Playing with invisible animals: An interactive system of floor-projected footprints to encourage children’ s imagination

Moriya, Kodai ; Iio, Takaya ; Shingai, Yukiya ; Morita, Tomoharu ; Kusunoki, Fusako ; Inagaki, Shigenori ; Mizoguchi, Hiroshi

(Citation)
International Journal of Child-Computer Interaction,32:100407

(Issue Date)
2021-09-15

(Resource Type)
journal article

(Version)
Version of Record

International Journal of Child-Computer Interaction 32 (2022) 100407

Contents lists available at ScienceDirect

International Journal of Child-Computer Interaction

journal homepage: www.elsevier.com/locate/ijcci

Playing with invisible animals: An interactive system of floor-projected footprints to encourage children's imagination

Kodai Moriya [a,*], Takaya Iio [a], Yukiya Shingai [a], Tomoharu Morita [a], Fusako Kusunoki [b], Shigenori Inagaki [c], Hiroshi Mizoguchi [a]

[a] Department of Mechanical Engineering, Tokyo University of Science, 2641, Yamazaki, Noda, Chiba, Japan
[b] Department of Information Design, Tama Art University, 2-1723, Yarimizu, Hachioji, Tokyo, Japan
[c] Graduate School of Human Development and Environment, Kobe University, 3-11, Tsurukabuto, Kobe, Hyogo, Japan

A R T I C L E I N F O

Article history:
Received 6 November 2020
Received in revised form 11 August 2021
Accepted 31 August 2021
Available online 10 September 2021

Keywords:
Full body interaction
Interaction design
Floor projection

A B S T R A C T

Playing is essential for a child's development, and it has various positive effects. In particular, playing with toys enhances children's imagination. In recent years, children have been tending to play with smart toys equipped with built-in computers, which present various advantages that leverage their digital characteristics. For example, smart toys can provide augmented reality functionalities through which digital information can be added to physical reality. These characteristics offer an important benefit of stimulating the interest and presence of children. However, wearable devices may be required to realize this. Wearable devices are ineffective when people do not own or cannot wear them. Therefore, we developed a system that stimulates the imagination and interest of children in playing without any wearable devices. Our system projects animal footprints onto the floor, encouraging children to play with invisible animals based on their imagination from the footprints. The footprints respond to the children's movements. To evaluate the developed system, we conducted several experiments with children. First, we investigated the fundamental effects of the system on elementary school students. Then, we investigated the different effects of various interactions. Our experimental results showed that the developed system encourages the imagination of children while playing.

1. Introduction

Playing is essential for development in children, and it has several positive effects. It helps children to develop self-confidence, collaborative skills, emotional expression and to take initiatives (Ekin, Cagiltay, & Karasu, 2018). Therefore, providing stimulating activities in playing is an important social issue.

To provide better play for children, it is important to understand which elements of play influence the player's experience (Dillon, 2010). In recent years, research has been conducted on such elements, suggesting that the play works better with human emotions and instincts, of which attachment is the most important. Familiarity with the object at play can enhance its attractiveness (Dillon, 2014). Presence is another important element of playing that makes us forget reality and experience existence in a different world and is deeply related to the motivation to play (Suhonen, Äätäjä, Virtanen, & Raisamo, 2008; Yee, 2007). By using their imagination to perceive the object beyond the information available to their eyes, players become immersed in the play (Cairns, Cox, & Imran Nordin, 2014). Their interest in playing increases their enthusiasm (Csikszentmihalyi & LeFevre, 1989).

Playing with toys can help shape children's experience and enhance their imagination (Kara, Aydin, & Cagiltay, 2014). In recent years, children are increasingly playing with toys that have computers built into them, which are quite engaging (Yilmaz, 2016). These computerized toys are called "smart toys", and they have various advantages owing to their digital characteristics. One of the benefits of smart toys is that they provide an interactive environment, in which children can develop their social, thinking, and behavioral skills (Spector, Merrill, Elen, & Bishop, 2014). Another advantage comes from augmented reality, which adds digital information to physical reality (Kara, Aydin, & Cagiltay, 2013). Augmented reality increases the interest and presence of experience (Gradl, Eskofier, Eskofier, Mutschler, & Otto, 2016). One such smart toy is digitally augmented physical spaces (Cagiltay, Kara, & Aydin, 2014). This is a seamless integration of the virtual world and the real world, which can enhance the player's experience.

In recent years, research has been conducted on the interactive floor, a digitally augmented physical space. iGameFloor is

* Corresponding author.
E-mail address: 7520573@ed.tus.ac.jp (K. Moriya).

https://doi.org/10.1016/j.ijcci.2021.100407

an interactive floor developed to provide children with a new playing experience (Grønbæk, Iversen, Kortbek, Nielsen, & Aagaard, 2007a, 2007b). This system is based on the principle of iFloor (Krogh, Ludvigsen, & Lykke-Olesen, 2004). The interactive floor is realized by projecting a screen from the bottom onto a 12 m^2 glass surface built into the floor of a school and tracking the contact points of the limbs using a camera. This allows children to experience games that they can control with their bodies. However, this system requires a glass surface and a space at the bottom for projection; thus, it is limited in terms of location. Wall Play is an interactive floor that was developed as a new mobile game (Winkler, Hutflesz, Rukzio, & Holzmann, 2012). This system allows users to play games such as bowling and golf by projecting the game screen onto the floor or wall using a cell phone with a projector function. However, the system requires special equipment to play, making it difficult for multiple people to play together. During multi-player play, children learn to get along with others and develop leadership skills (Hinske, Langheinrich, & Lampe, 2008). Therefore, there is a need for a system that enables multiple players to play together. FUTUREGYM is an interactive floor developed to promote social interaction among children with special needs such as autism and intellectual disabilities (Takahashi, Oki, Bourreau, Kitahara, & Suzuki, 2018a; Takahashi, Oki, Bourreau, & Suzuki, 2018b). This system projects a screen on the floor from a projector installed on the ceiling of a gymnasium and provides children with interactive play using wearable devices. However, since it requires a wearable device, it is not effective for those who do not have or cannot wear a wearable device.

In this study, we attempted to create an interactive floor projection that can be played without the need for a specific location or wearable device, to enhance children's imagination, admiration, presence, and attachment while playing. The idea of increasing the interest and presence was inspired by an interactive playground proposed previously, created by projecting the scenario onto a slope (Soler-Adillon, Ferrer, & Parés, 2009). Children use their imagination to play pretend games (Weisberg, 2015). Children also become attached to animals from an early age (Jalongo, 2015). Based on these ideas, we developed a floor projection system that provides interactive play with invisible animals.

In our previous studies, we first examined the fundamental effects of such a system (Morita et al., 2019a). Next, we examined the differences in our results with and without interaction (Morita et al., 2019b). In this study, we focused on the type of interaction to test whether it makes a difference on the effectiveness of the system. We investigated whether the type of interaction with footprints projected on the floor affected imagination, admiration, presence, and attachment. This paper discusses the impact of the type of interaction on the effectiveness of the proposed system.

The remainder of this paper is organized as follows. An overview and configuration of the floor projection system are provided in Section 2. The fundamental effects of the system are described in Section 3. The effects of different types of interactions are discussed in Section 4. Finally, the concluding remarks are presented in Section 5.

2. Floor projection system

2.1. Overview

The proposed system was developed for improving the interest, imagination, presence, and attachment of children in playing, without the use of wearable devices. Fig. 1 depicts the basic concept of this system. The system projects various animal footprints

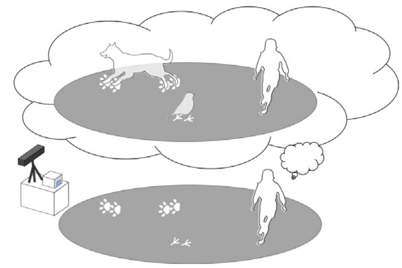


Fig. 1. Concept of the system.

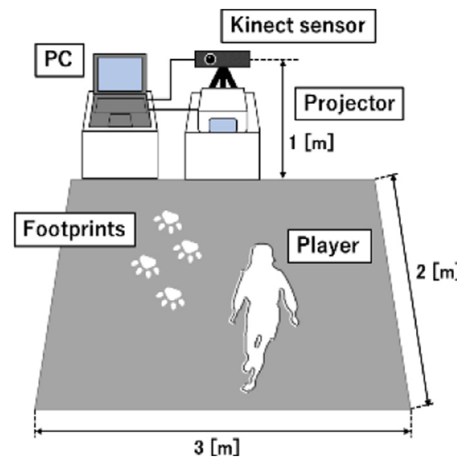


Fig. 2. Overview of the system.

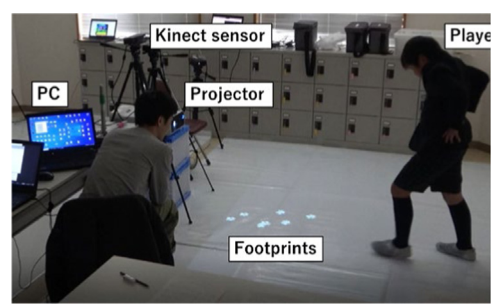


Fig. 3. Actual installation of the system.

onto the floor, and the player imagines the invisible animals from the footprints. The projected footprints are interactive. Several types of interactions exist, e.g., footprints that run away upon approach, footprints that chase people, and footprints that run around people. These interactions are expected to engage the player's imagination and interest in playing.

2.2. System setup

Fig. 2 presents an overview of the system. The system comprises a single-focus projector (RICOH, PJW4152NI), a Microsoft Kinect v2 sensor, a PC, and a play space. The single-focus projector is used to project the footprints onto the play space. Kinect v2 is an RGB-D camera capable of acquiring color and distance images, and Kinect for Windows SDK 2.0 is provided to enable non-contact estimation of human position and skeletal coordinates. This is used to measure the player's position and movement. The measured position and movement are used to make the footprints interactive. The Kinect v2 sensor is placed approximately 0.5 m behind the projector, with the distance between the sensor and the edge of the play space being 1.0 m. Note that calibration is not required for this system. The PC is used to calculate the position and movement of the footprint. The play space is a 3 m × 2 m projector screen, on which the footprint is projected. The playable area within the play space is within a horizontal angle of 70° from the Kinect. Fig. 3 shows the actual installation of the system.

The system realizes interactive play by the following steps (Fig. 4). First, the player's sacral coordinates (x_k, y_k, z_k) are measured by the Microsoft Kinect v2 sensor and converted to the coordinates on the display (u_w, v_w).

Second, a 1200 × 800 pixel application window on the PC displays footprints that resemble an animal walking. The footprints are shown from the top to the bottom of the display as the player walks, one step at a time. In that case, footprints corresponding to the number of feet will be displayed at the same time. In doing so, the footprints change their movement according to the Euclidean distance D between the coordinates of the footprint and the player's coordinates. Finally, an application window on the display is projected onto a screen on the floor using a projector; it shows the footprints moving in response to the player's position. Through the above process, players can play with footprints projected on the floor that respond to their movements.

2.3. Implementing footprints and interactions

Several animal footprints and interactions were implemented in this floor projection system. Nine types of animal footprints were implemented: rabbit, dog, bird, elephant, giraffe, gorilla, lion, human, and wild boar, as shown in Fig. 5. The size of the footprints was scaled using actual animal footprints. Dogs and birds have footprints less than 100 mm, but elephant footprints can be as large as 400 mm. Each animal has its own set of interactions.

Fig. 6 presents the interaction implemented in this system. First, the footprints appear above the play space and move downward. Second, when the distance from the player is below a threshold, the footprints will move correspondingly for each interaction.

In interaction A, the footprints follow the player (Fig. 6a). In this interaction, the footprints are displayed in such a way as to shorten the distance between the player and the footprints, giving the player the experience of being followed by an animal. Interaction A is implemented in the dog's footprint. The reason is that dogs have a habit of following their owners.

In interaction B, the footprints avoid the player (Fig. 6b). In this interaction, the footprints are displayed in such a way that they maintain a certain distance from the player, giving the player the experience of an animal avoiding the player. Interaction B has been implemented for a dog, rabbit, bird, and human footprints. Interaction B is implemented in such footprints because these animals have a habit of avoiding collisions.

In interaction C, the footprints run away from the player (Fig. 6c). This interaction provides the experience of an animal running away from the player by making the footprints appear to move away when the distance between the player and the footprints becomes less than a threshold value. Interaction C is implemented in bird footprints because birds have a habit of running away when humans approach them.

In interaction D, the footprints face and avoid the player (Fig. 6d). In this interaction, the toes of the footprints are displayed facing the player, providing the experience of an animal facing and avoiding the player. Interaction D has been implemented for gorilla and lion footprints. Interaction D is implemented in the tracks of gorillas and lions because they are fearful of humans and have a habit of looking at others.

In interaction E, the footprints stop momentarily near the player and avoid him/her (Fig. 6e). In this interaction, when the distance between the footprints and the player becomes less than a threshold, a stationary footprint is displayed for 3 s, and then the footprint is displayed to move away from the player, providing an experience where the animal stops near the player and avoids him. Interaction E has been implemented for elephants and giraffes because herbivores have a habit of freezing and becoming immobile when faced with danger.

In interaction F, the footprints attack and pass by the player (Fig. 6f). This interaction provides the experience of an animal attacking the player by making the footprints appear to go straight toward the player. Interaction F was implemented on a wild boar because it is very ferocious and lunges at humans.

3. Fundamental effectiveness of the system

3.1. Overview

Morita et al. investigated the fundamental effects of the system in terms of interest and imagination (Morita et al., 2019a). However, they did not investigate presence and attachment, which are important elements of the play. Therefore, Morita et al. reported in part on the effects of the presence of interaction on imagination, interest, presence, and attachment (Morita et al., 2019b). In this study, we investigated the basic effects of the system on the aspects of interest, imagination, presence, and attachment based on data from previous studies (Morita et al., 2019a) and newly analyzed data.

Fourteen third-grade and fourteen fourth-grade students participated in the experiment. Of these, 14 were boys and 14 were girls. The participants were first given a basic explanation of how to play with the system, followed by practical training. There were two types of systems: with and without interaction. All participants experienced the system for one minute, of which 30 s were with interaction and 30 s without. To prevent bias arising from the order in which "with interaction" and "without interaction" were played, both orders were distributed equally among the participants. We used dog footprints for the animal footprints in the system. A survey was conducted on the participants after they experienced the system. The questions were created based on the game experience questionnaire (Krogh et al., 2004). The survey collected responses from four perspectives on animals: imagination, interest, presence, and attachment. Twenty questions were prepared: eight on interest, and four each on imagination, presence, and attachment. We used a seven-point scale for the questionnaire. After experiencing the system, the participants answered a questionnaire in each case of "with interaction" and "without interaction".

3.2. Result

Fig. 7 summarizes the results obtained from the questionnaire during the interactive experience. To confirm the fundamental effectiveness of the system, an exact binomial test was conducted on the bias of the responses to the questionnaire. The number of positive responses exceeded the negative ones for all items, and there was a significant bias in the number of responses. This result confirms that this system tends to encourage interest, imagination, presence, and attachment while playing.

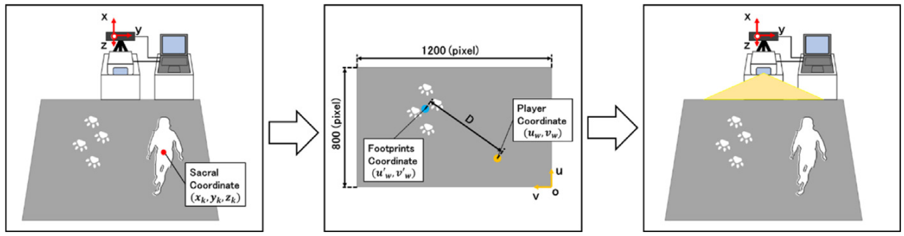


Fig. 4. Flow of interactive play provision.

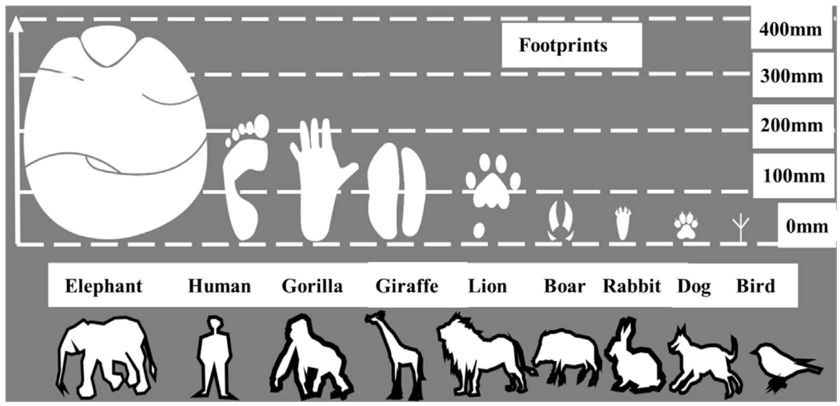


Fig. 5. Types of footprints.

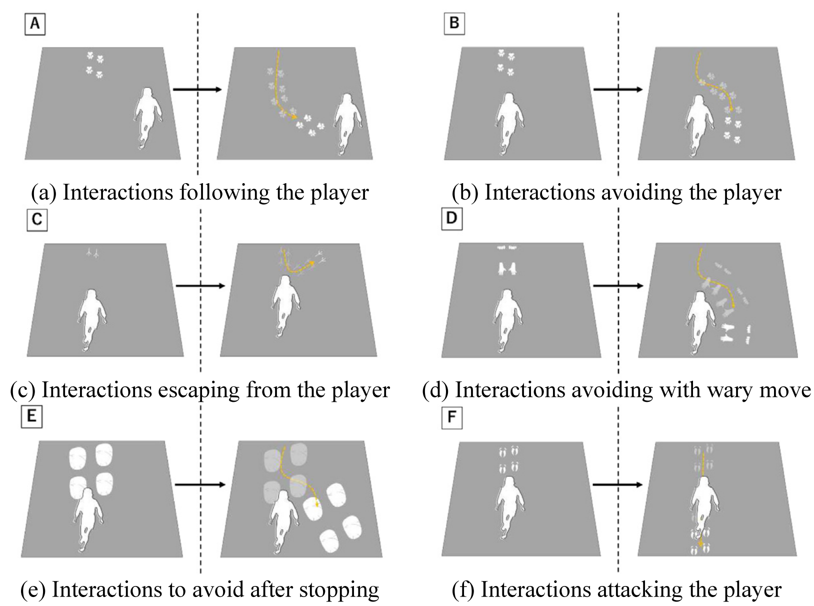


Fig. 6. Types of interactions.

4. Experiment to evaluate type of interaction

4.1. Purpose

We investigated the fundamental effects of the system in terms of interest, imagination, presence, and attachment. Then, in our quest for a more effective system, we investigated the differences in the effects of different types of interactions.

Such exploration of better systems has been done in the past as well. Thavikulwat et al. investigated the difference between the effects of realistic and unrealistic designs in a simulation game in the quest for better design (Thavikulwat, 2004). Bakker et al. investigated the difference in the effectiveness of designs with and without relevance to digital information for the pursuit of tangibles play piece design in games (Bakker, Vorstenbosch, van den Hoven, Hollemans, & Bergman, 2007). However, while there have been studies on the pursuit of such design, there have been no studies on the pursuit of interaction.

In this study, we investigated the difference in effect between realistic interaction A, in which the footprints follow the player, and unrealistic interaction B, in which the footprints avoid the player. For the footprints, we used dog footprints, which are predicted to produce interaction effects based on previous studies (Morita et al., 2019a, 2019b).

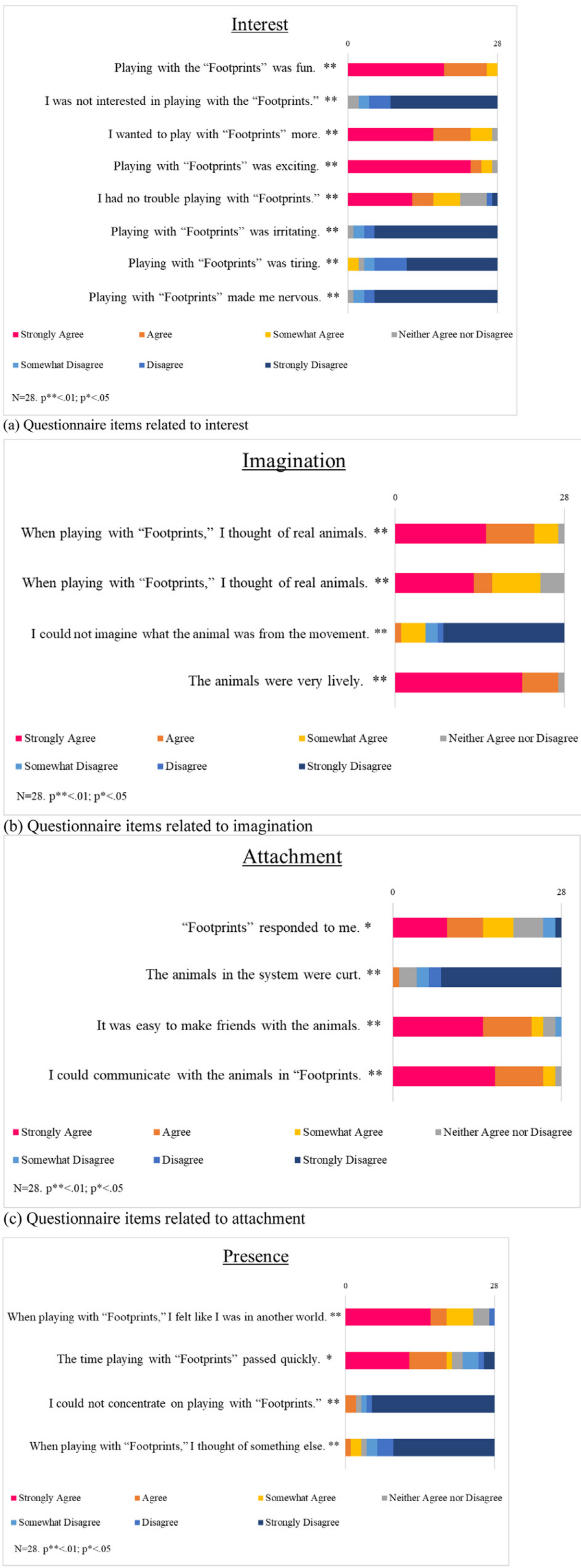


Fig. 7. Results of questionnaire survey on the fundamental effectiveness of the system.

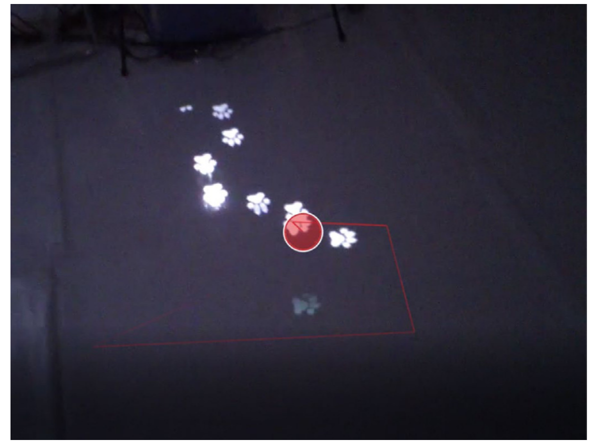


Fig. 8. Player's perspective through the eye tracker. The red line shows the player's line of sight. The red circle indicates where the player is watching from, and the longer the gaze, the bigger the circle. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Results of Shapiro–Wilk normality test.

	Interaction A		Interaction B	
	W	p	W	p
Fixation count	0.94	0.64	0.93	0.57
Total Fixation duration	0.81	*	0.97	0.91

$N = 7$. $^{**}p < .01$; $^{*}p < .05$

4.2. Methods

4.2.1. Participants

Twenty third-grade students and ten fourth-grade students at Kobe University Elementary School (seven of whom were measured using the eye tracker) participated in the study. Of these, 14 were boys and 16 were girls. Note that the subjects in this experiment had no prior experience with the system.

4.2.2. Procedure

First, the participants were instructed on playing with the system. The participants then alternated between interaction A and interaction B for 60 s each. To ensure that the order of interaction A and B did not bias the effects, both orders were distributed uniformly among the participants. The participants completed a paper questionnaire after each game.

4.3. Results

4.3.1. Data analysis

To investigate the difference in effectiveness of different types of interactions, we used a questionnaire as a subjective evaluation measure and eye tracking as an objective evaluation measure.

As a research task, the questionnaire was used to collect participants' responses regarding their imagination, interest, presence, and attachment while playing. The questions in the questionnaire were developed based on the game experience questionnaire (Ijsselsteijn, Kort, & Poels, 2013). The survey contained 20 items: 8 items on interest and 4 items each on imagination, presence, and attachment. The response method was a seven-point scale. The participants were asked to complete the same questionnaire at the end of interactions A and B.

To assess the relationship between the subjective evaluations from the questionnaire, we measured the frequency and duration

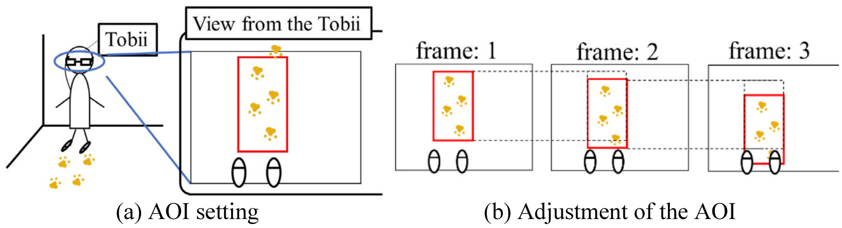


Fig. 9. Methodology for analyzing the AOI.

Table 2
Results of Wilcoxon signed rank test.

	Interaction A		Interaction B		z	p	r
	Median	(Q1–Q3)	Median	(Q1–Q3)			
Fixation count	83	(67–106)	121	(104–145)	1.67	*	0.63
Total Fixation duration	24.23	(22.79–41.63)	25.52	(19.69–33.59)	0.36	0.68	0.14

Q1: First quartile Q3: Third quartile
$N = 7$. $^{**}p < .01$; $^{*}p < .05$

Table 3
Correlation between eye tracking results and questionnaire results.

		Interest	Imagination	Presence	Attachment
Fixation count	Spearman's ρ	−0.20	−0.06	−0.26	−0.14
	P-value	0.48	0.81	0.36	0.63
Total fixation duration	Spearman's ρ	−0.12	−0.29	0.14	0.48
	P-value	0.67	0.32	0.63	0.08

of the footprints seen by the participants using an eye-tracking device. The human gaze reflects cognitive processes and provides cues for understanding thoughts and intentions (Majaranta & Bulling, 2014). There are two main types of eye movements that represent the human gaze: saccades and fixations. Saccades are the quick movements of the eyes when following an object. Fixation is the locking of the eyes on an object to obtain a clear vision. In this state of fixation, humans acquire information (Land, 2006). To measure fixation, the indices "fixation count" and "fixation duration" are mainly used. Fixation count is the number of times a fixation occurs in the gazing area. Fixation duration is the amount of time that the gaze is fixed on the object. Fixation count and the fixation duration are indicators of what the player is thinking about (Fowler, 2013).

Tobii Pro Glasses 2 was used as the eye-tracking device, and the sampling rate of the measurement was set at 25 Hz. Gaze measurements were taken while playing with both interaction A and interaction B. Fig. 8 shows the player's line of sight using the eye tracker. With the eye-tracking device, it is possible to estimate the trajectory of the player's line of sight and identify the point and time of the gaze. We compared the number and duration of times the players saw the footprints for each type of interaction. We analyzed the areas of interest (AOI) to evaluate the number and duration of times for which the players saw the footprints. The AOI is represented by a rectangle, which allows us to calculate the fixation count and fixation duration within the area. To calculate the number of times and duration of gazing at the footprints, the AOI was placed on the footprints. The AOI analysis methodology involves the following steps:

(i) The AOI is set to enclose the four newly displayed footprints (Fig. 9a).

(ii) For each frame of the video in the experience, the AOI surrounding the footprints should be adjusted to enclose the four newly displayed footprints (Fig. 9b).

(iii) For each interaction, we calculated the fixation count and total fixation duration of the footprints seen by the player during the 60 s of the experience and compared them by the interaction type.

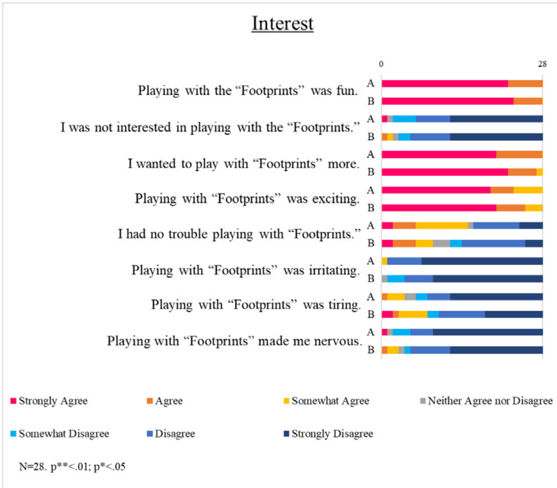
The AOI was set by two people. To validate this evaluation method, the Cohen's kappa coefficient was calculated as an inter-rater reliability index. As a result of the calculation, both the number of fixations ($\kappa = 0.77$) and fixation time ($\kappa = 0.76$) were validated, and representative values were selected for the values.

We analyzed the relationship between each item on empathy (imagination, interest, presence, and attachment) in the questionnaire and fixation count and total fixation duration. Using the following steps, we analyzed the relationship between the two. First, we calculated the total score for each item of the empathy questionnaire, with seven points for "Strongly Agree", and one point for "Strongly Disagree". For the questionnaire's reverse responses, "I could not imagine what the animal was from the movement in footprints", etc., we calculated one point for "Strongly Agree", and seven points for "Strongly Disagree". This total score was calculated for both interactions A and B. Next, we calculated the correlation coefficients for each questionnaire with the total score, and the number of times the footprints were seen. Similarly, we calculated correlation coefficients for the duration, and total points on the questionnaire. Then, we calculated p-values based on the calculated correlation coefficients and analyzed the correlation between the results of the empathy questionnaire, the number of times the footprints were seen, and the time spent looking at the footprints.

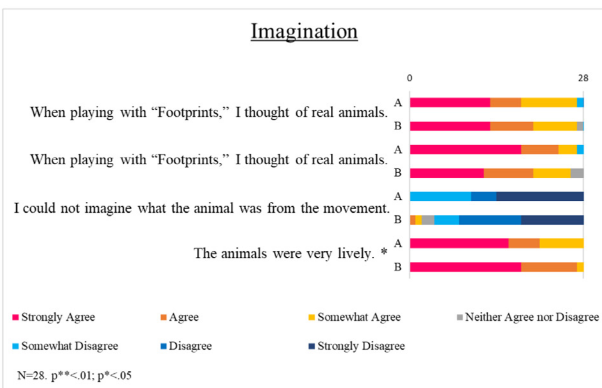
4.3.2. Analysis results

Fig. 10 summarizes the results obtained from the questionnaires. Significant differences in the effect of the type of interaction were assessed using the sign test. The results of the survey showed that there was a significant difference between the responses for interactions A and B for the item "The animals were very lively". For other items, there was no significant difference in the responses between interactions A and B.

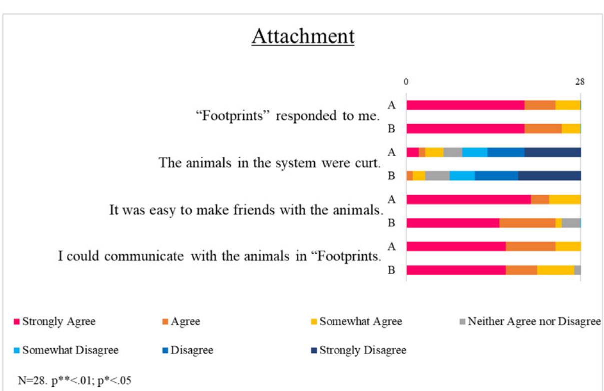
Fig. 11a, Table 1, and Table 2 show the results of the number of times the footprints were seen by different interactions. The normality of data was analyzed by the Shapiro–Wilk normality test. Significant differences in the results could be seen for the footprints in interactions A and B after analysis using the Wilcoxon



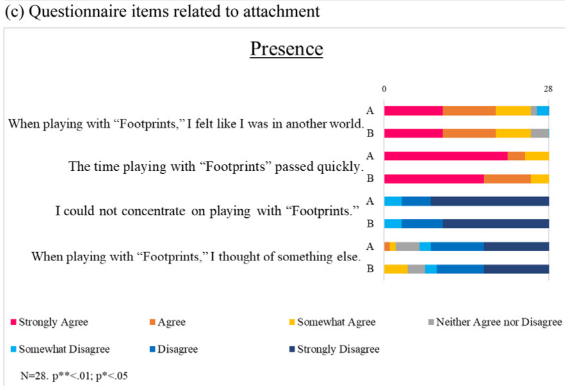
(a) Questionnaire items related to interest



(b) Questionnaire items related to imagination



(c) Questionnaire items related to attachment



(d) Questionnaire items related to presence

Fig. 10. Results of the subjective evaluations depending on types of interactions.

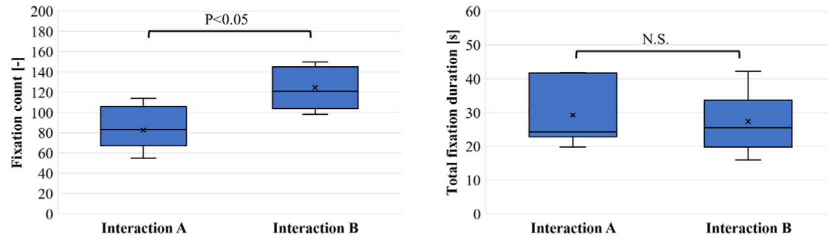
signed rank test. The analysis revealed a significant difference between interactions A and B ($p < 0.05$). Interactions in which the footprints avoided the players were seen more often than interactions in which the footprints followed. Fig. 11b, Table 1, and Table 2 show the results of the total time for which the players saw the footprints in different interactions. The results of the analysis show that there is no significant difference between interactions A and B.

Table 3 summarizes the correlation between each empathy item in the questionnaire, the fixation count, and the total fixation duration. The results of the analysis showed that there were no significant correlations among all the items.

4.3.3. Discussion

The floor projection system was developed to provide a better play experience for children. We investigated the effects of the type of interaction on interest, imagination, attachment, and presence while playing. The results suggest that the tendency to feel animals as lively is more likely in interaction B, which involves unrealistic movements, than in interaction A, which involves realistic movements. This result is similar to previous studies (Thavikulwat, 2004), which suggest that simulation games should not be designed to be realistic. The reason for this may be the difference in the speed at which the footprints move. In interaction A, where the footprints follow the experiencer, the footprints move in such a way that they reduce the distance to the experiencer. Therefore, if the experiencer does not move much, the footprints as well move less to follow the experiencer. In interaction B, in which the footprints avoid the experiencer, the footprints continue to move from the top to the bottom of the play space and avoid the experiencer when the distance between them is close. Therefore, the footprints are always in dynamic motion. The difference in footprint speed can also be supported by the results of gaze measurement: interaction B saw more footprints than interaction A. There was no significant difference in the time spent looking at the footprints between interaction A and interaction B. If the fixation time is the same and the number of fixations is higher, it can be inferred that saccades occur more frequently. Since saccades occur when we track and look at an object, the faster the speed of the object, the more saccades occur (de Xivry & Lefèvre, 2007). Therefore, we can infer that interaction B is a faster interaction than interaction A. Faster interactions require higher concentration and thus encourage imagination (Hsu, Peng, Wang, & Liang, 2014; Ip & Jacobs, 2004). Therefore, from the above differences in movement, we can infer that children tend to imagine animals as lively in interaction B.

As a result of examining the correlation between the number of times and time spent looking at the footprints, and each item related to empathy in the questionnaire, no significant correlation was found between these parameters. This result supports previous studies that found no significant correlation between imagination and gaze, and that gaze measurement is not suitable for sensing mental states such as attachment (Jennett et al., 2008; Lin et al., 2017). On the contrary, it is contrary to a previous study that found a significant correlation between gaze and presence (Jennett et al., 2008). The reason for this is the difference in the type of experience. In the previous study, Jennett et al. investigated the correlation between presence and gaze while experiencing a 2D computer game. In contrast, this study investigated the correlation between presence and gaze during the experience of a system using a three-dimensional space, where the player's body movements and gaze change significantly. The experience in the 3D space elicits body movements and large changes in gaze to the player. Presence is felt differently between virtual space and real space experiences (Sacau, Laarni, & Hartmann, 2008). Therefore, owing to these differences in conditions,



(a) Number of times the player saw the footprints (b) Total duration for which the player has seen the footprints

Fig. 11. Results of eye tracking with different interactions.

it is likely that no significant correlation was found between gaze and presence in the real-space experience. In addition, the results are contrary to a previous study that showed a significant correlation between gaze and interest (Walber, Scherp, & Staab, 2014). The reason for this is the difference in the number of gazing targets. In the previous study, Walber et al. presented multiple photographs to investigate the relationship between gaze and interest. In contrast, the object of gaze in this study was only the footprints. The room was darkened so that the subjects could concentrate more on looking at the footprints. Therefore, the subjects gazed at the footprints regardless of the intensity of their interest in the object. Because of these factors, no significant correlation is believed to exist between gaze and interest.

5. Conclusion

In this paper, we described an interactive floor projection system created to provide children with a better play experience. The system projects animal footprints that respond to the player's movements via a projector onto the floor, allowing the players to imagine the invisible animals as they play. The system implements nine types of animal footprints, such as those of dogs, rabbits, and lions, each with its own set of interactions. First, we investigated the system in terms of the key elements of play: interest, imagination, presence, and attachment, to ascertain its fundamental effectiveness. The results suggested that this system has the potential to encourage these elements of play. Next, we investigated the impact of the type of interaction on the elements of play in the search for a more effective system. We used two types of interactions in our experiments: realistic interactions that follow the player and unrealistic interactions that avoid the player. The survey was conducted by subjective evaluation using a questionnaire and by measuring the player's gaze using an eye tracker. The results showed a significant variance in the imagination item of the questionnaire, suggesting that interactions that avoid the player may encourage children's imagination more effectively. In addition, no significant correlation was found between the player's gaze and the elements of play. This result supports previous studies that reported that gaze measurement is not suitable for sensing mental states such as imagination and attachment. These results establish the possibility of a floor projection system that provides children with a better play experience without the need for a specific location or wearable device, which was required in previous studies. However, the following limitations have been identified in this system. The first limitation is that the maximum number of people the system can detect simultaneously is six. This system uses Kinect v2 and SDK to detect people. To learn interpersonal relationships through play, a system that can be played by a larger group of people is desirable. Therefore, in future work, we would like to develop a system that can detect a larger number of people at the same time by linking multiple Kinect v2 units. Another limitation is that evaluation using eye gaze measurement is inadequate for the evaluation of play elements. To evaluate mental states, such as attachment, it is necessary to sense biological signals. Therefore, in future, we would like to sense the galvanic skin response, which represents mental states. The goal of this research is to develop an engaging system that entices children to play. With such a system, we can better promote the physiological and social growth of children.

6. Selection and participation of children

All the study participants were students at Kobe University Elementary School, Japan. The study was conducted at the elementary school in a quiet, privacy-preserving room that was strictly designated for the experimental setup. Data related to the study were collected after approval from the Ethics Committee for Research Involving Direct Human Subjects at Kobe University Elementary School, following all the regulations and recommendations for research involving children. A researcher requested written consent for participation in the experiment and data collection from the children, the children's teachers, and their parents, and only those children who gave their consent were asked to participate. The children were informed in advance of the experiment and the data collection process, and their participation in the study was completely voluntary. The children had the option of stopping the experiment or withdrawing their consent for data collection at their own will.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work was supported by JSPS KAKENHI Grant Number JP18H03660. The authors would like to express their gratitude to Kobe University Elementary School, Hyogo, Japan, for the collaboration in the evaluation experiment.

References

Bakker, S., Vorstenbosch, D., van den Hoven, E., Hollemans, G., & Bergman, T. (2007). Tangible interaction in tabletop games: Studying iconic and symbolic play pieces. In *Proceedings of the international conference on Advances in computer entertainment technology* (pp. 163–170). New York, NY, USA: ACE '07. Association for Computing Machinery. https://doi.org/10.1145/1255047.1255081.

Cagiltay, K., Kara, N., & Aydin, C. C. (2014). Smart toy based learning. In *Handbook of research on educational communications and technology* (pp. 703–711). New York, NY: Springer.

Cairns, P., Cox, A., & Imran Nordin, A. (2014). Immersion in digital games: Review of gaming experience research. *Handbook of Digital Games*, *1*, 339–361.

Csikszentmihalyi, M., & LeFevre, J. (1989). Optimal experience in work and leisure. *Journal of Personality and Social Psychology*, *56*, 815–822.

de Xivry, J.-J., & Lefèvre, P. (2007). Saccades and pursuit: Two outcomes of a single sensorimotor process. *Journal Physiology*, *584*, 11–23.

Dillon, R. (2010). *On the way to fun: an emotion-based approach to successful game design*. Natick, MA: A K Peters/CRC Press.

Dillon, R. (2014). Towards the definition of a framework and grammar for game analysis and design. *International Journal of Computer Science and Information Technologies*, *3*, 188–193.

Ekin, C. C., Cagiltay, K., & Karasu, N. (2018). Effectiveness of smart toy applications in teaching children with intellectual disability. *Journal of Systems Architecture*, *89*, 41–48.

Fowler, A. (2013). Measuring learning and fun in video games for young children: A proposed method. In *ACM int. conf. proc. ser.* (pp. 639–642).

Gradl, S., Eskofier, B. M., Eskofier, D., Mutschler, C., & Otto, S. (2016). Virtual and augmented reality in sports—An overview and acceptance study. In *UbiComp 2016 adjun. - proc. 2016 ACM int. jt. conf. pervasive ubiquitous comput.* (pp. 885–888).

Grønbæk, K., Iversen, O. S., Kortbek, K. J., Nielsen, K. R., & Aagaard, L. (2007a). iGameFloor: A platform for co-located collaborative games. In *ACM int. conf. proceeding ser. 203* (pp. 64–71).

Grønbæk, K., Iversen, O. S., Kortbek, K. J., Nielsen, K. R., & Aagaard, L. (2007b). Interactive floor support for kinesthetic interaction in children learning environments. In *Lect. notes comput. sci. 4663 LNCS*, (pp. 361–375).

Hinske, S., Langheinrich, M., & Lampe, M. (2008). Towards guidelines for designing augmented toy environments. In *Proc. conf. des. interact. syst. process. pract. methods, tech. DIS.* (pp. 78–87).

Hsu, Y., Peng, L.-P., Wang, J.-H., & Liang, C. (2014). Revising the imaginative capability and creative capability scales: Testing the relationship between imagination and creativity among agriculture students. *The International Journal of Learning, Teaching and Educational Research*, *6*, 57–70.

Ijsselsteijn, W. A., Kort, Y. A. W. D., & Poels, K. (2013). In Eindhoven , M. J. Johnson, H. F. M. VanderLoos, C. G. Burgar, P. Shor, & L. J. Leifer (Eds.), *vol. 2005*, *The game experience questionnaire* (pp. 1–47).

Ip, B., & Jacobs, G. (2004). Quantifying game design. *Design Studies*, *25*, 607–624.

Jalongo, M. R. (2015). An attachment perspective on the child–dog bond: Interdisciplinary and international research findings. *Early Childhood Education Journal*, *43*, 395–405.

Jennett, C., Cox, A. L., Cairns, P., Dhoparee, S., Epps, A., Tijs, T., et al. (2008). Measuring and defining the experience of immersion in games. *International Journal of Human-Computer Studies*, *66*, 641–661.

Kara, N., Aydin, C. C., & Cagiltay, K. (2013). Investigating the activities of children toward a smart storytelling toy. *Educational Technology & Society*, *16*, 28–43.

Kara, N., Aydin, C. C., & Cagiltay, K. (2014). User study of a new smart toy for children's storytelling. *Interactive Learning Environments*, *22*, 551–563.

Krogh, P., Ludvigsen, M., & Lykke-Olesen, A. (2004). Help Me Pull That Cursor A collaborative interactive floor enhancing community interaction, Australas. *Journal Information Systems*, *11*.

Land, M. F. (2006). Eye movements and the control of actions in everyday life. *Progress in Retinal and Eye Research*, *25*, 296–324.

Lin, L., Lee, C. H., Kalyuga, S., Wang, Y., Guan, S., & Wu, H. (2017). The effect of learner-generated drawing and imagination in comprehending a science text. *The Journal of Experimental Education*, *85*, 142–154.

Majaranta, P., & Bulling, A. (2014). Eye tracking and eye-based human–computer interaction. In S. H. Fairclough, & K. Gilleade (Eds.), *Advances in physiological computing* (pp. 39–65). London: Springer London, http://dx.doi.org/10.1007/978-1-4471-6392-3_3.

Morita, T., Iwatate, S., Tokuoka, M., Taki, Y., Kusunoki, F., Inagaki, S., et al. (2019a). Let's imagine animals: An interactive system of floor- projected footprints to provide kindergartners opportunities to experience advanced art. In *EdMedia+ innovate learning* (pp. 1555–1560). Association for the Advancement of Computing in Education (AACE.

Morita, T., Taki, Y., Iwatate, S., Kusunoki, F., Inagaki, S., Mizoguchi, H., et al. (2019b). Ashiato: Advanced system to enable human to play interactively with animated tokens. In *CHI play 2019 - ext. abstr. annu. symp. comput. interact. play*. (pp. 565–571).

Sacau, A., Laarni, J., & Hartmann, T. (2008). Influence of individual factors on presence. *Computers in Human Behaviour*, *24*, 2255–2273. http://dx.doi.org/10.1016/j.chb.2007.11.001.

Soler-Adillon, J., Ferrer, J., & Parés, N. (2009). A novel approach to interactive playgrounds: The interactive slide project. In *Proc. IDC 2009-8th int. conf. interact. des. child.* (pp. 131–139).

Spector, J. M., Merrill, M. D., Elen, J., & Bishop, M. J. (2014). Handbook of research on educational communications and technology: Fourth edition. In *Handb. res. educ. commun. technol* (4th ed.). (pp. 1–1005).

Suhonen, K., Äätäjä, H., Virtanen, T., & Raisamo, R. (2008). Seriously fun: Exploring how to combine promoting health awareness and engaging gameplay. In *MindTrek - 12th int. mindtrek conf. entertain. media ubiquitous era.* (pp. 18–22).

Takahashi, I., Oki, M., Bourreau, B., Kitahara, I., & Suzuki, K. (2018a). Futuregym: A gymnasium with interactive floor projection for children with special needs. *International Journal of Child-Computer Interaction*, *15*, 37–47.

Takahashi, I., Oki, M., Bourreau, B., & Suzuki, K. (2018b). Designing interactive visual supports for children with special needs in a school setting figure 1. Interactive VS for cleaning in a special needs school. (a) Mop Game: a full-body interactive cleaning game. (b) Mop Guide: A floor-cleaning guidance tool. (pp. 265–275).

Thavikulwat, P. (2004). The architecture of computerized business gaming simulations. *Vol. 35*, In *Simul. gaming - simulat gaming.* (pp. 242–269).

Walber, T. C., Scherp, A., & Staab, S. (2014). Smart photo selection: Interpret gaze as personal interest. In *Proc. SIGCHI conf. human factors in comput. syst.* (pp. 2065–2074).

Weisberg, D. S. (2015). Pretend play. *Wiley Interdisciplinary Reviews: Cognitive Science*, *6*, 249–261.

Winkler, C., Hutflesz, P., Rukzio, E., & Holzmann, C. (2012). Wall play: A novel wall/floor interaction concept for mobile projected gaming. In *MobileHCI'12 - companion proc. 14th int. conf. hum. comput. interact. mob. devices serv.* (pp. 119–124).

Yee, N. (2007). Motivations of play in online games. *Journal Cyberpsychology Behavior*, *9*, 772–775.

Yilmaz, R. M. (2016). Educational magic toys developed with augmented reality technology for early childhood education. *Computers in Human Behaviour*, *54*, 240–248.