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Foggy fun: an exploration of mid-air gestural interaction with a fogscreen by children with attention-deficits

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ABSTRACT

This study represents the first exploration of active gaming based on mid-air gestural interaction with a fogscreen, focusing on its feasibility for children with attention deficits. The aim was to evaluate the practicality and effectiveness of gestural interaction in two interaction scenarios involving translation and selection of objects projected on the fog, through the assessment of interaction performance and subjective opinions. The proposed approach was investigated in a custom-designed puzzle-based game Tangram. Eighteen novice participants, namely, children with confirmed attention deficits or attention-deficit/hyperactivity disorder (ADHD) played the game collaboratively in pairs during six sessions. Our results demonstrated that gestural interaction with the fogscreen in the Tangram game was not only enjoyable and engaging but also facilitated effective task completion, as shown by an 81% game success rate. During object translation, the participants typically needed two to three attempts to accurately relocate a puzzle piece, with 42% of translation movements adjusting the pieces' placements. Further, in object selection, it was underlined the importance of visual feedback corresponding to the user's hand position for effective interaction. These insights underscore the potential implications of gestural interfaces for fogscreen interaction in active gaming for children.

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1. Introduction

Touchless gestural interaction provides unique and beneficial support for children due to its properties such as intuitiveness, playfulness, and embodiment (Guha and Fails 2018; Torres et al. 2021). It allows children to control devices and applications through physical body movements, for example, hand waves, finger gestures, and full-body motion. It has been therefore successfully applied in learning and gaming solutions for typically developing children (Rubegni et al. 2019) as well as in gamified therapies for children with developmental disorders such as autism spectrum disorder (ASD) (Garzotto et al. 2014) and attention-deficit/hyperactivity disorder (ADHD) (Gizatdinova et al. 2022; Remizova et al. 2023b). Maintaining motivation, interest, and engagement in learning and acquisition of new skills is sometimes challenging for children (Yap et al. 2015), particularly for those with ADHD, who face difficulties with concentration and sustaining motivation to continue with tasks (Modesto-Lowe et al. 2013; Smith and Langberg 2018; Van der Meere, Börger, and Wiersema 2010; Volkow et al. 2011). ADHD symptoms can present as mostly inattentive, mostly hyperactive-impulsive, or a combination of both symptoms. Noteworthy, hyperactivity may serve as a compensatory mechanism, where physical activity helps children to maintain focus on tasks (Tuckman 2012). Fogscreens, the emerging technology of walk-through, semi-transparent displays onto which interactive objects can be projected (see Figure 1(b), supplemented video, and section 2.1), possess specialised settings and environmental conditions for learning and training that can be both feasible and effective for children with ADHD. Fogscreens have been shown to enrich the touchless experience of children with embodiment and immersiveness, increasing children's motivation and engagement in

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(a) (b)

Figure 1. (a) Children play a physical version of the Tangram game. (b) A child interacts with aerially projected objects in the Tangram game.

gaming (Jumisko-Pyykkö, Weitzel, and Rakkolainen 2009; Rakkolainen et al. 2007).

Even though fogscreens seem to hold a promise to be useful in gamified therapies tailored specifically for children with ADHD, the interaction properties of fogscreens for child users remain underexplored. As it will be described in the next section, previous research has primarily focused on specific demonstrations and technical implementations of fogscreens (without user studies conducted), with some user studies examining interaction performance in adult user populations.

The goal of the present study was to investigate technical performance characteristics and child user experiences (UX) of a touchless gestural interface for gaming with a large fogscreen. This investigation is a part of a larger clinical study, in which two games (the Tangram game presented in section 3 and the other game (Gizatdinova et al. 2022; Remizova et al. 2023b) were used as an integral part of the neuropsychological group intervention of executive function and attention (EXAT) at the Psychology Clinic of Tampere University for school-aged children (6–12 years) with ADHD and attention deficits (Rantanen, Vierikko, and Nieminen 2018). In the current paper, we concentrated on the questions related to usability such as efficiency and effectiveness of the interaction (i.e. how well children succeed in their attempts to select objects on the fog, move objects, etc., resulting into the overall game success) and subjective experiences of the children (perceived accuracy, pleasantness of the fog as an interaction media, motivational factors to undergone prolonged training sessions with the fog, etc.). Usability aspects of the gaming are critical because ease-of-use and child satisfaction directly affect the efficacy of the gamified therapy – if the gaming is not fluent or tedious, children may lose motivation to train, perform poorly or even reject performing the tasks. The study also examined specific factors that influence the interaction performance with fogscreens for young users, such as visual feedback.

To study these aspects of interaction, we designed and implemented a collaborative game Tangram puzzle (i.e. a Chinese jigsaw, see Figure 1 and supplemented video). The Tangram game was aiming to support children with attention deficits by improving their self-regulation in task requiring collaboration and communication skills, such as, listening and maintaining focus. In our study, the collaboration was implemented using a barrier game format (Lind 2009), in which one child provided verbal instruction to another to assemble a Tangram puzzle on a fog screen. While the Tangram game is widely recognised for enhancing spatial reasoning and problem-solving skills (e.g. Kohanová and OchodnicAnová 2014), their benefits extend to other cognitive domains (e.g. impulse inhibition, working memory, sustaining attention). Children with ADHD often face challenges in these domains (Barkley 1997). The Tangram game is a suitable tool for cognitive training in children with attention difficulties as it requires careful planning and patience (impulse inhibition) and engages working memory by necessitating the recall of instructions and the target shape while manipulating the pieces. This dual demand on cognitive resources can enhance their ability to understand and execute multi-step tasks. For children with ADHD, Tangram games has also been employed therapeutically to help them develop impulse control in social interactions, improve their ability to give and follow instructions, and regulate emotions during collaborative tasks (Moore and Ledbetter 2019). Furthermore, as previous studies have demonstrated effectiveness of applying Tangram game for improving visual perception skills, visual-motor coordination, and fine motor skills in children (Kohanová and OchodnicAnová 2014), we aimed at the training of these skills as well.

In our implementation, the Tangram game was tailored for fogscreen interaction with the use of *selection confirmation* and *translation* interaction actions (Azah et al. 2014). *Selection confirmation* (hereafter referred to as *selection*) resembles point-and-click computer mouse interaction. It occurs when a user makes a selection, such as choosing an option from a menu or selecting a file to open and then performs an action to confirm it (Erazo et al. 2019). *Translation* (a.k.a. drag-and-drop computer mouse function) is defined as dragging or moving an item to an intended target position while retaining the item's size and rotation (Remizova, Gizatdinova, and Surakka 2022). Eighteen child participants with attention deficits undergoing neuropsychological intervention took part in six Tangram gaming sessions over seven weeks, allowing us to observe the effects of prolonged fogscreen-based mid-air interaction. We evaluated interaction performance and subjective opinion for both interaction scenarios in mid-air gesturing context with fogscreen technology and discussed the implications of fogscreen-based interaction and active gaming for children with attention deficits.

2. Literature review

In section 2.2, we review demonstration and technical research papers focusing on fogscreen technology and its applications, highlighting their innovative uses and challenges. Section 2.3 will review available literature concerning child interaction with conventional projector screens (as formal studies with fogscreens and child participants are currently limited).

2.1. Fogscreens

Fogscreens are commonly employed in settings like trade shows, theme parks, museums, and concerts (Sand et al. 2022). Equipped with different types of sensors, fogscreens can act as interactive touchscreens or walk-through virtual reality screens, where users may feel a slight sensation of air, humidity, and coldness, similar to walking through a mist, but unlike handheld devices, these screens do not provide tactile feedback (Palovuori and Rakkolainen 2015; Remizova et al. 2023b; Sand et al. 2020). The advantages of fogscreens include their ability to be unbreakable and recover automatically and immediately when penetrated, as well as to stay clean and hygienic preventing the spread of bacteria or viruses as there is no solid touch surface (Rakkolainen et al. 2009; Sand et al. 2022). An additional advantage of this interaction modality is its ability to limit vandalism by placing displays out of reach, a valuable consideration in contexts involving children, who might roughly interact with displays (Müller et al. 2014; Sorce et al. 2017).

2.2. Studies on interaction with fogscreens

Tables 1 and 2 summarise the state-of-the-art works on interaction properties of walk-through displays. As Tables 1 and 2 show, no formal evaluations have been made so far concerning children as the end users of the fogscreen technology. Table 1 shows that most

Table 1. Overview of technical studies and demonstrations on fogscreen applications.

Reference	Display type	User group/ Participants	Technology to support interaction with a fogscreen*	Application domain	Metrics
Rakkolainen and Palovuori (2005)	Large Fogscreen	Not specified	Laser-scanner device	–	–
Lugmayr and Piirto (2006)	Large fogscreen	Children	Laser-scanner device	Gaming	–
Rakkolainen and Lugmayr (2007)	Large fogscreen	Not specified	Laser-scanner device	Interactive advertisement	–
Rakkolainen et al. (2007)	Large fogscreen	Not specified	–	Physical exercise, gaming	Observation
Plasencia, Joyce, and Subramanian (2014)	Small fogscreen	Not specified	Kinect	–	–
Palovuori and Rakkolainen (2015)	Large fogscreen	Not specified	Kinect	–	–
Lam, Huang, and Chen (2015)	Small volumetric fogscreen	Not specified	Kinect	3D Drawing	–

* Kinect – Microsoft Kinect sensor.

Table 2. Overview of usability studies on interaction with fogscreens.

Reference	Display type	User group/ Participants	Technology to support interaction with a fogscreen*	Application domain	Metrics
Jumisko-Pyykkö, Weitzel, and Rakkolainen 2009	Large Fogscreen	10 children	–	Gaming	Observation
Sand et al. 2015	Small fogscreen	12 adults	Mid-air gestures (Leap Motion) + Tactile feedback	General	Entry speed, error rate, subjective opinion
Otao and Koga 2017	Small fogscreen	10 adults	Mid-air gestures (Leap Motion)	General	Subjective opinion
Sand et al. 2020	Large fogscreen	20 adults	Mid-air gestures (Kinect) + Tactile feedback	General	Movement time, target re-entries, subjective opinion
Remizova et al. 2023a	Large fogscreen	20 adults	Mid-air gestures (Kinect) + Tactile feedback	General	Throughput, error rate, movement time, subjective opinion

* Leap Motion – Leap Motion Controller, Kinect – Microsoft Kinect sensor.

existing studies were reported in the form of demonstrations or technical explorations, proposing hardware advances for interaction with a walk-through display without exploration of its interaction properties (Lam, Huang, and Chen 2015; Palovuori and Rakkolainen 2015; Plasencia, Joyce, and Subramanian 2014; Rakkolainen and Palovuori 2005). Furthermore, the studies have attempted to envision potential application domains of fogscreens (Lugmayr and Piirto 2006; Rakkolainen et al. 2007; Rakkolainen and Lugmayr 2007). In terms of interaction, a variety of methods were applied for hand tracking, primarily including laser-scanner devices (Lugmayr and Piirto 2006; Rakkolainen and Lugmayr 2007; Rakkolainen and Palovuori 2005) and depth sensors (Lam, Huang, and Chen 2015; Palovuori and Rakkolainen 2015; Plasencia, Joyce, and Subramanian 2014). In early studies, a laser scanner device positioned parallel to the fogscreen was applied to track hand movements (Rakkolainen and Palovuori 2005). This method was found as reliable but cost-prohibitive, limited to 2D scanning, and affected by the turbulence disturbances of the fog flow. Subsequent research efforts explored the application of commercial off-the-shelf depth-sensing tracking methods (typically used for conventional projection screens). However, the fogscreen's aerial nature and the visual disturbances caused by the fog significantly hindered the effectiveness of these tracking methods (Palovuori and Rakkolainen 2015).

Table 2 shows the results of usability studies involving individuals in which they, for example, investigated the interactive properties of fogscreens (Otao and Koga 2017; Remizova et al. 2023a; Sand et al. 2015). Jumisko-Pyykkö, Weitzel, and Rakkolainen (2009) concentrated solely on the exploration of how children naturally interact with a large walk-through display and the space around it. They observed different ways of physical interaction with a fogscreen, such as moving inside of the fog and using their whole body to manipulate the projected content (images or videos), although it did not explore direct manipulation of the content itself (drag-and-drop, pointing, selection, target acquisition). This remained the main evaluation method until the actual interaction with fog has been implemented and evaluated in a series of further user studies. Sand et al. (2015) used a desktop-size fogscreen prototype to experiment with ultrasonic mid-air tactile feedback. Their findings with adult participants revealed the participants' preference for tactile feedback when selecting targets, however, with respect to a small fogscreen. Later, Sand et al. (2020) reported that haptic feedback might be useful for dwell-time-based selection in interactions with a large walk-through fogscreen. Remizova et al. (2023a), formally investigated the applicability of Fitts' law in mid-air interaction with a large fogscreen and showed that the tapping gesture without haptic feedback was a prospective confirmation method. They also found that incorporating haptic feedback into the tapping gesture for selection tasks did not improve the performance. Furthermore, they concluded that mid-air gesturing in the fog was easier for users compared to mid-air gesturing with large projected screens, as the fog provided a visual reference that aided performance.

2.3. Mid-air gestural interaction studies involving children

Table 3 summarises studies involving children and mid-air gestural interaction in general, covering interaction with large displays and projector screens, excluding fogscreens, which underlines the need for further exploration of this topic. Past studies covered a wide range of applications, including game environments (Ab Rahman, Ali, and Mohd 2018; Moser and Tscheligi 2015; Waje et al. 2016), education (Rubegni et al. 2019), specialised applications for children with special needs (SEN) (Lee-Cultura et al. 2020; Sharma et al. 2016; Tang, Falzarano, and Morreale 2018), and many others. Notably, a significant number of studies compared mid-air gestural interaction against other modalities such as

Table 3. Summary of the research on children's hand gesture interaction (excluding fogscreens).

Reference	Study type /Application domain*	Gesture Recognition Technology**	Display type	Participant number (age)	Scenario*** (Gesture)	Evaluation methods or metrics
Carvalho, Bessa, and Magalhães 2014	CS (mouse vs TS vs tangible vs gesture)/ General	Kinect	22″ LCD	20 (9–12 years)	Selection (dwell 0.8 sec)	Speed, errors, subjective opinion, ranked list
Carvalho et al. 2015	CS/General	Leap Motion vs Kinect	22″ LCD	20 (9–12 years)	Selection (dwell 0.8 sec)	Fitts law study, subjective opinion
Moser and Tscheligi 2015	CS (TS vs gesture)/ Game	Leap Motion	TS vs Desktop	20 (11–14 years)	Swipe	Subjective opinion
Sharma et al. 2016	ES	Kinect	Large display	18 SEN (n/a)	Selection (dwell) translation (fist)	Observations
Waje et al. 2016	CS (TS vs gesture) / Game	Kinect	Tabletop vs 55″ LCD	35 (8–15 years)	Selection (grab); rotation (swipe)	Observations
Ab Rahman, Ali, and Mohd 2018	CS (TS vs gesture) / Game	Kinect	Large display vs tablet iPad	20 (5–6 years)	Selection (dwell 3 sec); free hand movements	Observations, subjective opinion, accuracy, duration
Tang, Falzarano, and Morreale 2018	ES/ Education applications and game	Leap Motion	Large projection screen	S1: 5 SEN (n/a); S2: 5 SEN (n/a); S3: 9 SEN (n/a)	S1: finger gestures; S2: hand gestures; S3: hand gestures	Observations
Munsinger and Quarles 2019	CS (voice vs gesture vs controller)/ General	HoloLens	AR	22 (9–11 years)	Selection (AirTap)	Fitts law study, subjective opinion, fatigue, usability, time
Rubegni et al. 2019	ES/Jigsaw game	Kinect	55″ LCD	107 (2–10 years)	Translation (grab)	Subjective opinion, task time
Lee-Cultura et al. 2020	ES/Educational game	Kinect	n/a	8 SEN (mean age 8,7)	Selection (1 hand, 2 hands); translation (grab)	Observations, reaction time
Lyu et al. 2023	Ex.S/General	Kinect	12.5″ LED	20 (6–12 years)	Selection (Dwell 1 sec), translation (Dwell 0.8 sec)	Fitts law study

*CS – Comparative study, ES – explorative study, Ex.S – Experimental Study; TS – touchscreen.
** Leap Motion – Leap Motion Controller, Kinect – Microsoft Kinect sensor, HoloLens - Microsoft HoloLens.
*** The table uses unified names for mid-air gestural techniques. *Selection* refers to menu selection, selection confirmation, and selection tasks. *Translation* – drag and drop, drop, moving, and target acquisition.

tangible, touch, voice, and hand-held controller interaction (Ab Rahman, Ali, and Mohd 2018; Carvalho, Bessa, and Magalhães 2014; Moser and Tscheligi 2015; Munsinger and Quarles 2019; Waje et al. 2016). These studies revealed that for children hand gestures cause fatigue (Moser and Tscheligi 2015; Munsinger and Quarles 2019) and are difficult (Ab Rahman, Ali, and Mohd 2018; Carvalho, Bessa, and Magalhães 2014; Munsinger and Quarles 2019), especially in executing fast movements (Moser and Tscheligi 2015). On the other hand, the studies revealed the potential of mid-air gestural interaction to enable natural and intuitive input for children within the learning and gaming systems, as well as support engagement in learning and fun (Ab Rahman, Ali, and Mohd 2018; Rubegni et al. 2019; Tang, Falzarano, and Morreale 2018). Additionally, it is critical to note that many of these studies based their findings only on qualitative assessments through observations and subjective participants' feedback, demonstrating a need for more rigorous, quantitative research methods to deepen our understanding of mid-air interaction for children and objective comparison of the proposed gestures across studies.

As Table 3 shows, most studies applied selection and translation interaction scenarios, which were previously found as common within touch-based applications and acceptable for young children (Azah et al. 2014). Rubegni et al. (2019) further investigating the interaction blindness of touchless avatar-based large display interfaces found that prior experience with touch-based interfaces influences children's mid-air interaction with large displays. Interestingly, younger children without prior experience in touch-based interactions tended to figure out mid-air gestural interaction more quickly than older children who were familiar with touchscreen devices. This convergence of results highlights the potential of using familiar gestures from touch-based interfaces when developing natural and intuitive mid-air gestural interfaces for children.

Several studies evaluated gesture-based interaction properties in selection and translation scenarios form various perspectives. For instance, Sharma et al. (2016) evaluated the use of gesture-based learning applications for children with SEN and found that drag-and-drop task was unreliable and challenging for these users. Lyu et al. (2023) examined spatial constraints in mid-air gestural interactions for children and discovered that in target acquisition tasks children performed the pie menu task more accurately in the upward (90∘) and downward (270°) directions, with eight items being the most suitable number for such menus. Moreover, Lee-Cultura et al. (2020) observed that involving both hands in interaction increased the likelihood of errors when using the non-dominant hand, likely due to decreased motor control.

Together, these studies provide a deeper understanding of how children engage with mid-air gestures in different interaction scenarios and also demonstrate the continued need for further research to refine gestural interfaces and better accommodate the diverse needs of young users, especially in educational and therapeutic contexts.

3. Tangram game: a system design for fogscreen

3.1. Game description and environment

The Tangram puzzle (i.e. a Chinese jigsaw, see Figure 1 and supplemented video) consists of several pieces of basic shapes of geometry and should be arranged into another form (Renavitasari and Supianto 2018). In our implementation of the Tangram puzzle, 3–7 different shapes were used (see Appendix A). Two roles were assumed for the participants who collaboratively played the game: *instructor* and *implementer*. The instructor provided the implementer instructions on how to solve a puzzle projected on a fogscreen according to a picture the instructor had. The instructor was located on the implementer's left side approximately 3 m away with a semi-restricted view of the fogscreen (see Figure 2). The implementer stood in front of the fogscreen, moving puzzle pieces on the fog according to the instructions from the instructor. The instructor could see how the implementer was progressing with the puzzle task via a computer monitor linked to the fogscreen. The projector faced the user from the opposite side of the fog. In this configuration, the image appeared brighter than when projecting from the implementer's side, and the implementer did not block the projector's light with their body. The depth-sensing camera, placed below the projector, was tasked with monitoring the region directly in front of the screen and performed gesture tracking of the implementer.

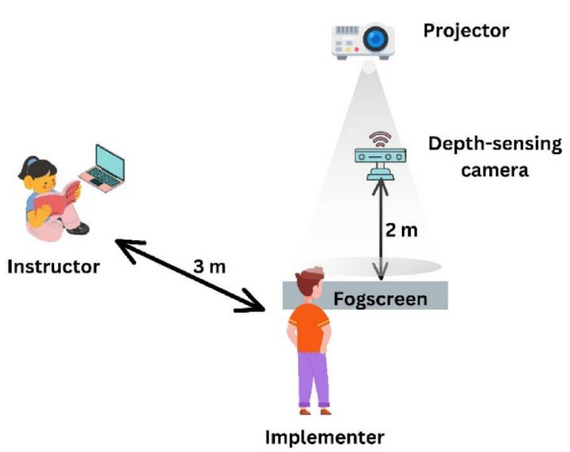

Figure 2. Location of the instructor and implementer in the game.

3.2. Graphical interface and feedback

As Figure 1(b) shows, the game interface's dark background attenuates the bright spot of the projector in front of the screen, which may otherwise create uneasiness for the participant's eyes. Because of fog turbulence and low visibility of the projected content on the fog, it may be difficult to select a particular piece located close to another. To solve this challenge, we proposed a design solution to divide the graphical interface of the game into two parts: *a control panel* (a bar displaying available pieces) on the left, and *a play zone* (the main playing field where the pieces are arranged) on the right, as Figure 3 shows. The control panel can contain from one to seven pieces and is filled with pieces from bottom to top (Figure 3 shows the control panel with six pieces). If a piece is located on the control panel (identified by the blue colour on the control panel), the user can directly transfer the piece from the control panel to the play zone (Figures 3(a–b)). If the piece is already located in the play zone (the control panel has a grey placeholder of the piece) but is not currently active (the piece is blue in the play zone), the user can select it from the panel and make it active and available for manipulation in the play zone (after which the piece turns yellow as Figure 3(c) shows). The idea is to make a single piece the only one active and available for manipulation in the play area at a time (while manipulation with all other pieces is not permitted and therefore ignored). The interaction scenarios of selection and translation by hand gestures will be described in the next section.

The status of puzzle pieces was indicated by the following colours (see Figure 3):

- ***Blue*** (control panel and play zone) indicates a non-selected piece.
- ***Grey*** (control panel) signifies an empty placeholder - a piece was translated from the control panel to the play zone.
- ***Yellow*** (play zone) indicates a currently selected piece.
- ***Green*** (control panel and play zone) means that the piece is currently under translation to a designated place.

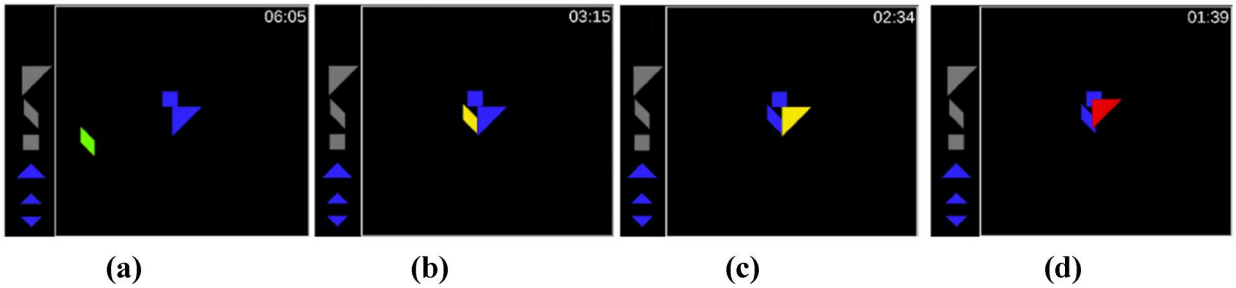

Figure 3. The graphical interface of the Tangram game with different visual feedbacks: (a) a diamond piece was selected from the control panel (turned green) and is currently being translated to the play zone; (b) after arriving at its designated place, the diamond piece turns yellow, signifying its active state (available for manipulations in the play area); (c) a triangle selected from the control panel turns yellow and is available for manipulation in the play zone; (d) the triangle turns red when hovers over the blue pieces, signifying a non-permitted collision of the shapes (the triangle will return to the control panel if placed on top of another piece).

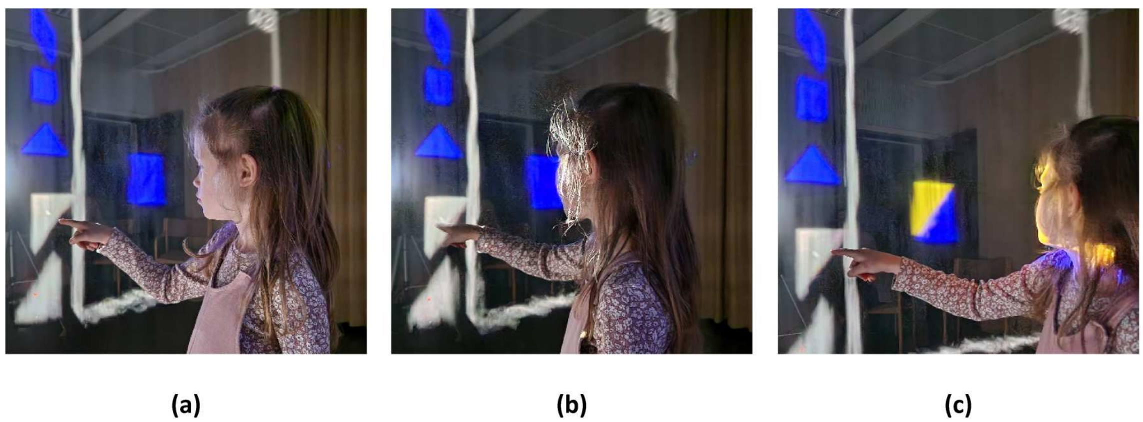

Figure 4. Participant selects a puzzle piece from the control panel: (a) preparation for selection, the finger is outside the fog; (b) positioning the finger inside of the required piece within the fog; (b) removing the finger from the fog; the selected piece is indicated as yellow on the play zone.

- ***Red*** (play zone) alerted players that the selected piece overlaps with another.

3.3. Gestural interface and user tracking

The gestural interface encouraged two interaction scenarios: selection and translation, executed differently in the control panel and play zone. The selection scenario refers to choosing pieces by tapping the grey placeholders from the control panel (see Figure 4). The choice of tapping was driven by the our earlier studies as a prospective selection method for interaction with fogscreens (Remizova et al. 2023a). In selection, the acquisition state was triggered when the finger entered the selectable area – an area inside of the puzzle pieces. As long as the finger remained inside the fog, it was possible to adjust the position of the piece (applies only to blue pieces in the control panel and yellow pieces in the play area). To successfully execute selection, the finger had to leave the fog within the piece's boundaries. By design, selections in the play area were not permitted.

The translation scenario referred to translating or moving a piece from one location to another (applicable to yellow pieces in the play zone only) and employed the tapping gesture mechanics (see Figure 5). In this context, as the finger entered the area inside of the active piece's boundaries (blue on the control panel or yellow on the play zone), the piece was captured and followed the finger's position as long as the finger remained inside the fog. When the finger is removed from the fog in the play zone, the puzzle piece stays in the last fixed finger position. If the piece capture ends up overlapping with other pieces or out of the play zone, the piece is returned to the control panel. If the translation is applied to an inactive object (blue on the play zone) then the existing selection is cleared.

Utilising the Kinect for Windows SDK 2.0, the system tracked skeletal data of the user's hand while our software analysed hand gestures. The design required the user's index finger of the dominant hand to enter the

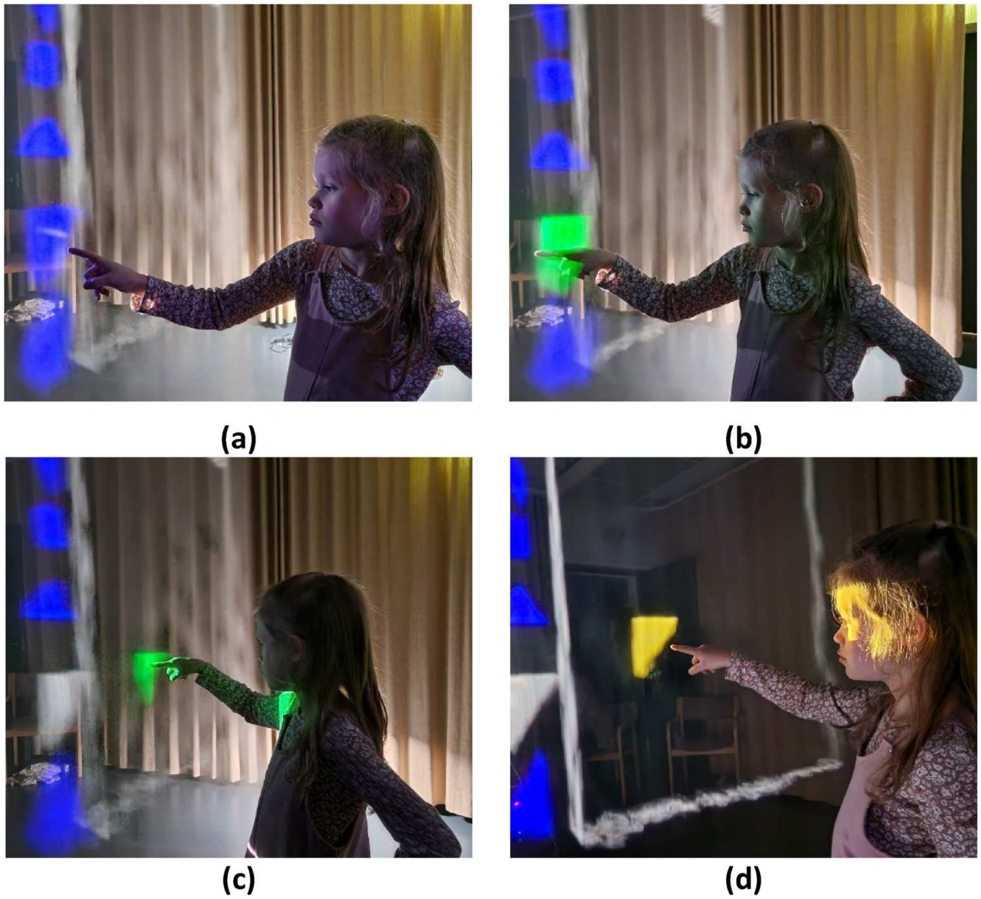

Figure 5. Participant translating the puzzle piece from the control panel to the play zone: (a) preparation for translation, the finger is outside the fog; (b) positioning the finger inside of the required piece within the fog; (c) moving the piece by moving the finger inside the fog; (d) removing the finger from the fog.

fog. Thus, the system detected each entry/exit point of the finger into/from the fog in the physical space. A hand tip (usually detected as a fingertip of the index finger of the right or left hand) controlled the mouse pointer. A four-point calibration matrix converted the depth vector obtained via the Kinect API (CameraSpacePoint.Position) into the screen point (Remizova et al. 2023a). The matrix contained Kinect vectors collected by pointing at the four corners of the fogscreen. The best possible calibration was used throughout the tests for all participants, as geometry of the hardware setup (i.e. the Kinect, fogscreen and projector positions) was fixed throughout the whole study.

4. Experimental setup

4.1. Participants

The study was conducted with 18 children (16 males and 2 females with mean age $M = 9.11$, $SD = 1.32$, range 8–12 years) referred for neuropsychological intervention due to confirmed attention deficits or diagnosed ADHD. The severity of attention deficits was determined with the teacher-rated Conners' 3TM (Conners 2008) and T-scores were used (mean $M = 50$, $SD = 10$). Clinically significant deficits of inattention and/or hyperactivity-impulsivity (T-score>65) were reported in 11/18 participants, three participants were within the high average range (T-score 60–64), three participants scored within the average range, and for one information was missed; six participants were on psychostimulant medication. According to self-reports from parents and children, none had noticeable problems with body coordination, muscle power control, or eyesight.

The participants played games on a computer, console, or mobile phone with different intensities: 61% played almost daily, 27% at least once a week, and 6% once a month or less. In physically active computer or console games, only 6% of children engage daily, 35% play at least once a week, and 59% once a month or less frequently. The participants also reported playing sports games or exercising at school daily (72%) or at least once a week (28%). All participants were novices regarding gestural interaction with a fogscreen.

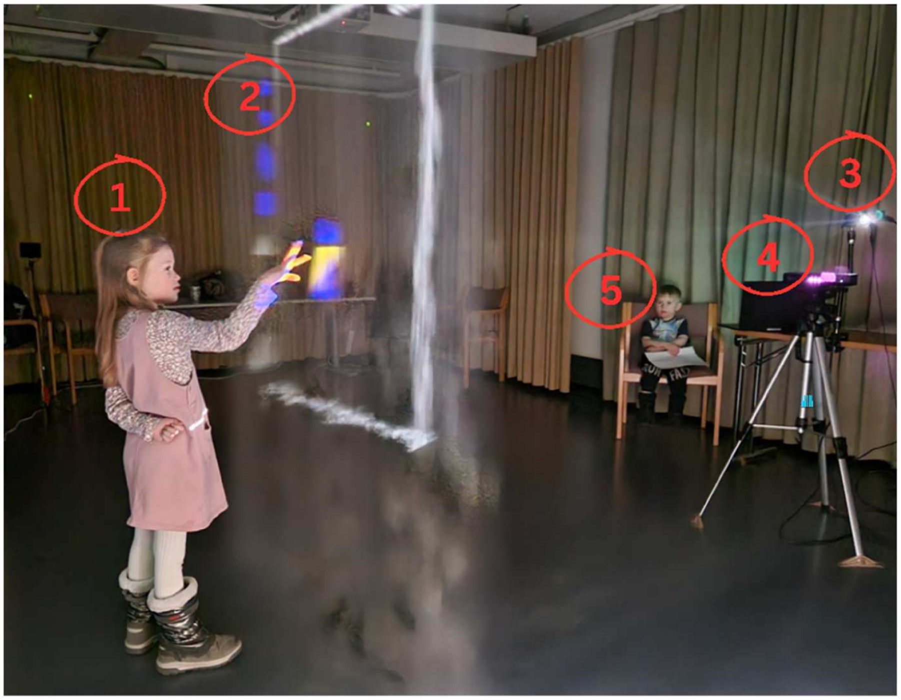

Figure 6. (1) Participant standing in front of the fogscreen (implementer); (2) fogscreen with a projected image; (3) projector; (4) Kinect sensor; and (5) instructor.

4.2. Apparatus

Experimental sessions were conducted in a spacious room with no direct sunlight and subdued lighting (see Figure 6). The fog was visible in an area roughly 1.55 × 2.05 m, but the lowest part was unusable for interaction due to strong fog fluctuations near the floor (see Rakkolainen and Palovuori 2002). The projected image ratio resulted in a 1.55 × 1.05 m area available for interaction. An Optoma ML750e mini LED projector was employed, producing 700 ANSI lumens at a contrast ratio of 15000:1. A laptop computer used in the experiment had the following specifications: MSI GT72S Dominator Pro (Windows 10, 2.7 GHz Intel Core i7-6820HK, 16 GB RAM, 1920 × 1080 pixels resolution). For interaction, we utilised a depth-sensing Microsoft Kinect Sensor V2 for Windows placed in front of the user, on the opposite side of the fogscreen, for monitoring the region directly in front of the screen. The graphical interface of the Tangram was developed in Unity game engine version 2018.2.9f1.

For further analysis of children's activities, we recorded each session from the perspectives of both the implementer and instructor. We used Logitech Pro 9000 web cameras for video recording, which were placed (1) close to the Kinect device and (2) the instructor.

4.3. Procedure

The study was conducted according to a protocol reviewed by the Ethics Committee of the Tampere Region (number of the protocol 36/2018). The children and their caregivers provided written informed consent to participate in the study. Background information about the children's gaming experience was collected from their parents using a questionnaire. During the experiment children played Tangram game and another game that is out of the scope of the current study (details presented in Gizatdinova et al. 2022; Remizova et al. 2023b). The order of game presentation was counterbalanced.

The study consisted of six gaming sessions, conducted over seven weeks, with a one-week break between each session. In each session, two children were playing the game as a pair. Each session was divided into four gaming tasks. In every task, one child assumed the role of the instructor, while the other acted as the implementer. The roles of instructor and implementer were counterbalanced and switched after every task.

The number of puzzle pieces and the difficulty of the game increased from session to session. The time for puzzle implementation was limited based on the number of pieces constituting the shape (with one minute allotted per puzzle piece) and lasted from three to seven minutes. The elapsed time of the gaming task was displayed in the upper right corner of the graphical interface. The task was deemed successfully completed if the participating pair managed to assemble the puzzle correctly within the specified time frame. Before the actual gaming, each participant had a short practice trial to ensure that they were able to reach the pieces on the control panel. The implementer was instructed to use the index finger of their dominant hand for interacting with the fogscreen.

The following bodies were presented in the room during each experiment session: two participants, one observer, one moderator responsible for the technical side of the experiment and data collection, and one neuropsychologist/psychologist from the psychology clinic. The moderator's role was only to change the levels when the tasks were completed and to provide clarification and technical aid if confusion or technical issues arose. Neuropsychologists/psychologists did not provide any advice on how to solve the task but took care that the children followed the instructions and received help in case of emotional or behavioural challenges. The participants received no advice on how to improve their performance in any way during the gaming tasks.

Children played one game (Tangram game or another game), had a short break with snacks, and then played another game. The participants' feedback was collected after each gaming session. After the first and the last gaming sessions, a questionnaire (see Appendix B) and a semi-structured interview (see Appendix C) were used. After the intermediate sessions only a questionnaire was used (see Appendix B). The scales ranged in value from 1 (negative) to 5 (positive) (five-point smiley rating scales) for questions after all game sessions and from value 0 (negative) to 2 (positive) (three-point Likert scale) for questions after the first and sixth game sessions. Altogether, the experiment lasted about an hour.

4.4. Experiment design

The experiment was a within-subject design across six game sessions, with the primary independent variable - game session (six values). Overall Game Success Rate GSR is defined as the percentage of successfully completed tasks (by implementer) to the total number of tasks across all sessions. In selection scenarios that are applicable only to interactions with the control panel (refer to section 3.3), Panel Selection Rate PSR represents the percentage of correct selections of pieces from the panel (made according to the game logic) to the total number of selections from the panel per task. A selection is correct when it is applied to an inactive piece, which then begins to undergo translation. Low PSR values may indicate difficulties in participants' understanding of the game interface.

Analysing the data in the context of the translation scenario, we separated two different terms: translation movement and translation event. *Translation movement* is a single drag-and-drop manipulation of an individual puzzle piece. Translation event, on the other hand, starts with the user selecting a particular piece and ends when the player selects another piece from the control panel. This way, the translation event may include uninterrupted translations of a particular piece as long as the user attempts to relocate it within the play area (it may involve multiple translation movements). The following translation-related dependent variables were analysed:

(1) *Translation Movement Time TMT (in sec.)* represents the duration of a single translation movement. It starts from the moment when the index finger enters the fog inside the piece borders (the piece turns green) and ends up when the finger leaves the fog (the piece turns yellow). Thus, the metric approximates the time when the finger of the player stays in the fog during translation.
(2) *Translation Event Time TET (in sec.)* is calculated as a cumulative sum of all TMTs in a single translation event (may also include translations from the control panel to the play zone). The mean value shows how long it takes on average to re-adjust the position of a single piece in one go.
(3) *Translation Attempts TA* is defined as the number of times when the piece was moved during a single translation event. High values indicate that children may encounter difficulties when translating a piece in fog due to technical difficulties (i.e. persistent loss of hand tracking) or unclear instructions.
(4) *Translation Success Rate TSR* is measured as the percentage of successfully completed translation movements to the total number of translation movements per game. A translation movement is considered to be successful when the translated piece is positioned in the play zone (otherwise when the piece returns to the panel, the translation movement is considered to be unsuccessful). Low success rates are referred to as indicators of children encountering difficulties when translating a piece.
(5) *Adjustment Rate AR* measures the percentage of successfully completed translation movements that required an adjustment in the piece's position to the total number of all successful translation movements per task. High adjustment rates may indicate low levels of translation precision and significant difficulties in controlling fog interaction.
(6) *Colliding Rate CR* is defined as the percentage of unsuccessful translation movements that happened because a piece collided with an existing piece in the play zone to the total number of captures per game. Low colliding rates are referred to as indicators of high translation movement precision.
(7) *Denied Rate DR* measures the percentage of rejected requests for a piece's translation movement to the

total number of all requests for a piece's translation movements per game. High denied rates may indicate difficulties in participants' understanding of the game interface.

Altogether, the designed data consisted of 18 participants × 6 sessions × 2 game tasks per participant (in implementer role) per session = 216 data points.

4.5. Data analysis

We collected a dataset consisting of data records from 182 game tasks played by 18 participants (with mean *M = 10, SD = 1.5* tasks per participant): eight children participated in all six sessions, six children in five sessions, and four children in four sessions (with mean *M = 5.22, SD = 0.81* sessions per participant); in total 48 h of video recordings. This large variation can be attributed to the participants who did not attend intervention programmes regularly due to personal reasons. As not all participants presented in all experiment sessions, for providing statistical analysis we replaced missing values with mean values of the sample (McKnight et al. 2007). In general, 14 values for each variable were missed (with mean *M = 2.3*, *SD = 1.11* values per session).

The Friedman test was used for the analysis performance measures across experimental sessions and subjective ratings. In case of a statistically significant effect, the Wilcoxon signed-ranked test was conducted for pairwise comparisons of subjective ratings. The Benjamini-Hochberg correction was applied to the *p*-values obtained from pairwise Wilcoxon Signed-Rank tests to address multiple comparisons across six experimental sessions.

Two independent raters reviewed the video recordings of each participant to note the key aspects of the users' experience of fogscreen interaction, as well as their behaviour and emotional state during the game. After independent reviewing, the raters convened to discuss their observations and reach a consensus. The primary purpose of these video observations was to obtain visual insights and enhance qualitative data extracted from the logs, offering a richer understanding of the interaction during the gaming.

5. Results

5.1. Quantitative measures

The grand mean game success rate GSR was 81% (*SD = 15.8*). In the selection scenario, selection from the control panel was applied only in 57% (*SD = 18.4%*) of game tasks, meaning that in 43% of the game tasks, the participants did not need to return to the piece translated from the control panel (no re-adjustments of its position were needed). In games where a selection scenario was applied, the grand mean of panel selection rate PSR was 44% (*SD = 17.2*).

In the translation scenario, the grand mean translation movement time TMT was 5.34 sec (*SD = 1.75*) (see Figure 7). The Friedman test showed that the effect of the session ($\chi^2(5) = 3.27$; $p = .659$) on TMT was not statistically significant. The grand mean translation event time TET was 11.9 sec (*SD = 3.95*) (see Figure 7). The Friedman test showed a statistically significant effect of the session ($\chi^2(5) = 3.27$; $p = .659$) on TET. Post hoc pairwise comparisons with the Wilcoxon signed-rank test showed that participants were significantly faster in the 6th session than in the 1st ($Z = 3.765$, $p = .006$), 2nd ($Z = 2.504$, $p = .012$), 4th ($Z = 3.245$, $p = .001$), and 5th ($Z = 3.464$, $p = .001$). The other pairwise comparisons were nonsignificant. The grand mean attempts per translation TA was 2.79 (*SD = 1.75*) (see Figure 7). The Friedman test showed a statistically significant effect of the session ($\chi^2(5) = 14.78$; $p = .01$) on TA. Post hoc pairwise comparisons with the Wilcoxon signed-rank test showed that participants did significantly less attempts in the 6th session than in the 3st ($Z = 3.027$, $p = .002$).

The grand mean success rate SR was 76% (SD = 12.7) (see Figure 8). The Friedman test showed that the effect of the session ($\chi^2(5) = 8.752$; $p = .119$) on SR was not statistically significant. The grand mean adjustment rate AR was 42% (SD = 21.5) (see Figure 8). The Friedman test showed a statistically significant effect of the session ($\chi^2(5) = 11.891$; $p = .036$) on AR. Pairwise post hoc comparisons showed that translation movements were significantly more accurate in the 2nd session than in the 4th session ($Z = 2.373$, $p = .018$) and in the 6th session than in the 3rd ($Z = 3.101$, $p = .002$), 4th ($Z = 2.548$, $p = .011$), and 5th ($Z = 2.070$, $p = .038$). The other pairwise comparisons were nonsignificant. The grand mean colliding rate CR was 11% (SD = 8) (see Figure 8). The Friedman test showed that the effect of the session ($\chi^2(5) = 4.212$; $p = .519$) on CR was not statistically significant. The grand mean denied rate DR was 8% (SD = 10) (see Figure 8). The Friedman test showed that the effect of the session ($\chi^2(5) = 7.681$; $p = .175$) on DR was not statistically significant.

5.2. Subjective evaluation

Figure 9 summarises the participants' ratings of the Tangram game in general and what they experienced as implementers. The Friedman test showed a statistically significant effect of the session on the participant

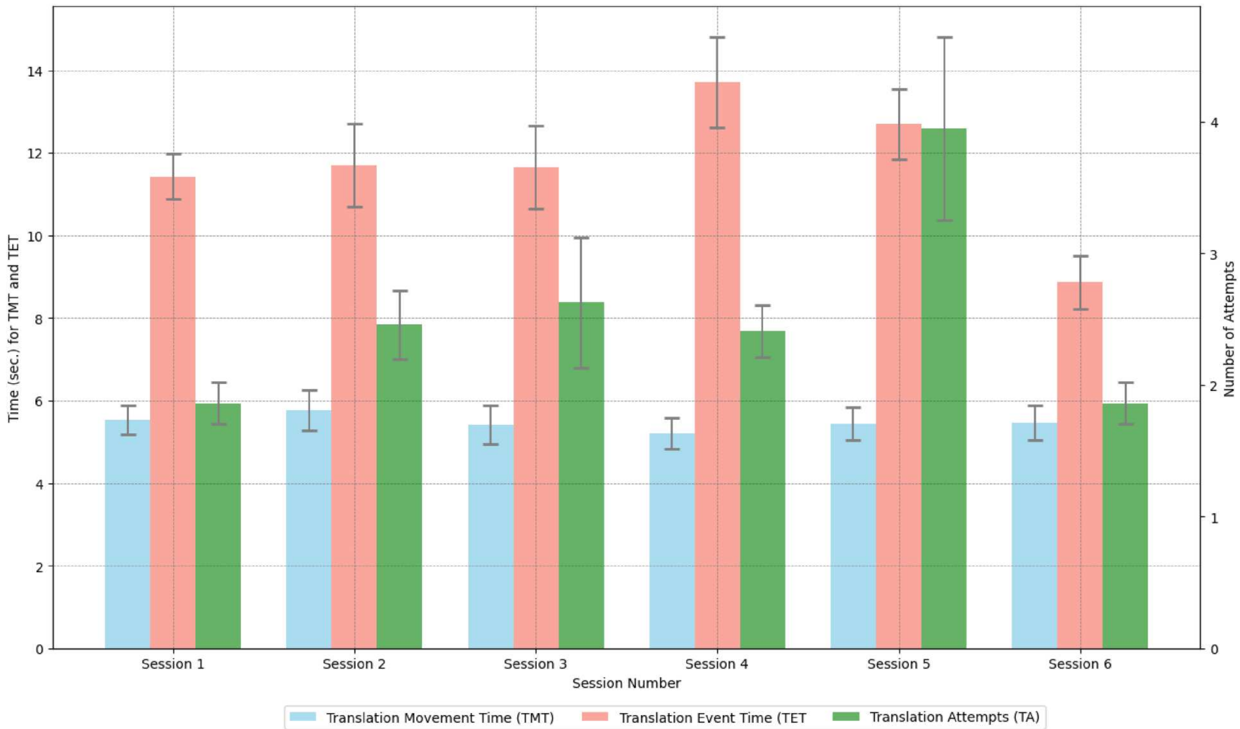

Figure 7. Plot of mean values for TMT, TET, and TA in sessions. Error bars represent ±1 SEMs.

evaluation in two questions (**Q1:** $\chi^2(5) = 11.49$; $p = .042$; **Q2:** $\chi^2(5) = 20.56$; $p < .001$), please refer to Appendix B. However, no statistically significant effect was observed for the third question (**Q3:** $\chi^2(5) = 5.53$, $p = .355$). Post hoc pairwise comparisons with the Wilcoxon signed-rank test did not show a statistically significant effect of sessions on the participants' subjective opinions. Most participants expressed a positive opinion about the gaming experience and their role as implementers and maintained it throughout all sessions.

In the interviews after the first and last session, some children mentioned that the best part of the game was being an implementer: 'Assembling the puzzle' [P1, 11 years] and 'Moving the pieces' [P2, 12 years]. While

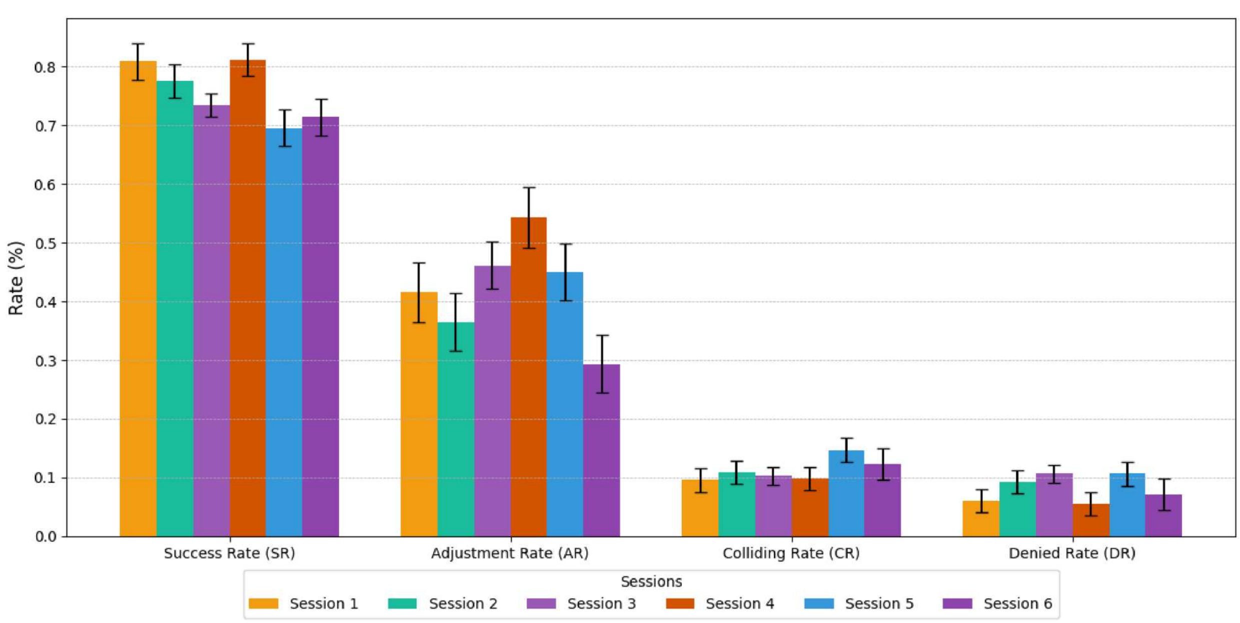

Figure 8. Plot of mean values for SR, AR, CR, and DR in sessions. Error bars represent ±1 SEMs.

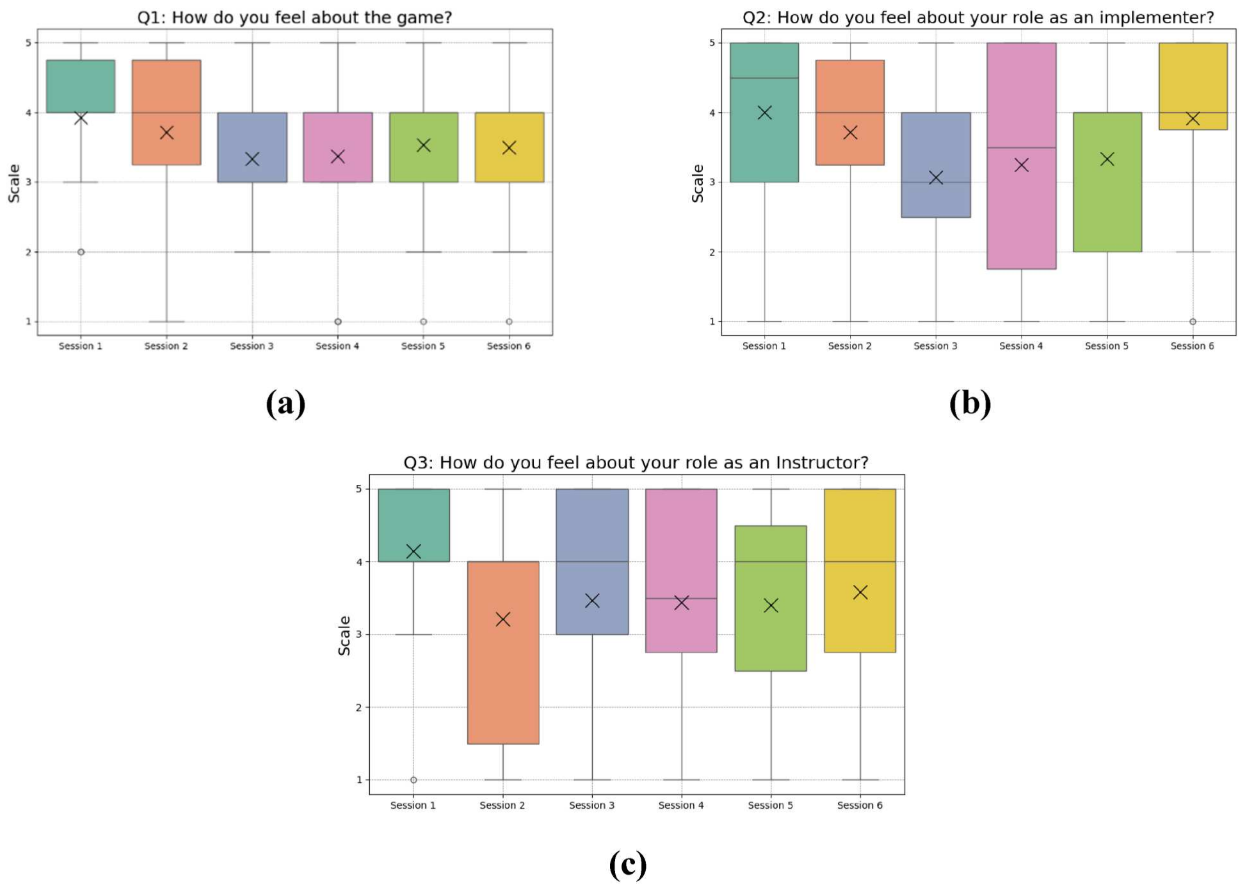

Figure 9. Plots of participants' evaluations (a) of the Tangram game in general and their experience as (b) an implementer and (c) an instructor. The scales varied from negative (1) to positive (5) experience. Error bars represent ±1 SEMs.

others found an instructor role as the best: 'The fact that I could instruct' [P3, 8 years]. The challenging nature of the game was also noted as engaging: '[It was the best part of the game] when I had to place the pieces so that it couldn't be red' [P4, 9 years]. Some of the children highlighted that they liked the presence of the fog: '[It was nice] when I was under the fog' [P5, 8 years]. In the negative aspects of the game, the children mentioned fatigue 'My hand got tired' [P6, 12 years], low fog visibility: 'It could be a bit stronger because they weren't very visible' [P7, 9 years] and 'Can't see the fogscreen up close properly' [P4, 9 years], and

Figure 10. Plots of the participants' responses from the first and the sixth Tangram game sessions: (a) the perceived difficulty of the game (with a scale 0 = difficult, 1 = middle, 2 = easy), (b) their willingness to play again (with a scale 0 = no, 1 = maybe, 2 = yes).

lagging in the system response when interacting: ‘the pieces didn’t come out the first time’ [P6, 12 years], ‘[I didn’t like] when I couldn’t reach the square’ [P5, 8 years], and ‘I didn’t like when it was slow, the pieces didn’t really start moving’ [P7, 9 years].

Figure 10 summarises the participants’ evaluations of the Tangram game in terms of perceived difficulty of the game playing and their readiness to play again from the first and sixth game sessions. The Wilcoxon signed-rank test did not show a statistically significant effect of the session on the participant evaluation for the two questions (**Q1:** $Z = 1$; $p = .317$; **Q2:** $Z = 1.897$; $p = .058$); refer to Appendix C. Most participants evaluated the game difficulty as easy and middle and expressed their desire to play the Tangram game again. All participants in both sessions reported that it was easy to understand how to play the game.

While reviewing the video data, some interaction issues were noticed. We observed that children exhibited a high level of excitement and engagement when interacting with the fog. That was demonstrated in their behaviour, for example, while waiting for the following instructions or the start of the game, some of the participants spontaneously engaged with the fog by tapping, hitting, and drawing invisible shapes on it, or even trying to eat it. During the gaming, emotional responses were notably pronounced; successful achievement of goals elicited jumping and expressions of joy, whereas irritation or frustration due to failures led to rough interactions with the screen, including hitting or kicking.

When the piece translation was successful and interaction with the fogscreen was smooth children tried to make this process more continuous and fun. They liked that the puzzle piece was following the finger, and they preferred circular trajectories over straight paths for translation. Also, when translating a piece, the participants were prone to unconsciously pulling the hand towards themselves, which led to the premature and sudden loss of the translation piece when the hand unintentionally left the recognition zone. This required children to adjust the position of the piece or take it from the control panel again in case it returned there. In the context of selection action, there were also some observations. The participants exhibited uncertainty in accurately selecting pieces and comprehending system responses. They often overlooked that the piece had already been selected (and turned yellow). Consequently, they repeated their selections from the control panel unnecessarily several times, their gestures became faster, and participants did not always enter their finger into the fog as required for optimal interaction. Visibility issues with the fogscreen were apparent, as children sometimes had to take a step back to look at the whole picture or to watch the screen from different view angles.

The participants did not use the entire play zone to place puzzle pieces. Notably, the preferred area of interaction for children in our study was the bottom-left part (close to the control panel) and the central part of the fogscreen, where children most often moved the figures. Despite the instructions to use only one dominant hand for interaction, there was a tendency for the children to use the other hand, likely due to fatigue. They also did not always follow instructions to use the index finger to interact and used hand gestures such as fist, whole palm, and pinch.

6. Discussion

Our findings indicate that interaction with the fogscreen offered an exciting and fun experience for children. The children evaluated both the game itself and their interaction experience with the fogscreen primarily from the positive side (see Figure 9(a)). They perceived the game difficulty as easy or moderate and found understanding how to play the game as easy (see Figure 10(a)). Based on these data and children’s free comments, we can assume that participants did not find understanding the instructions in the game or how to play the game to be difficult. Through all gaming sessions, children were motivated to complete all the required gaming tasks without interruption due to disliking the game itself or facing insurmountable difficulties while interacting with the fogscreen. The majority of participants consistently expressed positive feedback regarding their roles as both implementers and instructors throughout all sessions (see Figures 9(b and c)). Moreover, none of the volunteered children dropped out of the gamified therapy, likely reflecting the engaging nature of the game’s interaction mechanics, which provided sufficient variety and challenge to maintain interest over time. The high game success rate of 81% further confirms that interaction with the fogscreen supports the game process itself. This allows us to recommend a combination of gestural interaction and fogscreen interaction media as useful and usable means of active gaming for children with attention deficits. These findings are in line with previously reported which has shown that mid-air gesturing and physical interaction with the fogscreens can enhance and sustain motivation in gaming for children (Jumisko-Pyykkö, Weitzel, and Rakkolainen 2009; Rakkolainen et al. 2007; Rubegni et al. 2019). However, it is important to note that participants willingness to play again decreased by the sixth session (see Figure 10(b)). This suggests that while the game was initially engaging, participants' motivation to continue playing diminished over time. This reduction could be attributed to factors such as familiarity with the game or a decrease in gameplay novelty, which may have led to a lower desire to replay the game by the sixth session.

Our results further revealed that there was no significant difference in translation movement time throughout all game sessions. The average time of a finger spent in the fog during a single translation movement was about 5 s. However, there were significant differences in translation event time between game sessions. The children were significantly faster in the final session compared to the earlier sessions. This allows us to assume that the children learned how to interact with the fog more effectively over time, becoming confident users of this new technology. Based on the average translation event time, the screen size (1.55×1.05 m), and children's preferred interaction area (central with a slight shift to the left), we estimated that the average translation speed was about 6.5 cm per second. While we do not have direct data from previous studies to compare with our results, future research is needed to contrast mid-air gestural interaction on fogscreen with those on conventional large screens.

Our results showed that the translation event of one piece required 2–3 translation movements on average, including both successful attempts when a piece was placed in the play zone, and unsuccessful attempts when a piece returned to the control panel. Notably, 76% of all translation movements were successful (SR), of which 42% were adjustment translation movements (AR). We assume that one of the important reasons for such values of SR and AR was the hand being unintentionally pulled out of the fog and leaving the hand detection area. A possible solution to overcome this issue can be a definition of the exit point as closer to a user (relative to the entry point along the depth (Z) axis of the interaction space).

One of the reasons for unsuccessful translation movements was the collision of the translated piece with other pieces already placed in the play zone, which occurred in 11% of all translation movements. Furthermore, we noticed that children sometimes accidentally shifted the position of the piece from its intended place by unintentionally removing their hand from the fog. This was because when pulling the hand out from the fog, the children changed the tilt of their hand, in turn, this shifted the hand's centre of mass, which sometimes caused a change in the position of the pointer. As reported by the children themselves, overcoming additional challenges, such as placing a piece close to another and not colliding, sometimes may increase their motivation to play. However, in other cases, a solution resembling magnetism could be applied, in which the pieces, instead of automatically returning to the control panel in case of collision, would join to the edge of the colliding piece (Mäkelä, Heimonen, and Turunen 2014; Sharma et al. 2016).

Further, our results revealed that 8% of all requests to pieces for translation movement were done incorrectly. This happened when the children tried to translate inactive pieces (marked as blue in the play zone) instead of first selecting them on the control panel. The selection scenario was applied in 57% of the played tasks. Given that we assume that in other cases users could translate pieces in one translation event. However, in the games where the selection scenario was applied, only 45% of the control panel selections were made correctly. Incorrect selection included repetitive selections of already selected pieces or the selection of wrong pieces, not the ones that then started to translate. We can assume this to be due to improper visual feedback. The fogscreen is large, and its visibility is limited due to fog turbulence, therefore when the response to an action is displayed as not aligning with the current hand position or user's line of sight, it can be easily overlooked. Therefore, we can conclude that in the case of mid-air interactions with a large fogscreen, it is important that visual feedback is displayed where the hand is currently located, as it has been done with the translation scenario. For example, grey placeholders in the control panel could have a yellow outline if the corresponding puzzle piece in the play area is available to move (marked as yellow in the play zone).

While the mid-air gestural interaction with the fogscreen and the game experience for children generally received a positive assessment, we observed challenges related to hand fatigue in prolonged interaction. Extending one's hand horizontally or raising it for long periods can lead to fatigue feeling, often referred to as 'gorilla arm' syndrome, a common issue in mid-air gestural interaction (Anthony et al. 2016). Given that, we can assume the location of interaction elements should be predominantly located in the lower and middle parts of the play zone, without implying a high rise of the hands and prolonged stretching of them into the horizontal plane, as it happened in the case of pieces located on the top of the control panel.

We observed a trend to interact with the fogscreen not only with the index finger, as mentioned in the experiment instructions. Trying new gestures for interaction was also mentioned earlier in touchscreen interaction studies (Anthony et al. 2016). It is likely that this distinctive feature of children in exploring the boundaries of possibilities in interaction also helps maintain motivation to be involved in the game. Furthermore, our study observed that children sometimes interacted with the fogscreen in a somewhat hostile way, for example, due to frustration. This behaviour was somehow expected in our clinical group of children with problems in both impulse and emotion regulation. Similar behaviour was observed with touchscreen interaction earlier by Müller et al. (2014). However, due to the unbreakable structure of the fogscreen, children could safely express their negative feelings in such a way without the risk of injuring themselves or damaging the equipment which is an important aspect when designing game solutions for children that have limited self-control.

The present study has several limitations. Our study was conducted with children referred for neuropsychological intervention due to confirmed attention deficits or/and challenges in behaviour control and impulse inhibition. Provided that the children did not have motor difficulties, it is, therefore, reasonable to expect somewhat similar results regarding the quantitative interaction measures in the typically developing child population. However, absence of a control group of typically developing children limits our ability to determine whether the observed effects are specific to children with attention deficits or if they could be similarly observed in children without neurodiverse conditions. Future research including typically developing children could help to ascertain the uniqueness of our findings in relation to attention deficits or generalise them to broader population. Another limitation involves the gender composition of our sample, which consisted predominantly of boys (16 boys and 2 girls). Given that spatial cognition and behavioural differences can vary between boys and girls, this imbalance could impact generalizability and affect interaction performance (van Dun et al. 2021). To address this limitation, future studies should endeavour for a more balanced gender representation to better understand the influence of gender on interaction performance with fogscreens.

Notably, the primary goal of this explorative study was to investigate technical performance characteristics and explore the experiences of children engaging in mid-air gestural interaction with a large fogscreen. We focused on such usability-related measures as efficiency and effectiveness of the interaction, as well as subjective experience. This approach intentionally excluded assessments of attention and executive functions. While this focus aligns with our research objectives, incorporating cognitive and behavioural assessments in future studies could provide a more comprehensive understanding of the impact of such interaction technologies of children's development. It is important to highlight that in the current study, our statistical analyses were based on the means values of measures. However, the heterogeneity of behavioural manifestations in neurodiverse children can significantly influence the interaction outcomes. Future research should consider models that account for such heterogeneity, such as latent growth models, to better capture individual differences and understand the diverse manifestations of children with attentional deficits. Furthermore, ongoing research should consider additional variables that may influence user experience and engagement, such as variations in game design, task complexity, interaction modalities (e.g. comparison with a desktop application or a physical version of the Tangram game) or quality of co-operation and interaction between children. These efforts will help to highlight the specific contributions of mid-air gestural interaction with fogscreen to the overall gaming experience and its potential benefits for neurodiverse children.

In addition, our experimental design involved two roles for participants: Instructor and Implementor. The current study primarily focused on the Implementor role, as this required direct manipulation with the fogscreen, which aligns with the focus of this paper. The puzzles and the complexity of the instructions were selected according to the children age and their ability to provide instructions by the clinical neuropsychologists and a specialist teacher working with children with special needs. However, since children played in pairs, it is possible that the quality of the provided instructions by the Instructor influenced the Implementer's performance, affecting the overall gaming success and the therapy itself. Although the measures of TMT, CR, and DR were minimally (if at all) influenced by the quality of instructions, other dependent variables might have been affected. In the future, we plan to design and evaluate additional gesture-based applications for fogscreen that allow us to isolate and assess interaction performance more effectively, while exploring diverse application scenarios for children. Despite these limitations, our study provides initial evidence that mid-air gestural interaction with fogscreen technology can serve as an engaging and motivating medium for children with attention deficits, with promising potential for applications in therapeutic gaming.

To summarise our findings for actionable guidance in designing applications for walk-through displays, the following notions can be made. First, our results highlight the importance of providing visual feedback directly aligned with the user's point of interaction, rather than in peripheral areas where they might be easily missed. Designers should use high-contrast, clear, and contextually placed visual cues to guide users effectively, which can help avoid confusion and improve the intuitiveness of interaction, particularly for children. Moreover, our observations of fatigue during continues interaction underline the need for ergonomic considerations in design. Specifically, interactive elements should be placed at accessible heights—primarily in the middle part of the display reducing the need for extended arm raises. Designers should avoid prolonged horizontal or overhead hand stretches, which can cause discomfort and fatigue. Finally, the observed difficulties children experienced with precise placement of puzzle pieces could benefit from resembling magnetism. Due to fog turbulence and somewhat limited visibility implementing a magnetic-like effect, when objects 'snap' into place or align without colliding, could reduce user frustration and make interaction smoother, particularly for young users still developing motor control. Such design implications can improve both the user experience of interaction with walk-through displays and the overall usability of their applications.

7. Conclusion

This study represents one of the early attempts to systematically investigate in the explorative study the interactive properties of mid-air gestural interaction with large fogscreen for children, including those with behaviour control and impulse inhibition challenges. We described the observed challenges in the study and proposed potential solutions for them.

Our findings show the promising perspective of fogscreen technology in creating engaging and intuitive interactive experiences for children. The predominantly positive responses from participants, high-performance evaluation, and the ability to complete tasks without major challenges emphasize the fogscreen's suitability for children-centred applications. Moreover, our research revealed the importance of providing appropriate visual feedback during fogscreen interactions. Collectively, our study confirms the feasibility of fogscreens for enhancing interactive experiences for children and provides valuable insights into optimising interaction design for this novel technology, forwarding its application in education, therapeutic interventions, and beyond.

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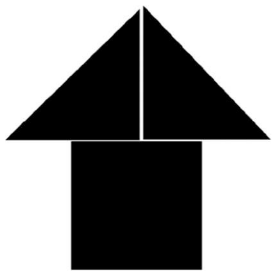
Appendices

A Tangram tasks

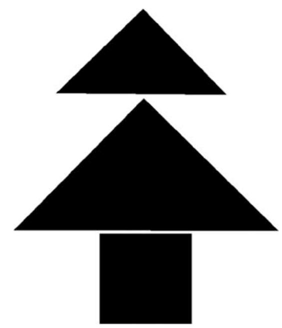
3 Piece House



3 Piece Trapezoid

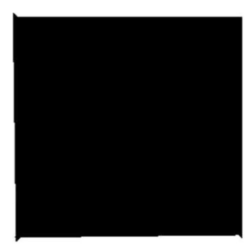
3 Piece Fox Head

3 Piece Tree

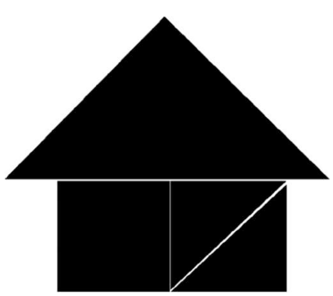


3 Piece Rectangle

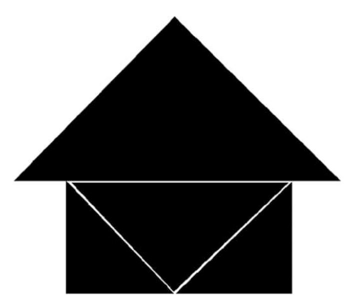
3 Piece Square



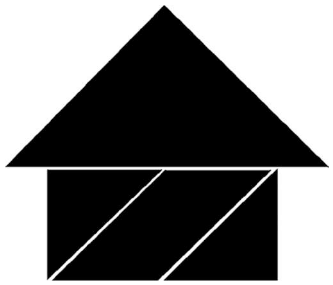
4 Piece House 1



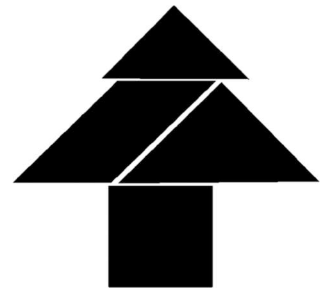
4 Piece House 2



4 Piece House 3

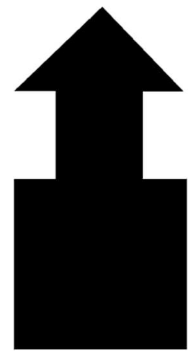


4 Piece Tree

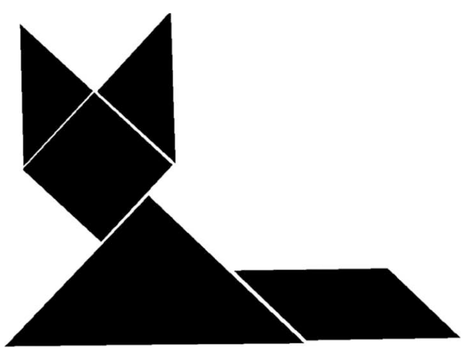


4 Piece A

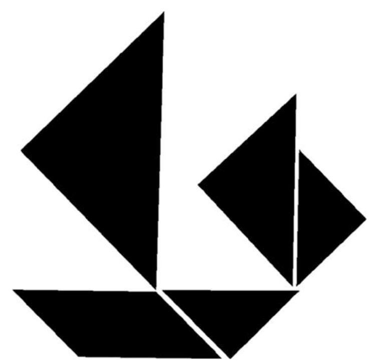
4 Piece Tower



5 Piece Cat

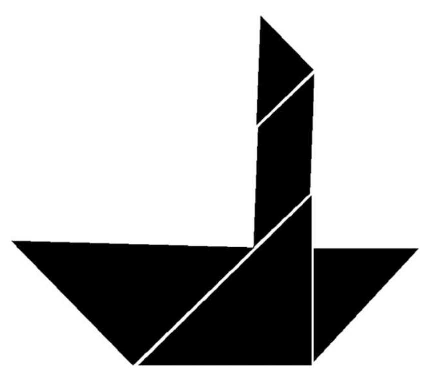


5 Piece Boat

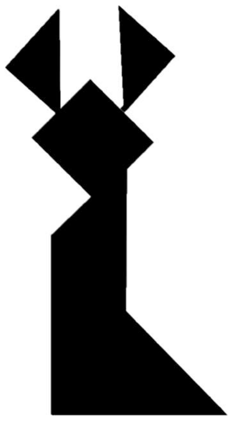


5 Piece Tree

5 Piece Steam Boat

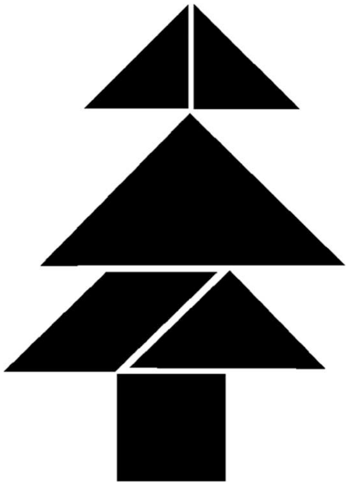


5 Piece Bunny

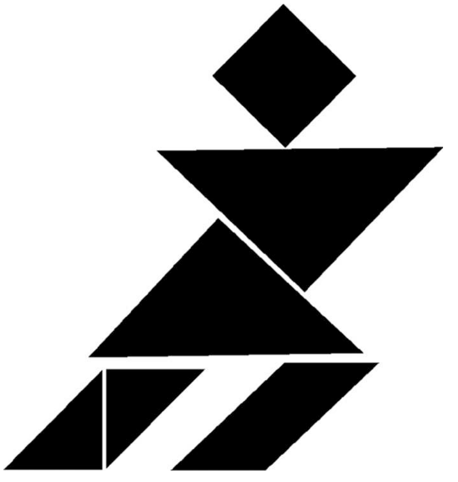


5 Piece Pipe

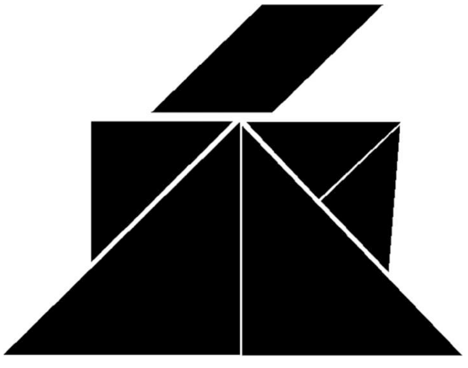
6 Piece Tree



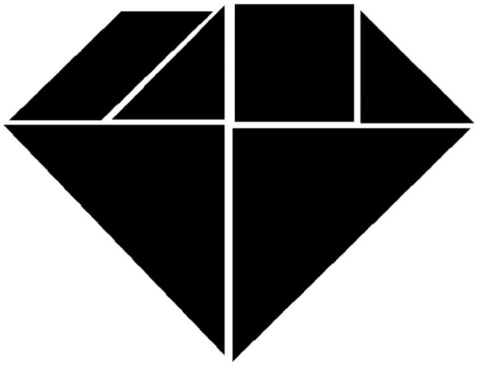
6 Piece Person



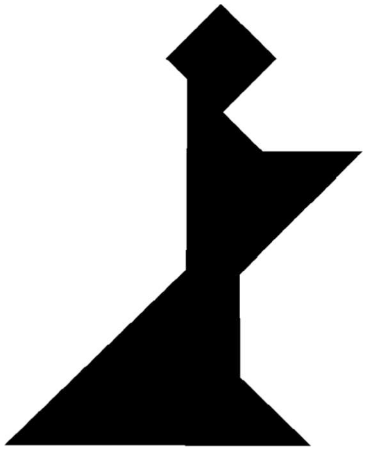
6 Piece Candle



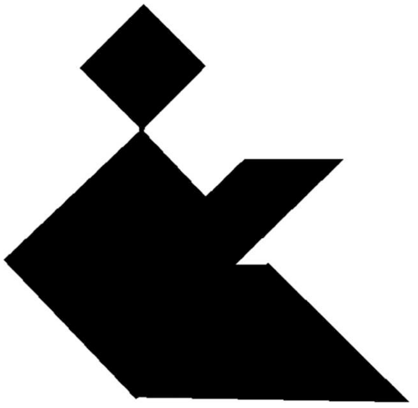
6 Piece Diamond



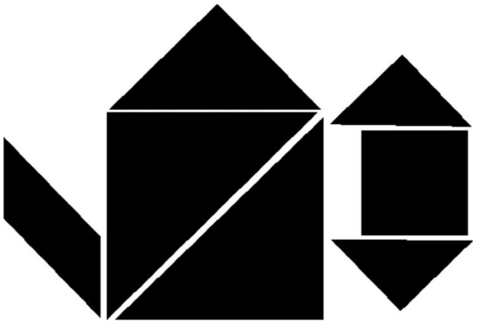
6 Piece Standing Man



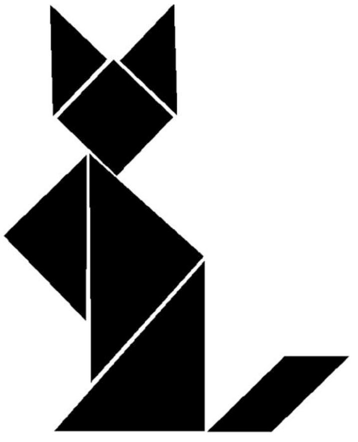
6 Piece Sitting Man



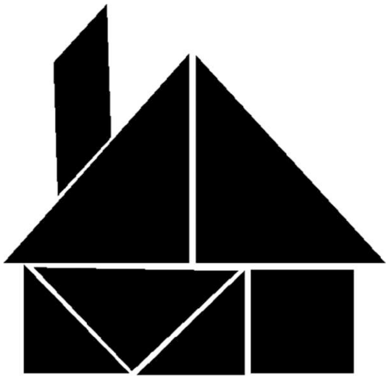
7 Piece Tea Pot



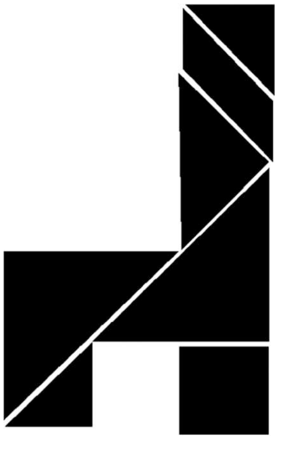
7 Piece Cat



7 Piece House



7 Piece Chair



B Questionary

(1) How do you feel about the game?
(2) How do you feel about your role as an implementer?
(3) How do you feel about your role as an instructor?

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) Did you notice that time passed too quickly? (quick/ moderate/ slow)
(6) 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)
(7) Would you tell your friends about this game? (Yes/ maybe/no)