Exploring Mid-air Gestural Interfaces for Children with ADHD

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ABSTRACT

This study examined the potential of mid-air gestural interfaces specifically designed for children, in the context of full-body motion control for confirmation actions while interacting with large conventional displays. The study aimed to investigate gestures for confirmation actions that were feasible for children, including children with challenges in behavior control and impulse inhibition. Two scenarios were explored, namely, active full-body gesturing (i.e., jumps and jumps with hands up) and freezing (i.e., motionless posture) to identify their usability for confirmation actions. Experiment I involved 11 typically developing children playing the game to check the system's general functionality and robustness. Experiment II involved 18 children with attention deficit/hyperactivity disorder (ADHD) to evaluate a prolonged usage of the confirmation gestures in six game sessions. The results showed that the children were able to interact with the large conventional displays with consistent accuracy and responsiveness in both active gesturing and freezing scenarios. Moreover, jumps with rising hands were significantly preferred as an interaction input method. Further, there was no significant difference in ratings of the difficulty of freezing gesture, and children successfully repeated the predefined postures. The findings provided insights into the functionality and suitability of mid-air gestural interfaces for confirmation actions in interactive applications targeted to children.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**.

KEYWORDS

Mid-air gestural interaction, Child-computer interaction, Motion-controlled games, Confirmation gestures

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1 INTRODUCTION

Mid-air gestural interfaces analyze body movements and postures captured by motion-sensing devices, thus enabling interaction with objects on a large media screen. These interfaces have been used in a variety of gaming applications, providing unique and beneficial support for children due to their intuitiveness, playfulness, and embodiment [Guha and Fails 2018; Torres et al. 2021]. Motion-controlled games are beneficial for typically developing children but also for children with developmental disorders such as autism spectrum disorder (ASD) and attention deficit/hyperactivity disorder (ADHD). A number of therapeutic gaming solutions based on embodied interactions, often referred to as full-body interaction or gestural interface systems, have been presented lately, with promising results. Thus, positive effects of motion-based gaming have been reported on children's physical strength (vertical jump [Çifci and Başpınar 2020]), body awareness and imitative skills, body coordination [Ou et al. 2020], and general physical ability [Ni Mhurchu et al. 2008]. Motion-controlled gaming, when combined with traditional neuropsychological rehabilitation, has demonstrated positive effects on social interaction and communication [Garzotto et al. 2014], attention, impulse inhibition, and behavior control [Gizatdinova et al. 2022; Ou et al. 2020], confirming the potential of this gaming approach for therapeutic purposes.

In the settings of motion-based therapeutic gaming, a gestural interface should function well to support a child in controlling the gameplay. It should also output meaningful information for clinical psychologists with insights into a child's performance in coping with therapy tasks [Bartoli et al. 2014]. The latter depends greatly on the design of the selected gestures and technical characteristics of a gestural interface in detecting motion and posture. Regrettably, earlier studies have primarily concentrated on therapeutic implications of motion-based gaming, somewhat overlooking the usability aspects of gestural interfaces and the particular needs of children in motion-based game design. More research is needed to identify usable and useful gestures suitable for specific tasks and interaction scenarios and to establish guidelines for implementing child-friendly gestural interfaces.

One of the fundamental interactions frequently employed in active gaming is a confirmation action. Once the player has selected an interface option, they must perform an action to confirm their selection by gesture or motion [Erazo et al. 2019]. Different researchers favored different gestures for confirmation tasks. For instance, dwell-based interactions have been recognized for their intuitiveness and accuracy [Erazo et al. 2019; Hespanhol et al. 2012], whereas pushing gestures have been fast and resembled touchscreen or physical button pressing [Panger 2012; Yoo et al. 2015]. [Höysniemi et al. 2004] applied the Wizard of Oz approach to investigate full-body interaction for children, focusing on basic movements such as running and jumping. They noticed that jumping gestures were similar in style for different participants. Moreover, they found that a child's previous experience, game context, and game character's animation played a significant role in defining the gestures for controlling the game and their intuitiveness. This notion was later echoed by [Connell et al. 2013], who suggested that children perceived themselves as the game protagonist. They employed more body-centered than world-centered gestures, moving their body the way they wanted to make the protagonist move.

Studies exploring interaction methods for confirmation tasks tailored for children revealed that hand gestures cause fatigue and are challenging for children as compared to voice, touch, or tangible interaction [Carvalho et al. 2015; Munsinger and Quarles 2019]. We consider that despite usability issues highlighted in earlier research, the considerable advantages of gestural interaction within active gaming necessitate further investigations into more suitable confirmation commands, tailored to children's abilities and comfort. A promising direction could be incorporating full-body gestures for confirmation tasks. Full-body interaction, including running, jumping, squatting, posturing, or freezing employs large gross movements that can be reliably detected by motion-sensing devices from a distance. The use of full-body interaction benefits children because it supports physical activity and high energy expenditure of the players [Silpasuwanchai and Ren 2015]. Full-body interaction may be preferred by children in continuous use as compared to fine hand and finger movements. For instance, full-body dwelling could mitigate the fatigue and discomfort typically associated with hand gestures. Additionally, full-body interaction could be especially beneficial for those children with ADHD who have developed hyperactivity as a compensatory mechanism - these children need to physically move to regulate their arousal level and stay focused on a task [Tuckman 2012].

In this explanatory study, we systematically investigated the functionality, usability, and UX aspects of jumping and freezing, quantifying their effects on the performance and subjective experiences of children, including children with challenges in behavior control and impulse inhibition. In Experiment I, our objective was to gauge the reliability of the gestural interface we developed and to understand how suitable the selected gestures are for children. To this end, we engaged neurotypical children to establish a foundational understanding of the system's performance without the variabilities that might arise from ADHD. Experiment II focused on children with ADHD, playing a motion-controlled game in five sessions. Prolonged usage gave us a deeper understanding of the sustainability of gestural interfaces in games and the potential long-term implications of employing gestures in gameplay. Our aim was to design and evaluate two types of full-body confirmation commands, namely, active full-body gesturing (i.e., jumps and jumps with hands up) and freezing (i.e., motionless posture).

2 SYSTEM OVERVIEW

The overall system consisted of the PigScape game module, which included a game engine and graphical user interface, and the gestural interface module, which detected jumps and body posture.

2.1 PigScape Game Module

For this study, we utilized the PigScape game, which was designed to be engaging and fun. It combines various goals, devices, and technologies to achieve the educational objectives outlined in our previous work by [Gizatdinova et al. 2022]. The game includes short intervals of physically active gameplay that last a few minutes, as well as shorter freezing tasks. In the context of ADHD treatment, the freezing exercise serves the purpose of instructing children on how to restrain excessive movement during moments of high arousal. It is recommended to enhance impulse control and, therefore, contribute to improved behavioral regulation [Baker et al. 2019; Gizatdinova et al. 2022]. The game is played in pairs and incorporates a mid-air gestural interface for both the active and freezing phases of the gameplay.

Figure 1 presents a graphical interface of the game. The game's protagonist is a pig running an obstacle course, moving from left to right in the game view. During the active period (as shown in Figure 1a), the users steer the pig avatar by jumping and, thus, avoiding obstacles and collecting coins and other items to earn points and treasures. After the game recognizes a jump, it becomes irresponsive to the user's input. This happens if, for example, a jump comes while another in-game event is still in process. Thus, it is not possible to make a pig avatar jump again if the pig is still in the air. The game can be played competitively or cooperatively. A skeleton avatar image of the users is displayed on the left side of the screen to help children remain in the sensor view.

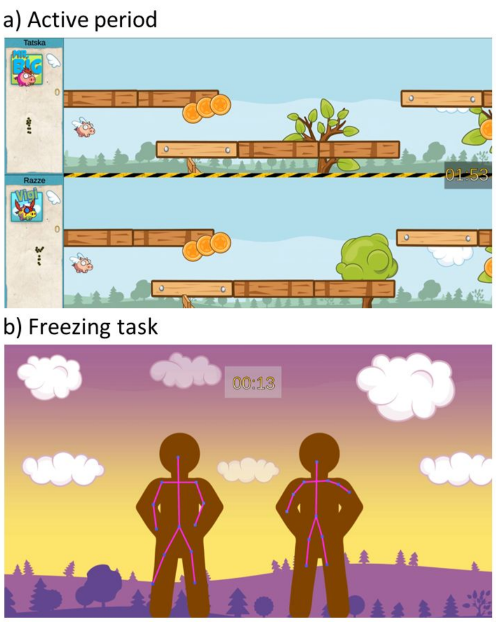

Figure 1: The PigScape graphical game interface. (a) Active period: The game interface is divided into two sections: the upper section for the left player and the lower section for the right player. Each section features a skeleton avatar representation of the respective player, prominently displayed on the left side of the screen. (b) Freezing task.

After a certain amount of time, the active period transits to a freezing task, where the players are presented with a silhouette of a certain posture and their Kinect-based skeleton (as shown in Figure 1b).

2.2 Gestural Interface Module

2.2.1 Active Period. The primary objective of the active period of the game was to encourage children to move and raise their level of arousal. Therefore, we focused on utilizing such human full-body motions as gestural inputs that were intuitive, robust in recognition, and appropriate for children. Among the possible human motions, we considered jumping, running, crouching, flying, and other similar activities. After careful consideration, we selected the jumping gesture (see Figure 2a) as the most suitable input because it has high physical expenditure, is easy to explain and implement by most children [Samozino et al. 2010; Sgrò et al. 2015], and satisfies the requirement of a relatively small gaming space. Furthermore, previous studies have noted the similarity of jumping styles among different participants, which is crucial for recognition technology [Höysniemi et al. 2004]. Moreover, it was consistent with the gameplay, as children often mimic the protagonist's actions in the game [Connell et al. 2013].

Figure 2: Children's actions in the PigScape game a) jump and b) double jump.

A jump with hands up (from now on double jumping) was chosen as the second gestural input. The choice was justified by following the game's consistency, moving in the direction of the protagonist. Double jump grants the avatar a superpower, namely wings, and increases the height of the jump to reach further collectibles (see Figure 2b).

2.2.2 Freezing Task. During the freezing task of the game, the children are required to replicate a predetermined posture by remaining motionless in that posture for a predetermined amount of time (see Figure 3). Varying levels of posture difficulty were incorporated, including easy, moderately easy, moderate, and difficult, to enhance the game's level of challenge and sustain player engagement. These posture levels differ in terms of the position of the hands and legs, with some postures requiring one or two hands up or down, as well as predefined leg positions. An overview of the different postures used in the game, categorized by difficulty level is provided in Appendix A. The selected predefined postures were chosen to be suitable for public use and did not require advanced physical abilities. For instance, postures that involved balancing on one leg were classified as challenging.

Figure 3: A child replicates a predetermined posture of the freezing task.

2.2.3 User Tracking. The gesture tracker was implemented using Kinect for Windows SDK 2.0 C++ wrapper. The Kinect device was placed and monitored the area in front of the large screen. The software tracked skeletal data of the user's full body and analyzed gestures (see Figure 4). For an active period, our software recognized jumps and double jumps by detecting a change in the position of the center of mass of the three points (head, left and right shoulders) and both hands. Specifically, the software detected the moments when the center of mass moves upward (reaching a certain threshold) and then returns to its original position upon landing in five frames. The double jump was detected when a jump was recognized, and the centers of both palms were raised above the center of the head at the highest point of the jump.

Twenty body-joint positions obtained from Kinect were tracked in the freezing tasks. Players were to fit all skeleton joints into the presented silhouette and stay frozen in the shown posture for a predetermined time. The skeleton served as visual feedback for players during the freezing task, allowing them to adjust their body inside the predefined posture (see Figure 3 (left)). Joints positioned inside the shape were marked in blue, while those outside were highlighted in red.

3 EXPERIMENT I: GAME TECHNOLOGY ASSESSMENT

At first, we explored how game technology recognizes children's movements and gestures in the physically active gaming settings, and how children generally evaluated the gestural interface within the game.

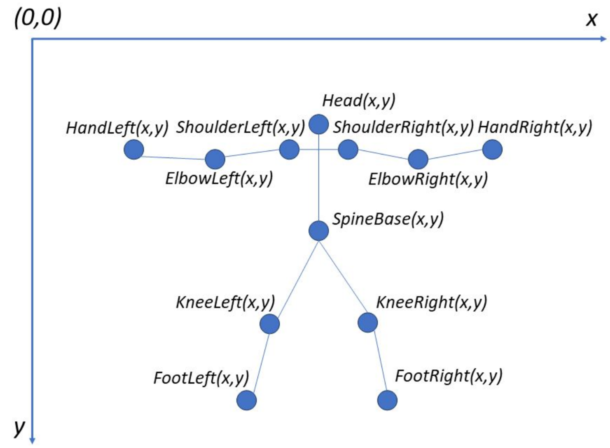

Figure 4: Skeleton joints detected by Kinect

3.1 Participants

The game's interface was evaluated on 11 children (4 males and 7 females). The age range of the participants varied from 6 to 13 years (mean age 8 years). Children's gaming background included computer, console, or mobile phone gaming with different intensities: 45% played almost daily, 27.5% at least once a week and 27.5% once a month or less. Physically active games were less popular among them: only one participant played such games on a daily base and one at least once a week. 73% of the participants reported not having prior experience playing games like this. Otherwise, they reported playing sports games or exercising at school daily (91%) or at least once a week (9%). All children had no noticeable problems with body coordination, muscle power control, or eyesight.

3.2 Procedure

The study protocol was reviewed by the Ethics Committee of the Tampere Region. Participants arrived at the laboratory with their parents, read an information sheet, gave informed consent, completed a background form, and received instructions about the gameplay. A gaming session consisted of 4 blocks, each including an active period and a freezing task. The duration of one active period was 2 minutes. Obstacles and collectibles randomly appeared on the screen and differed for each player (while the overall difficulty of the active period was similar for all players). The instruction for the child was to collect as many points (coins and fruits) as possible by jumping and jumping with hands up. Before the freezing task, children were given 5 second to adjust their position to match the silhouettes. The freezing task differed in the difficulty of the posture and the duration of the motionless period, which gradually increased from 30 seconds to 1 minute while gaming. The task for the child was to freeze in a pose and stay as still as possible. After the freezing tasks, a brief relaxation period continued for 20 seconds. One game session lasted 12 minutes.

The participants played the game individually. Participant feedback was collected after the gaming via a questionnaire (see Appendix B) and semi-structured interview (see Appendix C). Altogether, the experiment lasted about 40 minutes.

3.3 Apparatus

Experimental sessions were conducted in a spacious room (6,5x10 meters) without direct sunlight. The room was equipped with an NP-M402H projector attached to the ceiling, displaying game graphics on the large screen in front of the gaming zone (projector-to-screen distance was 3 meters). Projector specifications were as follows: brightness 4 000 lumens; contrast 10 000:1; resolution 1920x1080. The size of the gaming zone was 4x3 meters. As the game required jumping, the space was organized to provide safety for active children's movements. A laptop computer used in the experiment had the following specifications: MSI GT72S Dominator Pro (Windows 10, 2.7GHz Intel Core i7-6820HK, 16 GB RAM, 1920x1080 pixels resolution).

Depth-sensing Microsoft Kinect Sensor V2 was utilized to detect children and their bodily motion. The Kinect device was placed below the large screen to monitor the gaming zone in front of the screen. Kinect for Windows SDK 2.0 was used to obtain skeletal data from the device. A custom-built software was implemented and used to implement gestural control of the game using Kinect data, as described in Section 2.2.3.

Each session was recorded with an iPhone 11 Pro camera placed close to the Kinect device in front of the gaming zone to capture children's activities for further analysis. In addition, the computer screen showing the game graphics was recorded to capture both the skeletal silhouette of the players and the game graphics.

3.4 Data analyses

Two assessors independently viewed the motion data of each participant. They recorded the occurrence of jumps and double jumps in the active period and the participants' behavior in the freezing task. We identified a jump in the context of human movement as a sudden propelling of the body off the ground using the legs, resulting in an upward trajectory and subsequent return to the ground upon landing [Huang and Hu 2007; Samozino et al. 2010], and a double jump which is a type of jump in which an individual raises their hands upwards during the jump.

Correlation between assessors was compared using Interclass Correlation Coefficients (ICC). A two-way random effects model with single measures accuracy was used. The criteria for reliability coefficients acceptance was considered as ICCs of >0.75 excellent, <0.40 are poor, and those between the two ranges moderate [Rosenberg et al. 2016]. Inter-rater reliability for two accessors was calculated within the gameplay condition for the active period. The ICC for jumps was 0.99 with a 95% confidence interval (CI) from 0.98 to 0.99 and for double jumps – 0.98 with a 95% CI from 0.97 to 0.99. The ICCs comparisons revealed excellent reliability between assessors for both jumps and double jumps during the active period.

3.5 Results and Discussion

The accuracy of the movement recognition was assessed by counting the errors manually. The results of the manual annotation showed that the gestural interface module successfully recognized approximately 92% of the jumps and 95% of the jumps with hands up, which are comparable to the earlier results [Rosenberg et al. 2016]. Based on the game logic, the game software module ignored approximately 3% of the recognized jumps (that is, in two consecutive fast jumps, only the first jump was recognized and the second was ignored).

In freezing tasks, the gestural recognizer consistently tracked the body parts, supporting the gameplay. A jitter of the detected skeleton joint locations was sometimes observed, which varied with the position and orientation of the user's body. A substantial jitter, significant enough to influence the game score, was observed in 9% of the game blocks. Incorrect detections of body parts occurred in 11% of the blocks, mainly including the detection result of the hands, shoulders, and legs. Most errors occurred when body parts were intersected or hidden. There was no jitter if all body parts were visible and in the same plane.

Regarding subjective opinions, 64% of the participants rated the game difficulty as medium and only 9% rated it as challenging on a 3-point scale from 0 (difficult) to 2 (easy). As for understanding how to play the game, 73% of children found it easy, while 27% rated it as medium on the same 3-point scale.

In summary, the results suggest that the current movement recognition software was highly accurate and robust in detecting isolated jumps and double jumps in active game periods and reliably recognizing the body parts during the freezing.

4 EXPERIMENT II: A CLINICAL STUDY

In Experiment II, we study the prolonged use of mid-air gesturing in active gaming throughout five game sessions. Experiment II was conducted as a part of the "Rehabilitation of Executive Function and Attention" program, (EXAT or TOTAKU in Finnish [Rantanen et al. 2018]) at the Psychology Clinic of Tampere University. The program aims to enhance the executive function and attention capacities of school-aged children (6–12 years).

4.1 Participants

Eighteen children (16 males and 2 females) with ADHD and attention deficits participated in the study. The age range of the participants varied from 8 to 12 years (mean age 9 years). ADHD severity was determined with the teacher-rated Conners' 3TM[Conners 2008] and T scores were used (mean 50, SD 10). Significant deficits of inattention and/or hyperactive-impulsive (T-score >65) were reported in 11/18 participants, three participants were within the high average range (T-score 60-64), and three scored within the average range, of these all but one had confirmed ADHD diagnosis and/or were on psychostimulant medication.

The background questionnaire revealed that participants played computer, console, or mobile phone games with different intensities: 61% played almost daily, 27% at least once a week and 6% once a month or less. While almost all children played digital games quite often, physically active games were less popular among them: only 6% played such games on a daily basis, 35% at least once a week, and 59% once a month or never. The participants reported playing sports games or exercising at school daily (72%) or at least once a week (28%). All children had no noticeable problems with body coordination, muscle power control, or eyesight.

4.2 Apparatus

The experimental sessions in Experiment II were conducted under identical room conditions and with the same equipment used in Experiment I. To capture children's activities for further analysis, each session was recorded with a Logitech Pro 9000 web camera placed either close to the Kinect device in front of the gaming zone or behind it. In addition, the computer screen showing the game graphics was recorded to capture both the skeletal silhouette of the players and the game graphics.

4.3 Procedure

The study protocol was approved by the Ethics Committee of the Tampere Region. The children and their caregivers provided written informed consent to participate in the study. Additional information about participants' gaming experience was collected before the experiments from their parents using a questionnaire.

The clinical study consisted of six gaming sessions. In each session, two children were playing the game as a pair. Clinical study sessions were held for six weeks, with a one week break in between.

Participants walked to the experiment premises with an interventionist or a psychology student who assisted with the study. The following bodies were presented in the room during each experiment session: 2 participants, 1 observer, 1 person responsible for the technical side of the experiment and data collection, 1 interventionist from the psychology clinic who took care that children followed the instructions, and 1 psychology student who assisted with instructing children about the gameplay and collecting their subjective responses. Psychologists observed the children during each game session. Participants' feedback was collected after each gaming session. After the first and the last gaming sessions, a questionnaire (see Appendix B) and semi-structured interview were used (see Appendix C), while after intermediate sessions only a questionnaire.

A gaming session consisted of 4 blocks, each including active periods and freezing tasks. The duration of one active period was 2 minutes. Obstacles and collectibles randomly appeared on the screen and differed for each player. Prior to the freezing task, participants had a 5-second window to adjust their position with the silhouettes. The freezing task differed in the difficulty of the posture and the duration of the motionless period which gradually increased from 10 seconds to 1 minute through game blocks and sessions. The posture difficulties were counterbalanced between the sessions and the same for all children. In the freezing task, children were instructed to freeze in a pose and stay as still as possible. Between game blocks, a short relaxation period lasted for 20 seconds. The one game session lasted 10-13 minutes depending on the duration of the freezing blocks.

During the game, participants were in the middle of the room while other people were standing aside (outside of the Kinect sensing area). Altogether, the experiment lasted about a half hour.

4.4 Design

4.4.1 Metrics and Data Analyses. The primary independent variables were the type of movement for the active period and the level of difficulty for the freezing task. Thus, in the active period, the experiment was a two-way within-subject design with 2 types of actions (jumping and double jumping) (N participants = 18) × 4 blocks and a two-way within-subject design with 2 types of actions (jump and double jump) × 5 sessions. The first session was considered a practice and was not included in the analyses. In the freezing task, the experiment was a one-way within-subject design with 4 levels of difficulties. A within-subject analysis of variances (ANOVA) was performed on the data. Greenhouse-Geisser corrected degrees of freedom were used in case of violation of sphericity.

The dependent variables for the active period were the number of jumps and double jumps per block and per game session. In all, 540 minutes of jumping and double jumping in the active period were analyzed for 18 participants. For the freezing task, the dependent variables were the percent of fitting in the shape and the assessors' subjective evaluation of posture repetition and movement. In all, 284 freezing tasks were analyzed for 18 participants.

A Friedman test was used to compare the subjective ratings. In case of a statistically significant effect, the Wilcoxon signed-ranked test with Bonferroni corrections was conducted for pairwise comparisons.

4.4.2 Video Analysis. The video analyses for the active period and the assessment of jumps and double jumps were conducted using the same procedure as described in Section 3.4. During the freezing task participants were assessed according to the following patterns according to posture repetition as follows: (1) repeating the posture: a participant repeats or tries to repeat the posture accurately and makes an attempt to maintain it over time; (2) Stay inside the shape: a participant does not repeat the posture completely, but they keep their detected body joints inside the shape over time; (3) not repeating: a participant does not repeat the posture and not following the task instructions. Movement description during the task was as follows: (1) does not move: a participant stays frozen in position over time, excluding small movements of the head and palms or speaking; (2) moving inside the shape: a participant stays inside the shape over time, but makes some movements, for example dancing, and controls that their joints do not cross the shape borders; (3) move: a participant changes their posture over time or moves spontaneously.

Inter-rater reliability for two accessors was calculated within the gameplay condition for both active period and freezing task. The ICC for jumps was 0.95 with a 95% CI from 0.94 to 0.96, for double jumps – 0.96 with a 95% CI from 0.96 to 0.97, and freezing - 0.96 with a 95% CI from 0.95 to 0.97. The ICCs comparisons revealed excellent reliability between assessors for both the active period and the freezing task.

4.5 Results

4.5.1 Active Period. The grand mean for the number of movements per block was 38. The grand mean for the number of jumps was 14 and 24 for double jumps. The highest number of movements per block was 50 for jumps, while the lowest was 2 for jumps and double jumps (see Figure 5 and 6). A two-way ANOVA showed a statistically significant main effect of the movement type ($F_{1,17}$ = 4.59, p = .047), while the main effect of the block on the number of movements was not statistically significant ($F_{1.09,18.6}$ = 2.23, p = .15). The interaction of the main effects of the movement type and the block on number of movements was not significant ($F_{1.26,21.43}$ = 1.76, p = .20). Post hoc comparisons showed that participants did significantly more double jumps than jumps (t' = 2.14, df = 17, p = .47). However, a two-way ANOVA showed that the main effect of the movement type ($F_{1,6}$ = 2.81, p = .14) and the main effect of the session ($F_{2.15,12.94}$ = 1.62, p = .23) were not statistically significant on number of movements. The interaction of the main effects of the movement type and the session on the number of movements was not significant ($F_{1.38,8.27}$ = 0.46, p = .58).

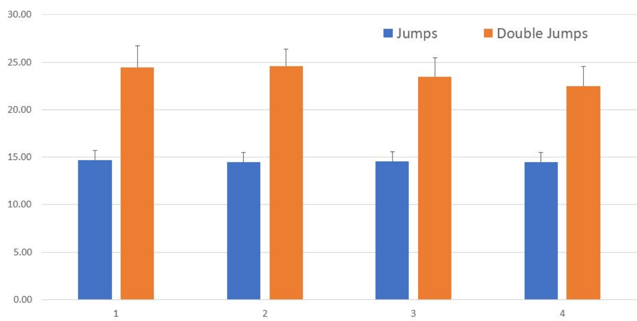

Figure 5: Number of jumps and double jumps per block (N = 18). Error bars represent ±1 standard error of the means (SEMs).

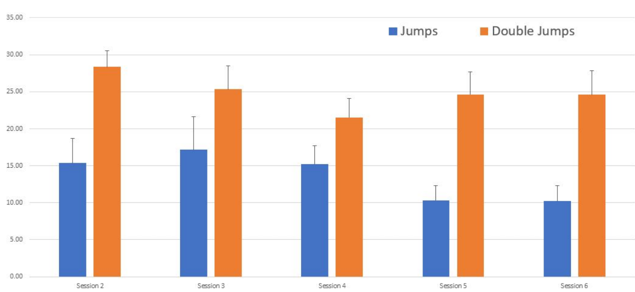

Figure 6: Number of jumps and double jumps per session (N = 18). Error bars represent ±1 SEMs.

In observing the video data, some interaction issues were noticed. During the game, some participants showed types of emotional jumps. These jumps occurred not as a physical action but rather as an emotional response to the successful completion of a task or acquisition of collectibles or the opposite because children did not receive what they desired. Moreover, participants frequently selected a specific movement type and consistently used it throughout the game block. During the game, the children tried to jump as high as possible, although the height of their jump did not affect the movement of the protagonists.

4.5.2 *Freezing Task.* The grand mean value for fitting in the shape was 96%. The highest value for fitting in the shape was 100% on the first and second levels of difficulty, while the lowest value for fitting in the shape was 84%, also for the first level of difficulty (see Figure 7). A one-way ANOVA showed that the main effect of the difficulty level on the fitting in the shape was not statistically significant ($F_{2.44,41.57}$ = 1.75, p = .18).

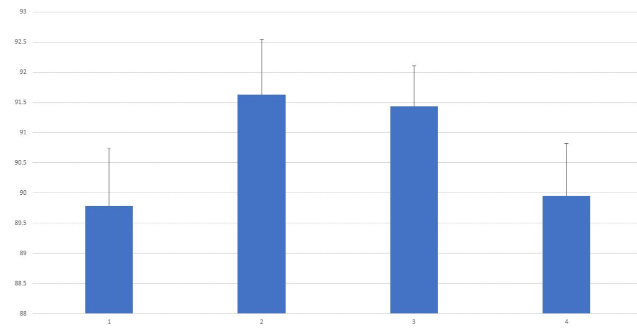

Figure 7: Average value (in %) of fitting in the shape at four levels of difficulty. Error bars represent ±1 SEMs.

The Friedman test did not show a statistically significant difference in levels of difficulty in participants' posture repetition or movements in the freezing task across all sessions (see Table 1). It was observed that the participants successfully followed the predefined posture in 83% of tasks and fitted in shape in 16.7%. Remarkably, the participants did not follow the instructions in less than 1% of tasks only. Regarding remaining still, the children demonstrated the ability to stay motionless over time in 73% of tasks and did control movements inside the predefined shape in 21% of tasks. Spontaneous movements were observed in 6% of the tasks.

Table 1: The Friedman test for levels of difficulty in participants' posture repeating and movements across all sessions.

	Posture repeating	Movement
Session 2	$\chi^2(3) = 5; p = .172$	$\chi^2(3) = 4.1; p = .247$
Session 3	$\chi^2(3) = 6.1; p = .141$	$\chi^2(3) = 6.6; p = .087$
Session 4	$\chi^2(3) = 5.5; p = .107$	$\chi^2(3) = 6.2; p = .099$
Session 5	$\chi^2(3) = 4; p = .261$	$\chi^2(3) = 1.9; p = .578$
Session 6	$\chi^2(3) = 5.6; p = .132$	$\chi^2(3) = 6.5; p = .089$

While reviewing the video data, we observed that in instances where participants were unable to precisely replicate the designated posture during the task, they attempted to fit their movements within the shape to achieve the highest score. Some participants even engaged in playful interactions with the silhouette displayed on the screen. For example, they would dance while ensuring their movements remained within the predefined shape.

4.5.3 *Subjective ratings.* Figure 8 summarizes the participants' ratings of the game in general, jumping in the active period, and the freezing task across all game sessions. Friedman test did not show a statistically significant effect of the session on the participant evaluation in all three questions (Q1: $\chi^2(1) = 1$; p = .317; Q2: $\chi^2(1)$ = 1.8; p = .180; Q3: $\chi^2(1) = 1.8$; p = .180). Most participants expressed a positive opinion about the gaming and kept it through all the sessions.

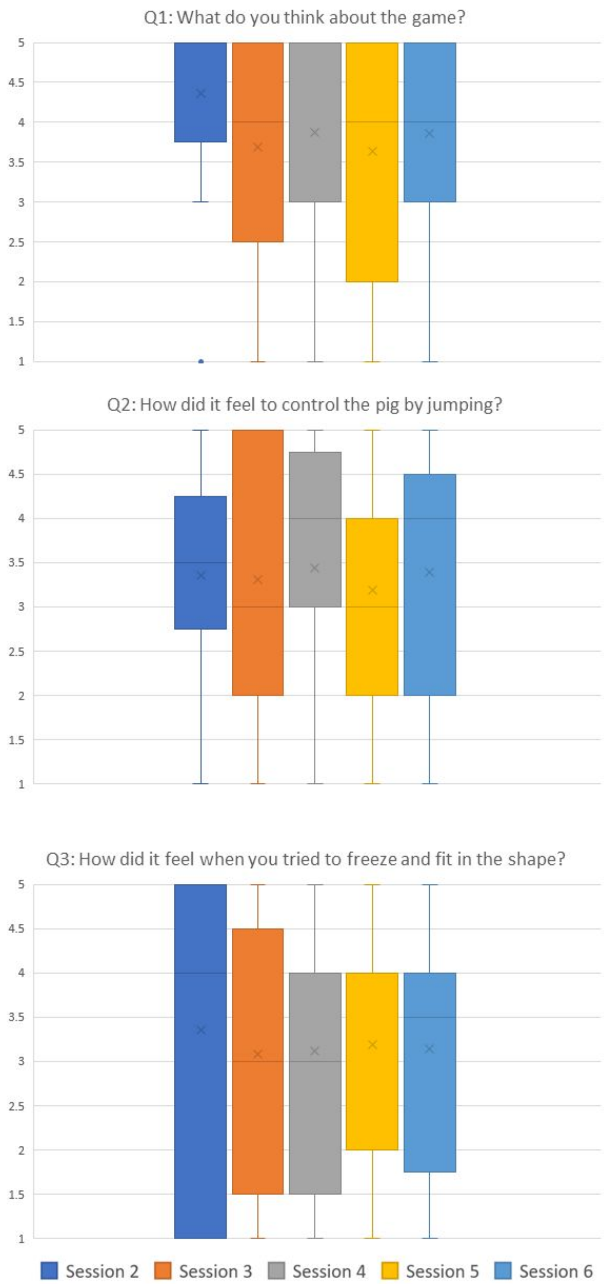

Figure 8: Plots of participants' evaluation of the PigScape game and the game's gestural interfaces. The scales varied from negative (1) to positive (5) experience. Error bars represent ±1 SEMs.

In the interviews after the first and last sessions, some children mentioned that the best part of the game was jumping: "[It was nice] to be able to jump and collect points. Good pastime" [P1, 10 years] and "I like jumping with a pig" [P2, 9 years]. Furthermore, they indicated that the game's flying aspect, related to double jumps, was joyful: "It was fun to be able to fly" [P3, 9 years]. While other children found the freezing part as the best: "It was when I tried to fit into that hole" [P4, 9 years] and "Being motionless" [P5, 8 years]. In the negative aspects of the game, the children mentioned fatigue both in the active period and in the frozen task: "It hurt my neck when freezing" [P6, 8 years] and "When I jump, my legs start to hurt" [P7, 8 years]. Moreover, children did not like long periods of freezing: "It was annoying when you had to stay still for a long time" [P8, 9 years].

5 DISCUSSION

This study represents one of the early attempts to systematically investigate the interactive properties of mid-air gestural interaction with large conventional displays for children, including children with behavior control and impulse inhibition challenges. Our result showed that both scenarios, active gesturing and freezing posture posed potentially useful and interesting design implications for confirmation actions interacting with large conventional displays.

In the active period, to our surprise, participants selected jumping with their hands up more often for protagonist control. Thus, our results indicated that the number of double jumps was 53% higher than the number of jumps in the active period of gaming. This value remained across all blocks and sessions. Interestingly, some participants could use only double jumps throughout an entire game block. The frequent selection of jumps with hands up could be explained by the gameplay elements that enhanced children's motivation. Using double jumps endowed the protagonist's pig superpower, which contributed to getting more collectibles and points and avoiding obstacles. Nevertheless, these allow us to assume that jumping with hands up is a feasible gesture for children in mid-air interaction. However, recent studies have previously reported that jumps with hands up may impose higher physical demands and consume more energy compared to simple jumps [Biddiss and Irwin 2010; Hupp and Reitman 1999].

Furthermore, observing the trend of using one type of movement in game block (either jumps or double jumps) can be described by the fact that children may not easily and rapidly shift from one movement to another. These findings align with early studies investigating motion-based interaction for children [Höysniemi et al. 2004].

Our study observed the Midas touch problem, which appeared as accidental jumps when the children reacted emotionally to the game events. Midas touch is one of the crucial problems in midair gestural interaction [Kjeldsen and Hartman 2001; Remizova et al. 2022]. Addressing this issue would require conditions that help to prevent accidental system engagement. For instance, double jumps could be one of the solutions. Double jumps, with their distinct phases of initial preparation, take-off, and landing (see Figure 2b), offer a more intentional, controlled gesture, thus reducing the likelihood of accidental activation.

In the freezing task, putting together the score of fitting in shape and subjective evaluation of pose repetition and movement, it seems that the children were able to precisely imitate predefined postures. Additionally, there was no significant difference in the difficulty level of postures. This could be due to the careful selection of suitable and repeatable postures for the children.

In terms of confirmation action, freezing can be considered a special case of dwell-based gestures in mid-air gesture interaction or in broader terms, full-body dwelling. However, the predefined posture should be meticulously chosen to avoid the Midas touch problem. Moreover, our findings indicate that staying motionless for a certain amount of time might pose more difficulties for some children. According to our results, a preferable solution seems to be permitting movement within the predefined shape. We conjecture that this approach enhances the system's robustness and makes gesture execution more feasible for children. However, further research is needed to explore the time frame in which accidental triggering can be prevented and still not cause fatigue.

Other solutions that could support the feasibility of freezing as a confirmation action come from previous studies [Bartoli et al. 2014; Garzotto et al. 2014]. For example, fitting in shape could have a threshold level for covering the shape to enhance the doability of the gesture for children. However, more research is also needed to determine an acceptable threshold level.

Subjective evaluation from the participants was overall positive (see Figure 8). They found both the active period and the freezing task enjoyable and fun. However, they also reported that prolonged periods of jumping and freezing could lead to fatigue.

It is important to note that our research primarily focuses on assessing the interaction properties of jumping and freezing gestures for confirmation actions within a gaming context. However, future research should explore how our proposed solutions for confirmation can be integrated into real-world, non-gaming environments.

Combining the statistical analyses of qualitative and quantitative evaluations, it seems that both scenarios - jumping in active period and freezing task - were applicable for confirmation action in the context of large conventional screen interaction. Thus, jumps with hands up in active periods were preferable and reliable, as they helped avoid the Midas touch problem. The jumps with hands up can be applicable in real-life applications for tasks such as button pressing or menu selection. In the freezing task, the best solution for confirmation was fitting in shape while allowing minor movement inside, which can also be helpful for children who may not be able to maintain a completely motionless posture. We expect that freezing as a confirmation command could be slower than other gestures explored previously, resembling dwell-based confirmation gestures [Erazo et al. 2019; Yoo et al. 2015], so it may be applicable in tasks that do not require haste, such as confirming a switching between game modes, changing game settings, or turning off the game.

6 CONCLUSION

We studied mid-air gestural interaction with large conventional screens for children with ADHD. The confirmation actions were explored in two scenarios: active gesturing (i.e., jumps and jumps with hands up) and freezing (i.e., motionless posture), as being feasible for children with challenges in behavior control and impulse inhibition. The results showed that jumps with hands up were favored by participants and could be more reliable. The freezing task was considered a full-body dwell and the best solution for confirmation action was fitting in shape while allowing minor movement inside.

The current results can be applied to the development of educational or therapeutic gaming applications tailored to children, including children with challenges in behavior control and impulse inhibition, to support their motivation and engagement in learning.

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A DESCRIPTION OF DIFFERENT DIFFICULTY LEVELS OF THE FREEZING TASK IN THE PIGSCAPE GAME

Level of difficulties	Posture 1	Posture 2	Posture 3	Description
Easy				The much relaxing posture, hands down
Moderately easy				One hand up
Moderate				Two hands up
Difficult				Two hands up and special legs position

B QUESTIONNAIRE

- What did you think about the game?
- How did it feel to control the pig by jumping?
- How did it feel when you tried to freeze and fit into the silhouette?

C SEMI-STRUCTURED INTERVIEW QUESTIONS

(1) What was the best part of the game?
(2) What was the worst part of the game?
(3) How easy/difficult was it to play the game? (easy/ moderate/ difficult)
(4) Was it easy/difficult to understand how to play the game? (easy/ moderate/ difficult)
(5) Was it difficult to freeze after moving and jumping? (easy/ moderate/ difficult)
(6) How easy/difficult was it to stay still? (easy/ moderate/ difficult)
(7) Did you notice that time passed too quickly? (quick/ moderate/ slow)
(8) Did it feel like the game lasted too long? (Yes/no)
(9) If yes, did you want to stop playing at some point? (Yes/no)
(10) Would you like to play again if you had the chance? (For example, if you had the game at home, would you play it?) (Yes/ maybe/ no)
(11) Would you tell your friends about this game? (Yes/ maybe/ no)