing 3.1.1. The illustrations of the game were developed using Adobe Illustrator and Photoshop CS5. All the procedures were manually controlled from the Media Studio by clicking the mouse of the content server. The constellation pictures on the stage's screen were projected by a laptop computer at the Media Desk.

6.1. Viability test

It was investigated whether the Constellation Game promotes PB and facilitates HB. This experiment was conducted by counting the number of PB (e.g., Fig. 1b left) and HB (e.g., Fig. 1b right). As Table 1 summarizes, PB includes clapping hands (PB1), jumping

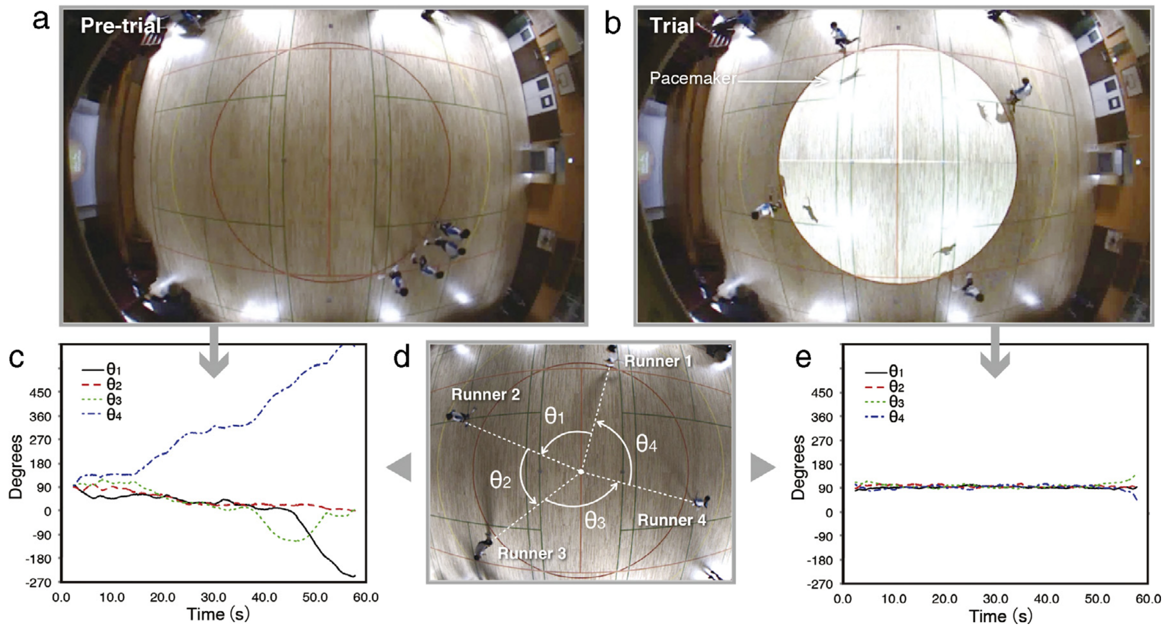

Fig. 8. Representative running position of the students in Group 1: (a) Pre-trial at 30 s from the beginning. (b) Trial at 30 s from the beginning. (c) Transition of θ_1 to θ_4 during the Pre-trial. (d) Definition of θ_1 to θ_4. (e) Transition of θ_1 to θ_4 during the Trial.

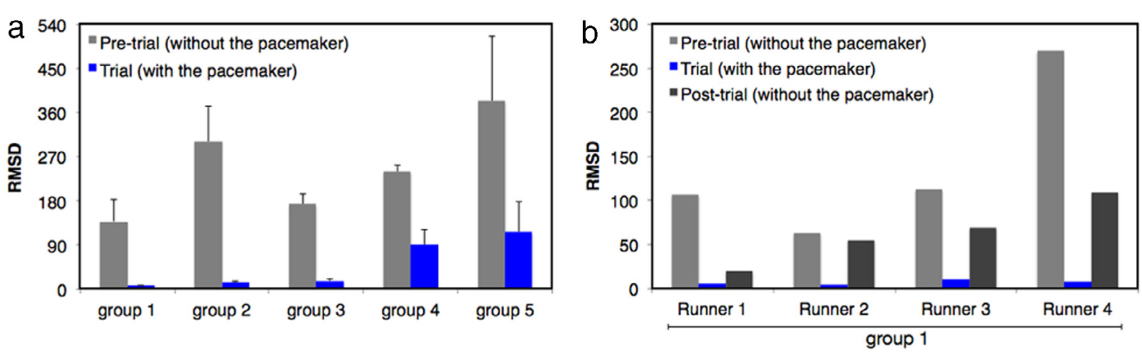

Fig. 9. (a) Average of RMSD of each group during the Pre-trial and Trial (The bar represents the standard error). (b) RMSD of each student in Group 1 before (Pre-trial) and after (Post-trial) the Trial.

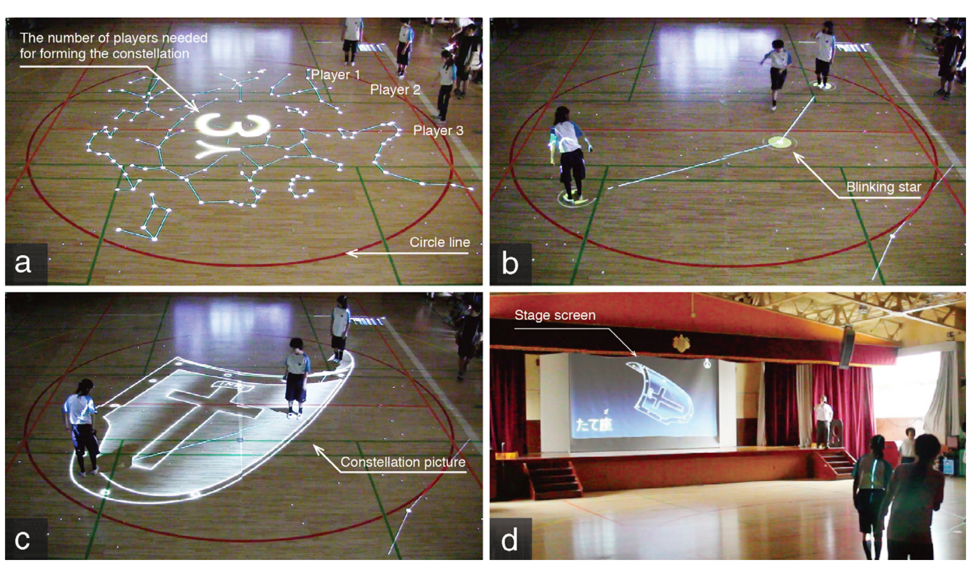

Fig. 10. (a) Indication of the number of players required for forming a constellation. (b) Blinking of the stars. (c) A constellation picture (Scutum) appearing on the floor. (d) A constellation picture projected on the stage screen.

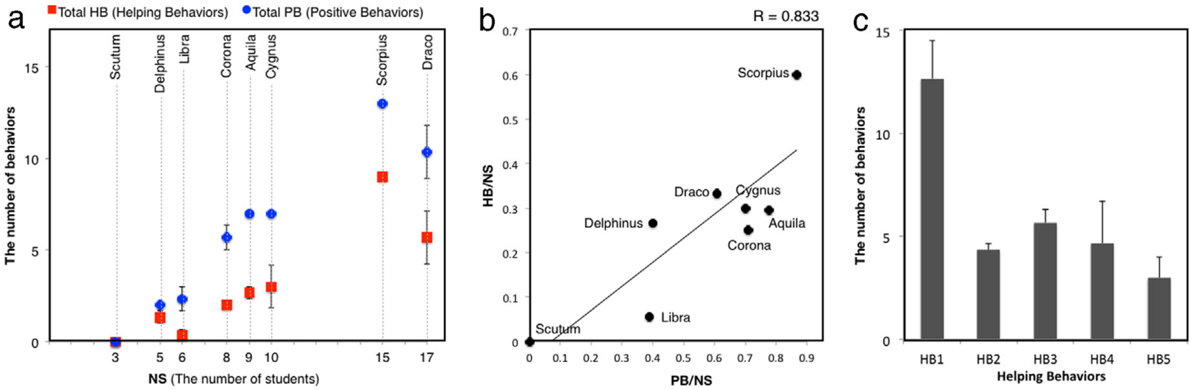

Fig. 11. (a) Transitions of total HB and total PB over NS. (b) Scatter plot of PB/NS and HB/NS. (c) The number of each type of helping behavior observed during the eight trials of the Constellation Game. (The bar represents the standard error. NS: The number of students who joined the game. Total PB: Total number of positive behaviors observed during the game. Total HB: Total number of helping behaviors observed during the game.)

Table 1
Positive behaviors observed during the game procedure (iv).

Positive behaviors (PB)	Description
PB1	Clapping hands
PB2	Jumping
PB3	Raising hands

(PB2), and raising hands (PB3); these are actions that express a positive mood. The types of HB are listed in Table 2. HB includes beckoning a peer to a vacant star (HB1), pushing a peer from behind to guide him/her to a vacant star (HB2), taking a hand of a peer to lead him/her to a vacant star (HB3), getting close to a peer for providing advice (HB4), and giving a star to a peer (HB5). Although a number of instances of finger-pointing behavior were observed during the game, this behavior was not counted as a HB, because the object of attention is often uncertain (for instance, a few players were simply pointing at a vacant star to unspecified peers). The number of PB was counted solely at step (iv) of the procedure as this was the occasion when the players displayed their expressions for having achieved completion, which largely reflects the mood of the player. The number of HB was counted at step (iii). These counts of HB and PB were manually noted by three observers from a recorded video. The observers were instructed to observe PB and HB listed in Tables 1 and 2. Acceptable matching of the noting was obtained as shown in Fig. 11a.

Twenty-three students (fourteen males and nine females with mild/moderate ID and/or ASD), of ages ranging from 15—18 years, participated in the game. The game encompassed eight types of constellations presented in sequence from small (three stars) to large ones (up to seventeen stars). This straightforward and steady order was used because it ensures success from the beginning, enabling players to maintain their motivation until the end. The participants were instructed in the rules of the game prior to its start through a demonstration with a sample constellation (Vulpecula, 3 stars).

6.1.1. Results

Fig. 11a shows the transition of the total number of PB (Total PB) and the total number of HB (Total HB) over the number of students (NS). The bar represents the standard error. As the figure shows, Total PB and Total HB increased according to NS. Although NS biases the parameters, this result indicates that the game facilitated students' PB and effectively brought about frequent HB according to the increasing number of students who joined the game. Focusing on the trends in this figure, Total PB and Total HB exhibit similar transitions: Total HB increases and decreases according to Total PB. Fig. 11b shows the scatter plot of the parameters normalized by NS. The correlation coefficient of these two parameters (0.833) indicates a strong positive linear relationship between them. This result suggests that the game facilitated players to exhibit more HB when a positive mood developed among them.

Fig. 11c shows the number of each type of HB (HB1 through HB5) observed during the eight constellation trials. The bar represents the standard error. Although all types of HB require eye or physical contact, they were on an average observed more than three times, and HB1 was observed more than twelve times. This result verifies that the game also satisfies Bratman's third feature of cooperative activities. All the types of HB listed here rarely happen intentionally among children with ND. Thus, it is assumed that the Constellation Game is an effective methodology for providing them an opportunity to help others. It can be applied as a tool for enhancing their helping behavior.

7. Discussion

FUTUREGYM was designed for supporting activities of children with special needs. By using the large-scale interactive floor projection and careful design consultations with the teachers, two group activities – Circle-Run and Constellation Game – were designed, and interesting trends in children's behavior were observed in the viability tests. Both the activities are designed so as to provide an opportunity for children to drill behavior of being aware of social cues, which is a prerequisite for interpersonal interactions. Cooperative running and helping behavior can be regarded as outcomes of the activities. Although this study presents preliminary results, FUTUREGYM exhibits high potential for providing opportunities for social interactions to children with ND.

The study, which was developed with the above aim in mind, can be summarized as follows: Circle-Run overlays a pacemaker on the floor for a group run, and it was demonstrated that it effectively enables the students to coordinate their pace and positions while running. In addition, trends of behavior modification during the group run was observed after the intervention that used the pacemaker overlaid on the floor. The running formation exhibited enhancements during the Post-trial compared with the Pre-trial. The result confirmed that the visual aid potentially maintained students' pace and positions based on their voluntary wayfinding behavior. During Pre-trial, each runner is required to be aware of the other three runners' pace and position to grasp the running formation prior to deciding whether to accelerate or decelerate his/her own pace. In contrast to this, the Trial condition requires each runner to perceive only the pace and position of an animal, which simplifies the task. It is assumed that running with the pacemaker enabled them to formulate a method to realize the

Table 2
Helping behaviors observed during game procedure (iii).

Helping behaviors (HB)	Description
HB1	Beckoning a peer to a vacant star
HB2	Pushing a peer from behind to guide him/her to a vacant star
HB3	Taking a hand of a peer to lead to a vacant star
HB4	Getting close to a peer for giving advice
HB5	Give a star to another peer

desired running formation. According to this preliminary result, it was verified that the visual aid has the capacity to modify students' running behavior. It exhibits potential for application in assisting children's behavior of paying attention to others, which is an important factor for effective interpersonal interactions. The strategy of providing an opportunity to experience interpersonal interaction in Circle-Run is similar to our prior studies by using wearable devices such as "EnhancedTouch" [39] and "Enhanced Reach" [38] that guide children to a certain behavior leading to social interaction. Circle-Run used the visual guidance on the floor to escort children to experience cooperative running. The floor projection system effectively overlays visual guidance on the real-world environment, where children conduct the group running, that cannot be done by wearable devices or wall projections. The projected images and guidance are also effective to support verbal instructions as a visual aid for the given task, which corresponds to the benefit for the broad field of ND (ex. [25,26]). It is important to note that the pacemaker does not directly improve the skill of the cooperative running, but it helps children to minimize taking actions to incorrect behaviors. The concept resembles errorless learning, which is an approach that reduces errors to help children maintain their motivation and reinforce learning [56].

Constellation Game was designed with the aim of providing opportunities for helping behavior by defining a shared goal. As the shared goal requires being aware of challenges encountered by peers, it successfully facilitated helping behaviors during the game. In addition, the result suggested that the game stimulated children to exhibit more helping behavior when a positive mood developed among them. It is believed that association of these two types of behavior would enhance learning and performance of helping behavior as a prior study indicated [54]. The strategy taken in Constellation Game for facilitating social interaction is similar to the prior studies such as "Lands of Fog" [31,32] and "Hunting Relics" [34] that uses a game with a shared goal. The result strengthens the importance of providing a situation to achieve a common target for eliciting interpersonal interactions from children. Constellation Game demonstrated it in the school setting with a large number of children. It could not have been done without the floor projection that allows groups of children into the same space at the same time. It is noteworthy that the effect of encouragement by teachers could not be precluded in Constellation Game. It probably has contributed to the result of the game. The teachers praised the students with words and gestures when they completed a constellation. However, it is considered in a positive perspective as it is a desirable behavior in a classroom. It was determined that the game has the potential for creating a positive mood, and students' motivation and teacher's encouragements facilitate the positive outcomes, which is suitable for application in schools.

In this study, characteristics of the large-scale floor projection and the school setting played important roles. Both of the activities required a large number of children and/or vigorous movements, which could not have been done without the environment. Moreover, conducting activities in the school setting, which is the students' accustomed environment, helped them to get used to the floor projection. For example, in the Circle-Run, children use both of a circle line already existing on the floor and a pacemaker overlaid by the floor projection system. It also enabled the teachers to respond immediately to some issues or difficulties that happened to the students. Because the school gymnasium is bonded to the physical domain in which the students learn and the teachers give support for them, it is an ideal place to deploy the visual guidance for their interpersonal interactions.

7.1. Limitations

The feasibility of group activities using the FUTUREGYM system, Circle-Run and Constellation Game, is established by this study. However, several limitations have been identified for each activity.

One of the limitations is that the environment is required to be adequately lighted when the students conduct physical movement activities such as Circle-Run, for safety concerns. White was used as the color for visual aids in order to realize high light intensity. Black curtains and anti-reflection coating on the floor are also applied in the gymnasium to increase the visibility of the projection in the bright condition. Although the brightness was achieved as shown in Figs. 1, 6 and 8, further enhancement is required for activities that require overlaying vivid colors on the floor. The present authors plan to delineate design guidelines to address the visibility of the visual aids in bright conditions.

Besides, dark space plays an important role in certain cases for creating positive moods, such as in Constellation Game. The atmosphere for Constellation Game could not have been created under a bright condition, and it yielded a few unexpected positive effects. For example, a remarkable incident occurred when a girl, who often exhibited fear of entering the gymnasium, joined the game voluntarily. A number of the teachers who participated in the game were amazed at the behavioral modifications in the children during the game conducted in a dark space setting. Four other activities were conducted in FUTUREGYM as outreach activities for explaining the project to the students, alumni, and parents. More than 150 children and their parents experienced the activities in the gymnasium without exhibiting any severe physical and mental problems. This fact confirms that the careful considerations are maintaining the safe environment that the school gymnasium should perform.

An issue that is considered as a limitation of Constellation Game is that images overlaid on the floor were partially covered with the children's shadows; this degraded recognition of the images in certain cases. For example, when the number of stars increased and a larger number of individuals entered the field, a number of stars were covered by their shadows. Although this did not manifest as a critical issue while implementing the game, it is desirable to enhance visibility. One of the solutions is to increase the number of projectors and beam an image from various angles. It is assumed that twelve to fifteen projectors are adequate to enhance the quality of the projected image.

Another limitation is that the manual monitoring using a video camera is not adequate for the evaluation of moods observed during the game. Moreover, measurement of facial expressions or biosignal responses of the players are required for a precise evaluation of positive behavior. It is considered that this can be achieved with devices developed by the present authors in previous studies [37,40]. In addition, real-time, precise, and individual-motion tracking using the ceiling camera is not available. To enhance the motion detection algorithm, depth cameras are planned to be installed to increase precision. However, it is highly challenging to capture small behavior of children by using the ceiling cameras. This limitation can be overcome by using wearable devices to detect and augment the reaching behavior and handshake reported in previous studies [38,39]. A long-term investigation is also a key requirement for more meaningful results from the study. The activities introduced in this paper are preliminary studies on FUTUREGYM. It is planned to implement a long-term intervention to verify whether certain modifications observed in this study are maintained over time.

8. Conclusion

In this paper, FUTUREGYM, which supports activities conducted in the school gymnasium for children with special needs, is proposed. It aims to develop their interpersonal interactions by using a large-scale floor projection system in the school setting. The system overlays individual visual aids on a floor to facilitate children's voluntary wayfinding behavior, which is spontaneous behavior that impels them to solve the problems they encounter. Two group activities, Circle-Run and Constellation Game, were designed and interesting trends were observed from the viability tests. We observed interesting trends in children's behavior from these activities. We consider that these are useful to assist children with ND to experience more interpersonal interactions that would help to enhance social interactions, which will be confirmed in the future studies. Circle-Run took an approach to make children experience a behavior that requires essential actions for practicing social interaction. This approach is similar to the studies that guiding them to a certain behavior, for example getting closer to each other [38] or shaking hands [39]. Circle-Run demonstrated the way of support in the context of interpersonal interaction among children through a group running. The result of the viability test indicated that the visual guidance effectively escorted children to experience cooperative running. There was an interesting trend that their running behavior improved after the experience of cooperative running with the visual guidance. Constellation Game took an approach to facilitate an opportunity to trigger helping behavior by providing a game with a shared goal that is similar to prior studies such as [31,32,34]. The exergame demonstrated the approach in the school setting with a large number of children up to 17 children. A trend was observed at the viability test that the children exhibited more helping behavior when a positive mood developed among them. The potential of FUTUREGYM has been established through these activities described in this paper. The next step is to provide scientific evidence of the activities from a long-term perspective and integrate these activities into the school curriculum. Moreover, additional activities are required in order to develop children's social interaction so as to realize successful inclusive education. The present authors intend to dedicate their future studies toward achieving this goal, which includes a focus on providing long-term support for students with special needs and realizing a model of inclusive education through FUTUREGYM.

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