Child-Display Interaction: Exploring Avatar-based Touchless Gestural Interfaces

Elisa Rubegni*
University of Lincoln
Lincoln, United Kingdom
erubegni@lincoln.ac.uk

Vito Gentile*
Università degli Studi di Palermo
Palermo, Italy
vito.gentile@unipa.it

Alessio Malizia
University of Hertfordshire
Hatfield, United Kingdom
Molde University College
Molde, Norway
a.malizia@herts.ac.uk

Salvatore Sorce
Università degli Studi di Palermo
Palermo, Italy
salvatore.sorce@unipa.it

Niko Kargas
University of Lincoln
Lincoln, United Kingdom
nkargas@lincoln.ac.uk

ABSTRACT

During the last decade, touchless gestural interfaces have been widely studied as one of the most promising interaction paradigms in the context of pervasive displays. In particular, avatars and silhouettes have been proved to be effective in communicating the touchless gestural interactivity supported by displays. In the paper, we take a child-display interaction perspective by exploring avatar-based touchless gestural interfaces. We believe that large displays offer an opportunity to stimulate child experience and engagement, for instance when learning about art, as well as bringing a number of challenges. The purpose of this study is twofold: 1) identifying the relevant aspects of children's interactions with a large display based on a touchless avatar-based interface, and 2) understanding the impact on recalling the content that arises from the interaction. We engaged 107 children over a period of five days during a public event at the university premises. Collected data were analyzed, and the outcomes transformed into three lessons learnt for informing the future design.

CCS CONCEPTS

• **Human-centered computing → Gestural input**; *User studies*; • **Social and professional topics → Children**; • **General and reference →** *Empirical studies.*

KEYWORDS

children-computer interaction, gesture-based interfaces, avatar, pervasive displays, ubiquitous computing

ACM Reference Format:
Elisa Rubegni, Vito Gentile, Alessio Malizia, Salvatore Sorce, and Niko Kargas. 2019. Child-Display Interaction: Exploring Avatar-based Touchless Gestural Interfaces. In *Proceedings of the 8th ACM International Symposium on Pervasive Displays (PerDis '19), June 12–14, 2019, Palermo, Italy.* ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/nnnnnnn.nnnnnnn

*Both authors contributed equally to this research.

1 INTRODUCTION

Touchless gestural interaction has been widely studied during the last decade, as one of the most promising solutions for allowing interacting with displays of various sizes [3]. In particular, prior work investigated the use of such paradigms in the context of public displays. Indeed, supporting mid-air gestures (or touchless gestures, as often reported) is crucial in order to increase accessibility (e.g. for wheelchair users) or to avoid vandalism (e.g. by placing displays in unreachable places, still keeping their interactivity) [31]. However, one of the most common issues in this context is *interaction blindness*, i.e. the inability of the users to guess the interactive capabilities of displays [25]. Moreover, researchers are still looking for effective ways to overcome the problem of *affordance blindness* – the inability to understand the interaction modalities of a public display [8]. In this case, even if users notice or imagine that a display is interactive, they also need to figure out how to interact with it. This is particularly true for touchless-enabled displays that are often mistaken for the more common touch-based ones. In this context, visual interfaces play a key role both before and during the actual interaction. Indeed, an appropriate interface could strongly contribute to address both the interaction blindness and affordance blindness and could make the interaction itself more intuitive and straightforward. Many prior works suggested the use of avatar-based interfaces, where a predominant human-shaped entity continuously reproduces user movements [18, 23, 33, 34]. These studies revealed the effectiveness of silhouettes, mirror images or avatars in communicating the supported interactivity and its touchless nature. Considering such advantages of avatar-based interfaces in supporting adults' interaction, we aim at understanding whether similar effects happen also in child-display interaction. In fact, prior work showed how touchless gestural interfaces may facilitate learning in children [1, 26], and how these can be suitable and have been widely adopted in serious games [5, 13]. For these reasons, in our research we investigate the multiple facets of the children-display interaction mediated by an avatar-based interface.

In this paper, we present the outcomes of our research, which has the purpose of: 1) identifying the relevant aspects about children interacting with a large display based on an avatar-based interface, and 2) understanding the impact on recalling the contents provided through the interaction.

2 RELATED WORK

Our research builds upon prior HCI work, within areas such as touchless gestural interfaces for pervasive displays and child-computer interaction. This section provides an overview of the related work that guided and supports our research.

2.1 Gestural Interfaces and the use of Avatar

In the context of pervasive displays research, many touchless gestural interfaces have been proposed and implemented. They have been used in order to interact with 3D virtual objects [6], to access information provision systems [7, 18], to create and support playful interactions [23], and have many other applications. The use of touchless gestures, especially when applied to public displays, has many advantages. Among them, touchless gestural interaction limits vandalism by placing displays in unreachable places [31], keeping a high hygiene level of the screen surface [19], and removing constraints to the display size (see, for instance, works on media façades [9]). Walter et al. [34] focused their work on describing existing solutions found in literature, for user representation in touchless gestural applications. Recently, other works focused on the use of silhouettes or avatars [18, 23], since they have proved to be very effective in solving some common pervasive display issues, namely *interaction blindness* (i.e. the inability of the users to recognize the interactive capabilities of a display [25]) and *affordance blindness* (i.e. the inability to understand the interaction modality of the display [8]). Gentile et al. showed also that the presence of an avatar makes two-handed interactions more "natural" in the sense that it contributes to a reduction of the cognitive workload while interacting with public displays [17]. However, to the best of our knowledge, prior work has not focused on the use of avatar-based solutions by a specific class of users, such as children. For instance, Müller et al. showed that interactivity can be recognized after less than three seconds using avatars [23]; however, their work considers users of various ages, without an in-depth analysis of children's behaviors. Similar limitations can be found in [8, 17, 18, 33]. In the context of child-computer interaction, other facets of touchless gestural interaction have been investigated, mainly in order to understand the effect of such novel paradigm in learning activities [1, 5, 26], but also for gaming purposes [4, 5, 12]. Several applications described in the literature employ users' silhouettes [14, 36], but some authors opted for both "stick-man"-shaped avatars (e.g. Tweetris [12]), or more customizable avatars [4, 5]. Adachi et al. showed that full-body interaction promotes a sense of immersion in children [1]. Bailey et al. showed also that the customizability of avatars might make the gameplay experience more enjoyable [4]. Bartoli et al. showed that motion-based touchless games may have a positive impact in improving the learning capabilities of autistic children [5]. The ability to facilitate learning has been described more generally as an effect of engaging interactions [2]. Moreover, the relation between enjoyment and engagement of natural user interfaces interaction is well known, as shown for instance in [35]. Albeit there is an extensive literature on touchless gestural interaction with children, to the best of our knowledge, avatar-based interfaces have not been thoroughly studied with children in terms of the challenges relevant to the pervasive displays' community, as has been the case for instance with affordance blindness, or two-handed interaction.

2.2 Children Cognitive Development

In our study, we focused on participants aged from two to ten years old. Within this age range, a number of cognitive abilities are significantly developed such as executive functioning [21], visual and spatial perspective-taking (i.e. the ability to perceive a situation from another's point of view [11]), counterfactual thinking [30], and theory of mind (i.e. the ability to understand other people's mental and emotional states [27]). For example, three and four year old children often experience difficulties adopting the perspective of others in perceptually based tasks [29] and communication tasks [22]. According to Piaget's four stages of cognitive development [28], children are in their *pre-operational* (2-7 years old) and *concrete operational* (7-11 years old) stages. In the pre-operational stage, children are still in their egocentric phase, in terms of their ability to communicate, and they have difficulty in taking the perspective of other people (young and adults) including the emotions of those other people. In the concrete operational stage that follows this stage, children start thinking logically about concrete events and the egocentrism tends to disappear, however they struggle with abstract concepts. Thus, considering the skills of children in the different cognitive development stages it is relevant to understand how to design interaction patterns and interfaces of interactive system based on touchless gestural interaction that could be suitable for them. We have explored this issue on a study in which we have engaged children of different age. Following we present the study and its outcomes.

3 STUDY DESCRIPTION

The study was run during a summer public engagement event[1] organized by the University of Lincoln, UK. During the event, children and parents were invited to play with different research showcases. The event lasted five days, with eight different sessions (one on Monday, one on Friday, and two on each other weekday) and a total of 24 showcases. Each showcase was installed in a room in order to allow researchers to collect data properly and for participants to have their own space. The event organizers informed parents and obtained their consent. Children knew that they could decide to abandon the study any time they wanted. Researchers acted as facilitators and made sure children did not feel under pressure but were comfortable with and enjoyed the activity. Prior to the study, a faculty ethical approval was obtained. In this context, we conducted our study, aiming at investigating some of the issues that have an impact on improving children's experiences when interacting with touchless visual interfaces. In particular, the main purposes of this exploratory study are: 1) identifying the relevant aspects of children's interactions with a large display based on an avatar-based interface, and 2) understanding the impact that the interaction had on recall of the content.

[1] Lincoln Summer Scientist 2018: https://summerscientist.blogs.lincoln.ac.uk/

Figure 1: Interface appearance, showing the avatar over the interactive jigsaw.

3.1 The Interactive Art Jigsaw

In order to explore our main research issues, we designed two 2x3-tiles interactive art jigsaws representing two paintings[2].

The interaction of the child with the jigsaw is based on an visual interface shown on a large display, and the manipulation of jigsaws pieces is based on mid-air gestures. The first jigsaw is initially filled with all pieces except one. The missing piece is placed randomly on the left or right side of the interface. When the user completes this first puzzle, a smiling face is shown to confirm completion. Then, when the researcher presses a key on the keyboard, a second jigsaw puzzle is shown, wherein all six pieces are arranged at the sides (see Figure 1). Right after the user correctly solves the puzzle, a video is automatically played providing additional textual and audio information about the painting (author age, name, origins, and where the painting is exhibited). The first jigsaw was intended to serve as an initial training phase for children, in order to let them understand how to interact with it (see section 3.5). Then, the second jigsaw can be completed after they have learned how to use the interface to solve the puzzle. Interaction with the jigsaw pieces was based on a virtual avatar shown in the middle of the screen, which continuously replays user's movements. Tiles can be dragged and dropped by driving the avatar's hands on top of them with users' own hands, and by closing (grab), moving (drag) and opening (drop) the hands correspondingly. As explained in section 2.1, the presence of the avatar allows for more natural interactions [17] and should facilitate users in understanding how to interact with the system, thus addressing the affordance blindness [23].

Considering the broad age range and abilities of our participants, we were aware that it would have been quite challenging to design an interaction that could be stimulating and at the same time easy to use. The design of the Interactive Art Jigsaw was based on a previous deployment [16] and adapted according to the specific needs of our user (children) sample.

[2]Without loss of clarity and/or generality, in the paper's figures we depicted only one painting, due to copyright restrictions.

3.2 Technical Apparatus

The Interactive Art Jigsaw system used for our study consisted of a 55" LCD display placed at the eye-level, connected to a computer and a Microsoft Kinect SDK v2 in order to gather information on users' body gestures.

3.3 Participants Selection and Recruitment

The event hosted 220 children (F=102, M=118) aged 2-10 years. Participants arrived at the beginning of each session and played with other children and the parents in a common room. Researchers (our team was composed of two researchers) had to recruit the participants by randomly selecting them from the crowd. The participants were involved on a voluntary basis. The researcher contacted the child, explained the study to him/her and their parents, and asked them to participate. If s/he agreed, they moved into the room with the installation; if not, the researcher acknowledged this and asked someone else. A total of 107 children (F=54, M=53) played with our Interactive Art Jigsaw. The age groups were quite evenly distributed: 2yrs=0.9%, 3yrs=6.5%, 4yrs=8.4%, 5yrs=15.0%, 6yrs=16.8%, 7yrs=15.9%, 8yrs=15.0%, 9yrs=16.8%, 10yrs=4.7%. We had 13.4 children per session on average.

3.4 Procedure

At the beginning of each test, children were invited, one at a time, to enter the room where our system was deployed. In a few cases, we needed to allow parents to be there in order to make the child feel comfortable. Then, the child was instructed in the tasks. In the first jigsaw, they had to figure out how to interact with the system in order to place the only missing piece in the right position. In the second, they had to complete the jigsaw by placing all the pieces in the right positions (see Figure 1). The first jigsaw was intended to serve as an initial training phase and no instructions about how to interact with the display were given to the children. However, if the child was unable to understand how to interact with the display, an experimenter gave her a suggestion every 30 seconds. The instructions were given by the researcher, from one to four:

(1) "step back": the experimenter used this suggestion in case the child tried to interact by touch, since being too close to the display did not allow the avatar to be visible
(2) "try to move your arms and hands": the experimenter used this suggestion if the child noticed the avatar, but did nothing else to interact with it
(3) "grab a piece": the experimenter explained to the child how to grab a piece, i.e. to close the hand into a fist after having driven the avatar's hand on top of the piece
(4) "mimic": the experimenter gave explicit instruction on how to use the body by enacting the interaction and asking the user to mimic her behavior

After the completion of the first task, if the child needed at least one suggestion, the experimenter asked them to perform the task again, in order to make sure that the child understood how to properly interact. After the completion of the first puzzle, a second one was shown, and the child was asked to complete it. At the end of this second task, the child was asked to watch a video, showing textual and audio information about the author of the painting in the last jigsaw. After the completion of the tasks, participants were asked to conduct a semi-structured interview, assessing their experience in playing the games.

3.5 Methods, Data Collection and Analysis

Data were collected from different sources: demographics from the organizers, notes taken by the two researchers during the task execution, and semi-structured interviews. To analyze the data collected, we adopted a mixed approach by merging qualitative and quantitative methods.

During the tasks, researchers took notes of the duration of the interaction, the number and type of suggestions given to the users during the first task, as well as other notable events. We also collected qualitative data based on observations, particularly focused on child interaction and other events, e.g. occasional parent intervention in giving some help.

The semi-structured interviews aimed at allowing children to self-report their experience:

- **Q1** How much did you enjoy the game?
- **Q2** Would you recommend it to other children?
- **Q3** What did you like about the game?
- **Q4** What did you not like about the game?
- **Q5** Have you ever made a puzzle?
- **Q6** Have you ever used a gesture-based game (including those based on Kinect or Wii)?
- **Q7** Do you remember something about the last painting/image? If yes, what?
- **Q8** Do you remember something about the author? If yes, what?

In Q1 and Q2, we asked children to give a mark from 1 (not at all) to 5 (very much). The scale was associated with emoticons, using a so-called *smile-o-meter* (based on [20]). Children's answers to questions Q3 and Q4 were transcribed and coded by the two researchers separately, in an inductive and deductive way. The main themes that emerged were organized with the other data to provide a whole overview of our findings and answer our research questions. Q5 and Q6 required a Yes/No answer. All the other questions were open. Answers to Q7 and Q8 were thus coded by the two researchers, who assigned a value ranging from 0 (i.e. the child remembered nothing of the content) to 3 (i.e. the child remembered at least three different details of the video displayed at the end of the second activity or the painting). The resulting values served as two learning indexes, providing a quantitative indication as to how much children recalled about the content.

4 RESULTS

In this section we report the results of our study, which aims to: 1) identifying the relevant aspects of children's interactions with a large display based on a touchless avatar-based interface, and 2) understanding the impact on recalling the content that arises from the interaction.

4.1 Children Interacting with the Avatar

4.1.1 Affordance Blindness. During our tests, we wanted to understand whether the touchless interaction mode was self-evident. However, we noted that 50% of the users started the interaction

Figure 2: On the left, an example of a child using only one hand. On the right, a child touched the display.

session by trying to touch the display (see Figure 2), despite the presence of the avatar on the screen. A Chi-square test showed that age had a significant effect (Chi-square = 9.8090, $p < 0.01$): 76% of children aged 2 to 4 years did not try to use touch at the beginning of the interaction session, while this percentage drops for the range 5-10 years (44%). Another interesting finding of our study concerns the time needed to understand the interaction modality, which prior work reported to be less than three seconds [23]. Our study showed a much higher average time was required by children. Since the average training time included both the time to figure out how to interact, and the time to complete the dragging of a single piece, we can estimate the average time required for understanding how to interact as the difference between the average training time (82.80s, st. dev. 62.49s) and 1/6 of the average task time (80.41s, st. dev. 57.22s), i.e. six single dragging tasks. The resulting time to understand how to interact is 69.40s, which is much higher than the upper limit of 3s provided in [23].

4.1.2 Age and Performance. Regarding the age of the participants in relation to the number of suggestions needed during the training phase, as well as the time required for completing the tasks, we noted a fairly homogeneous trend (see Figure 3). Older children generally required a smaller number of suggestions and a lower time to accomplish the tasks. In particular, a Kruskal-Wallis test showed a significant effect of age on task duration (Chi square = 32.841, $p < 0.01$, df = 8), as well as on training duration (Chi square = 23.282, $p < 0.01$, df = 8) and number of suggestions given during the training phase (Chi square = 25.841, $p < 0.01$, df = 8). This is probably a direct consequence of different cognitive capabilities, which has a primary impact on performance.

First of all, the age group has a significant effect on enjoyment: both the youngest children and the oldest did not much enjoy the game. We expected this effect on very young children (aged 2-4) since it is well known in the literature that at this age they have limited physical and cognitive abilities [21]. Concerning older children (7-10), the reason for this drop-in enjoyment is unclear. An explanation could relate to the difficulty of the task: for instance, ID17136 said he would like to play with a jigsaw with more pieces like those he had at home. However, this effect needs to be studied more in depth. In order to understand the enjoyment in more depth, we looked at questions Q8 and Q9 by performing thematic analysis. Codes were categorized into nine sub-themes and four main themes.

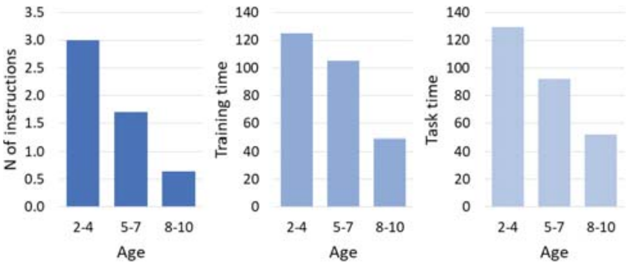

Figure 3: Trends of number of instructions, training time and task time compared to age.

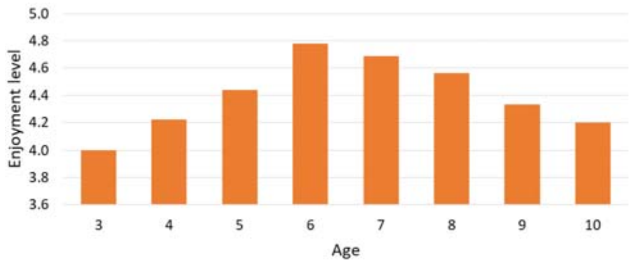

Figure 4: Enjoyment levels according to age.

A general appraisal of the game and the image. Children really liked the images of the two puzzles. They described the experience using positive adjectives such as fun, cool, fantastic, clever. Specifically, one child mentioned that it made him "*feel positive feelings*" (ID1763). They also appreciated solving the puzzle and "*mixing the pieces*" (ID1746). These general statements provided strong evidence that playing with the game was a pleasurable activity for them and the pictures we have selected were appreciated by them.

Enjoyment of being physically engaged. A child (ID17117) told us that he liked how the system "*get people moving instead of staying on the floor*", and another one (ID2181) said that she liked to "*control using your hands*", or "*I like to use my hands instead of the mouse*" (ID602). Often, they cited "*using my body*" (ID765) and "*moving my hands*" (ID1505). In other cases, they were very specific (e.g. "*grabbing the pieces and drag in the empty spaces*", ID17147). In addition, children mentioned peculiar hand movements such as "*squeeze*" and "*pick up*". Looking at this data, children really enjoyed the type of interaction based on body movement, and the hand gestures of pointing, squeezing and moving the piece onto the right place.

The challenge of understanding the interaction modality. Children showed an appreciation that they needed to put some effort in understanding how to interact with the interface i.e. "*You have to find your way to play with it*" (ID17136), (I like) "*understanding how to move in the space*" (ID1128), "*It was sort of creative, you can create your movement*" (ID1770). They described this first moment as "*tricky*" and "*challenging*" but in a positive way: "*It starts tricky and it goes easy*" (ID17115). In addition, they appreciated also the way the interaction modality made them "*think*" (ID1722) and "*stayed concentrated*" (ID17103). Thus, despite the interaction not being easy to understand at the beginning, the discovery of the interaction modality made the children more engaged in the play. It is worth noting, however, that the difficulty in understanding how to interact was also mentioned as a negative aspect by a few children (IDs: 1711, 1605, 1604, 287).

The avatar. The way in which children described the avatar gives us an indication of how they interpreted it. Children referred to the avatar in two main ways: as an external agent, or as "*myself*". In the first case, children saw the avatar as a different person or entity: "*the person on the screen is copying me*" (ID17129), or "*you have to stand back and the person that was on the screen wants me to grab the pieces*" (ID 1763). These children are aged 2-5 years and at this age they have generally not yet developed the ability to understand other people's mental and emotional states [27]. Older children (6-10 years old) interpreted the avatar as "*the copy of me*" (ID256) or mentioned that "*you can move and pretend to be a robot*" (ID1720), "*it shows your body*" (ID1766). However, both younger and older children expressed appreciation in playing with the avatar.

4.1.3 Enjoyment and Recalling Content. We also noted a relationship between the enjoyment and the recalling indexes resulting from the answers to questions Q7 and Q8 (see section 3.5). In particular, we categorized the enjoyment level in two categorical values: enjoy and no-enjoy, by counting as a positive value all the cases where the level of enjoyment was ranked as 4 or above. This binary choice is supported by the use of a smile-o-meter, where smiling faces correspond to 4 and 5 points in the Likert scale. This means that children who enjoyed the game were then able to better recall information. As mentioned in section 2.2, this is in line with prior work [2, 15, 35]. We did not notice any other significant effect (e.g. avatar representation, use of both hands) on enjoyment.

5 LESSONS LEARNT

In this section, we summarize the lessons learned from our study with the aim of informing the future design of avatar-based touchless gestural interfaces for children.

(1) *Avatar as a means to overcome affordance blindness*

The avatar is more effective in communicating touchless gesture-based interactivity to the younger children (2-4 years old) when compared with older children, who tried more often to touch the screen. However, compared with prior work, the avatar was less effective for understanding the interaction modalities in children than with adults (see section 4.1.2). Consequently, we recommend using the avatar with younger children in order to design an effective interaction. When designing for older children, using the avatar alone might not work as an effective way to overcome the affordance blindness. Indeed, for children aged 5 to 10 years, it is probably better to include also additional explicit call-to-actions or other techniques [10, 32].

(2) *The avatar as the main driver of engagement, enjoyment, and recalling*

Across the chronological ages, children enjoyed playing with the avatar and completing the jigsaw. Children perceived the avatar as an external agent ("*the robot*") and as "herself" mirrored on the display. In both cases, children enjoyed playing with the avatar. This enjoyment was often connected with the physical engagement of moving their body, or parts of it, in front of the screen. In literature, the relation between enjoyment and engagement is well known [35], as well as the effect of engagement in learning [2]. Our data demonstrated that the more children enjoyed the experience the better they recalled the contents provided during the interaction. With the avatar as the main interaction driver, it proved to be a winning choice for engaging pupils in the interaction, therefore facilitating information recall.

(3) *Balance the physical challenge and the engagement*

Children enjoyed moving their body and finding their own ways of interacting with the jigsaw via the avatar. The majority of the children (95%) enjoyed interacting with an interface that made them "*think*" and "*figure out*" how to move the pieces and perform the task. They also mentioned that they liked that it was "*challenging to discover how to move the pieces*". In addition, we estimated that children spent on average 69.40s in understanding how to interact. Also, acknowledging this as an overestimation, it is incredibly high when compared with the adult average (less than 3s [23]). Indeed, from our observations, we noticed that children spent this time playing with the avatar, which is not necessarily a bad thing considering that the physical engagement resulted in better recall. Thus, designing engaging interaction patterns within this context means creating a good balance between making children understand how to physically operate the interface components (e.g. jigsaw pieces), and at the same time to challenge them in finding their own way.

6 CONCLUSION AND FUTURE CHALLENGES

This study unveiled relevant outcomes in terms of children's enjoyment in interacting with an avatar. We also showed the role of an avatar in engaging children, which in turn drives them to better recalling contents. Moreover, we provided evidence indicating that chronological age influences the style of child-avatar interaction. Younger children (2-4 years old) tend to better guess how to correctly interact with the avatar (i.e. via mid-air gestures), when compared with the older children's behavior, who tried more often to touch the display. Recent investigations showed that younger children had lower experience in interacting with smartphones or tablets when compared with older children [24]. On the other hand, older children do not assume the availability of touchless interaction technologies and often opt for traditional modalities. A future direction could be to conduct a study in which we investigate the effect of prior experience with touch-based interaction, on affordance blindness in touchless gestural interfaces.

Finally, our results suggested that the avatar could facilitate the recalling of contents related to the pictures on the jigsaw. This could be an initial point to be further explored in order to understand how to use the avatar for developing new effective educational technologies for young children. In addition, we would like to redesign the Interactive Art Jigsaw according to our findings, and to replicate the study in a real context (i.e. a museum). This would allow us to better understand the effect of the interaction on children, and how they recall information about artworks.

REFERENCES

[1] Takayuki Adachi, Masafumi Goseki, Keita Muratsu, Hiroshi Mizoguchi, Miki Namatame, Masanori Sugimoto, Fusako Kusunoki, Etsuji Yamaguchi, Shigenori Inagaki, and Yoshiaki Takeda. 2013. Human SUGOROKU: Full-body Interaction System for Students to Learn Vegetation Succession. In *Proceedings of the 12th International Conference on Interaction Design and Children (IDC '13)*. ACM, New York, NY, USA, 364–367. https://doi.org/10.1145/2485760.2485830

[2] Mary Ainley and John Ainley. 2011. Student engagement with science in early adolescence: The contribution of enjoyment to studentsâĂŹ continuing interest in learning about science. *Contemporary Educational Psychology* 36, 1 (2011), 4 – 12. https://doi.org/10.1016/j.cedpsych.2010.08.001 StudentsâĂŹ Emotions and Academic Engagement.

[3] Carmelo Ardito, Paolo Buono, Maria Francesca Costabile, and Giuseppe Desolda. 2015. Interaction with Large Displays: A Survey. *ACM Comput. Surv.* 47, 3, Article 46 (Feb. 2015), 38 pages. https://doi.org/10.1145/2682623

[4] Rachel Bailey, Kevin Wise, and Paul Bolls. 2009. How Avatar Customizability Affects Children's Arousal and Subjective Presence During Junk FoodâĂŞSponsored Online Video Games. *CyberPsychology & Behavior* 12, 3 (jun 2009), 277–283. https://doi.org/10.1089/cpb.2008.0292

[5] Laura Bartoli, Clara Corradi, Franca Garzotto, and Matteo Valoriani. 2013. Exploring Motion-based Touchless Games for Autistic Children's Learning. In *Proceedings of the 12th International Conference on Interaction Design and Children (IDC '13)*. ACM, New York, NY, USA, 102–111. https://doi.org/10.1145/2485760.2485774

[6] Li-Chieh Chen, Yun-Maw Cheng, Po-Ying Chu, and Frode Eika Sandnes. 2017. Identifying the Usability Factors of Mid-Air Hand Gestures for 3D Virtual Model Manipulation. In *Universal Access in Human–Computer Interaction. Designing Novel Interactions*, Margherita Antona and Constantine Stephanidis (Eds.). Springer International Publishing, Cham, 393–402. https://doi.org/10.1007/978-3-319-58703-5_29

[7] Sarah Clinch, Jason Alexander, and Sven Gehring. 2016. A Survey of Pervasive Displays for Information Presentation. *IEEE Pervasive Computing* 15, 3 (July 2016), 14–22. https://doi.org/10.1109/MPRV.2016.55

[8] Jorgos Coenen, Sandy Claes, and Andrew Vande Moere. 2017. The concurrent use of touch and mid-air gestures or floor mat interaction on a public display. In *Proceedings of the 6th ACM International Symposium on Pervasive Displays - PerDis '17*. ACM Press, New York, New York, USA, 1–9. https://doi.org/10.1145/3078810.3078819

[9] Peter Dalsgaard and Kim Halskov. 2010. Designing Urban Media FaçAdes: Cases and Challenges. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)*. ACM, New York, NY, USA, 2277–2286. https://doi.org/10.1145/1753326.1753670

[10] Nigel Davies, Sarah Clinch, and Florian Alt. 2014. *Pervasive Displays: Understanding the Future of Digital Signage.* Morgan and Claypool. 128 pages.

[11] John H. Flavell. 2000. Development of children's knowledge about the mental world. *International Journal of Behavioral Development* 24, 1 (2000), 15–23. https://doi.org/10.1080/016502500383421

[12] Dustin Freeman, Fanny Chevalier, Emma Westecott, Kyle Duffield, Kate Hartman, and Derek Reilly. 2012. Tweetris: play with me. In *Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction - TEI '12*. ACM Press, New York, New York, USA, 319. https://doi.org/10.1145/2148131.2148201

[13] Fernando Garcia-Sanjuan, Vicente Nacher, and Javier Jaen. 2016. MarkAirs: Are Children Ready for Marker-Based Mid-Air Manipulations?. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction (NordiCHI '16)*. ACM, New York, NY, USA, Article 2, 8 pages. https://doi.org/10.1145/2971485.2971517

[14] Franca Garzotto, Mirko Gelsomini, Luigi Oliveto, and Matteo Valoriani. 2014. Motion-based Touchless Interaction for ASD Children: A Case Study. In *Proceedings of the 2014 International Working Conference on Advanced Visual Interfaces (AVI '14)*. ACM, New York, NY, USA, 117–120. https://doi.org/10.1145/2598153.2598197

[15] James Paul Gee. 2005. Learning by Design: Good Video Games as Learning Machines. *E-Learning and Digital Media* 2, 1 (2005), 5–16. https://doi.org/10.2304/elea.2005.2.1.5

[16] Vito Gentile, Mohamed Khamis, Salvatore Sorce, and Florian Alt. 2017. They are looking at me! Understanding how Audience Presence Impacts on Public Display Users. In *Proceedings of The 6th ACM International Symposium on Pervasive Displays (PerDis '17)*. ACM, Article 11, 7 pages. https://doi.org/10.1145/3078810.3078822

[17] Vito Gentile, Salvatore Sorce, Alessio Malizia, Fabrizio Milazzo, and Antonio Gentile. 2017. Investigating how User Avatar in Touchless Interfaces Affects Perceived Cognitive Load and Two-Handed Interactions. In *Proceedings of The 6th ACM International Symposium on Pervasive Displays (PerDis '17)*. ACM, Article

21, 7 pages. https://doi.org/10.1145/3078810.3078831

[18] Vito Gentile, Salvatore Sorce, Alessio Malizia, Dario Pirrello, and Antonio Gentile. 2016. Touchless Interfaces For Public Displays: Can We Deliver Interface Designers From Introducing Artificial Push Button Gestures?. In *Proceedings of the International Working Conference on Advanced Visual Interfaces (AVI '16)*. ACM, New York, NY, USA, 40–43. https://doi.org/10.1145/2909132.2909282

[19] Charles P. Gerba, Adam L. Wuollet, Peter Raisanen, and Gerardo U. Lopez. 2016. Bacterial contamination of computer touch screens. *American Journal of Infection Control* 44, 3 (2016), 358 – 360. https://doi.org/10.1016/j.ajic.2015.10.013

[20] Lynne Hall, Colette Hume, and Sarah Tazzyman. 2016. Five Degrees of Happiness: Effective Smiley Face Likert Scales for Evaluating with Children. In *Proceedings of the The 15th International Conference on Interaction Design and Children - IDC '16*. ACM Press, New York, New York, USA, 311–321. https://doi.org/10.1145/2930674.2930719

[21] Natasha Z. Kirkham, Loren Cruess, and Adele Diamond. 2003. Helping children apply their knowledge to their behavior on a dimension-switching task. *Developmental Science* 6, 5 (2003), 449–467. https://doi.org/10.1111/1467-7687.00300

[22] Peter Mitchell, Elizabeth J. Robinson, and Doreen E. Thompson. 1999. Children's understanding that utterances emanate from minds: using speaker belief to aid interpretation. *Cognition* 72, 1 (1999), 45–66. https://doi.org/10.1016/S0010-0277(99)00030-X

[23] Jörg Müller, Robert Walter, Gilles Bailly, Michael Nischt, and Florian Alt. 2012. Looking glass: a field study on noticing interactivity of a shop window. In *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI '12*. ACM Press, New York, New York, USA, 297–306. https://doi.org/10.1145/2207676.2207718

[24] Ofcom. 2017. *Children and Parents: Media Use and Attitudes Report.* Technical Report. https://www.ofcom.org.uk/__data/assets/pdf_file/0020/108182/children-parents-media-use-attitudes-2017.pdf Accessed: 2019-04-11.

[25] Timo Ojala, Vassilis Kostakos, Hannu Kukka, Tommi Heikkinen, Tomas Linden, Marko Jurmu, Simo Hosio, Fabio Kruger, and Daniele Zanni. 2012. Multipurpose Interactive Public Displays in the Wild: Three Years Later. *Computer* 45, 5 (may 2012), 42–49. https://doi.org/10.1109/MC.2012.115

[26] Felicia Clare Paul, Christabel Goh, and Kelly Yap. 2015. Get Creative With Learning: Word Out! A Full Body Interactive Game. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA '15*. ACM Press, New York, New York, USA, 81–84. https://doi.org/10.1145/2702613.2728657

[27] Josef Perner. 1991. *Understanding the representational mind.* The MIT Press.

[28] Jean Piaget. 1964. Part I: Cognitive development in children: Piaget development and learning. *Journal of Research in Science Teaching* 2, 3 (1964), 176–186. https://doi.org/10.1002/tea.3660020306

[29] Jean Piaget and Bärbel Inhelder. 1956. *The Child's Conception of Space.* Routledge & Kegan Paul, London.

[30] Kevin J Riggs and Donald M Peterson. 2000. Counterfactual thinking in preschool children: Mental state and causal inferences. In *Children's reasoning and the mind*. Psychology Press/Taylor & Francis (UK), Hove, England, 87–99.

[31] Salvatore Sorce, Vito Gentile, Cristina Enea, Antonio Gentile, Alessio Malizia, and Fabrizio Milazzo. 2017. A Touchless Gestural System for Extended Information Access Within a Campus. In *Proceedings of the 2017 ACM Annual Conference on SIGUCCS (SIGUCCS '17)*. ACM, New York, NY, USA, 37–43. https://doi.org/10.1145/3123458.3123459

[32] Daniel Vogel and Ravin Balakrishnan. 2004. Interactive public ambient displays: transitioning from implicit to explicit, public to personal, interaction with multiple users. In *Proceedings of the 17th annual ACM symposium on User interface software and technology - UIST '04*. ACM Press, New York, New York, USA, 137. https://doi.org/10.1145/1029632.1029656

[33] Robert Walter, Gilles Bailly, and Jörg Müller. 2013. StrikeAPose: revealing mid-air gestures on public displays. In *CHI '13 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 841–850. https://doi.org/10.1145/2470654.2470774

[34] Robert Walter, Gilles Bailly, Nina Valkanova, and Jörg Müller. 2014. Cuenesics: using mid-air gestures to select items on interactive public displays. In *MobileHCI '14 Proceedings of the 16th international conference on Human-computer interaction with mobile devices & services*. 299–308. https://doi.org/10.1145/2628363.2628368

[35] Lesley Xie, Alissa N. Antle, and Nima Motamedi. 2008. Are Tangibles More Fun?: Comparing Children's Enjoyment and Engagement Using Physical, Graphical and Tangible User Interfaces. In *Proceedings of the 2Nd International Conference on Tangible and Embedded Interaction (TEI '08)*. ACM, New York, NY, USA, 191–198. https://doi.org/10.1145/1347390.1347433

[36] Kelly Yap, Clement Zheng, Angela Tay, Ching-Chiuan Yen, and Ellen Yi-Luen Do. 2015. Word out!: learning the alphabet through full body interactions. In *Proceedings of the 6th Augmented Human International Conference on - AH '15*. ACM Press, New York, New York, USA, 101–108. https://doi.org/10.1145/2735711.2735789