Designing Textual Information in AR Headsets to Aid in Adults' and Children's Task Performance

Julia Woodward*
Department of CSE, University of South Florida, Tampa, Florida, USA
juliaevewoodward@usf.edu

Jaime Ruiz
Department of CISE, University of Florida, Gainesville, Florida, USA
jaime.ruiz@ufl.edu

ABSTRACT

Augmented reality (AR) headsets are being utilized in different task-based domains (e.g., healthcare, education) for both adults and children. However, prior work has mainly examined the applicability of AR headsets instead of how to design the visual information being displayed. It is essential to study how visual information should be presented in AR headsets to maximize task performance for both adults and children. Therefore, we conducted two studies (adults vs. children) analyzing distinct design combinations of critical and secondary textual information during a procedural assembly task. We found that while the design of information did not affect adults' task performance, the location of information had a direct effect on children's task performance. Our work contributes new understanding on how to design textual information in AR headsets to aid in adults' and children's task performance. In addition, we identify specific differences on how to design textual information between adults and children.

CCS CONCEPTS

• **Human-centered computing**; • **Human-computer interaction (HCI)**; • **Empirical studies in HCI**;

KEYWORDS

Augmented reality headsets, task performance, children, adults, information design

ACM Reference Format:
Julia Woodward and Jaime Ruiz. 2023. Designing Textual Information in AR Headsets to Aid in Adults' and Children's Task Performance. In *Interaction Design and Children (IDC '23), June 19–23, 2023, Chicago, IL, USA.* ACM, New York, NY, USA, 13 pages. https://doi.org/10.1145/3585088.3589373

1 INTRODUCTION

Augmented reality (AR) systems supplement the real world through combining virtual objects with the natural environment, therefore keeping users situated in reality and simultaneously allowing interaction with virtual objects [48]. Compared to more traditional AR platforms (e.g., tablets, smartphones), AR headsets are increasing in popularity due to providing more mobility, hands-free capabilities, and user immersion [64, 81]. These qualities are important in contexts in which another external device (e.g., tablet) could be cumbersome. Task completion is a common application for AR headsets, such as in maintenance [30, 92], healthcare [52, 66], and education [9, 34, 35, 42]. However, prior research studies have mainly concentrated on examining the applicability of using AR headsets in various environments and not on investigating how to design the information in the display. For example, Liu et al. [51] explored if an AR headset could aid anesthesiologists in monitoring patient information. When using AR, the anesthesiologists spent less time looking at the anesthesia workstation and more time monitoring the patient; however, the authors did not examine the design of information. While prior work has shown that AR headsets can be beneficial (e.g., fewer errors [10], faster completion time [31]), it is crucial to study how visual information should be presented to maximize task performance.

Much like adults, children are increasingly being presented with AR headsets. Juan et al. [43] developed an AR headset game for children (ages 7 to 12) focused on learning about endangered animals. Woodward et al. [85] created a conceptual model of children's (ages 7 to 12) understanding of AR headsets and found differences in expectations compared to adults, such as which interaction modalities to use. Also, prior work has shown differences in interaction behaviors and expectations between children and adults for other technological devices (e.g., touchscreens [4, 32, 86–88], voice input systems [44, 53, 54]). Therefore, it is important to understand how to design for both adults and children. Children are still developing cognitive abilities, such as memory and executive control, which can affect task performance [56, 68, 83, 90]. Children might require information to be designed differently to aid their developing cognitive abilities.

We conducted two studies, one with adults and one with children (ages 9 to 12), analyzing different presentation styles and locations of textual information in an AR headset during a procedural assembly task. Visual information, in the context of awareness, can be split into two categories: central or critical information (e.g., warnings) and peripheral or secondary information (e.g., nonessential information) [16]. Critical information is essential to comprehend when completing a task, while secondary information may be beneficial but not necessary. Current AR headset task-based applications include both types of information. For instance, in Liu et al.'s [51] AR headset application, anesthesiologists could see both critical information (e.g., patient alarms) and secondary information (e.g., the current time). Thus, we analyzed combinations of both critical and secondary information. For the procedural task, we chose food assembly because it represents a real-world assembly task and is easily understandable and engaging for both adults and children.

*This work was conducted while at the University of Florida.

IDC '23, June 19–23, 2023, Chicago, IL, USA

ACM ISBN 979-8-4007-0131-3/23/06…$15.00
https://doi.org/10.1145/3585088.3589373

Food assembly is a popular theme in video games (e.g., *Overcooked* [95], *Nickelodeon Cooking Contest* [97]), and cooking curriculums are being implemented for children in grades 3-8 (i.e., the grade level range of children in our study) [18, 39, 58]. During the study, participants completed different food orders listed in an AR headset using fake felt food while monitoring additional secondary information in the headset.

Overall, we did not find a main effect of the design of information on adults' task performance (e.g., recall of information, error rate); however, adults had a lower cognitive workload when the locations of the critical and secondary information were consistent. For children, we found that the location of critical information in the AR headset field-of-view had a significant effect on their information recall accuracy and error rate. For instance, children had significantly higher information recall accuracy when the critical information was in the bottom-center of the headset display. Our work contributes new understanding on how to design textual information in AR headsets to aid in adults' and children's procedural task performance, which has implications in contexts such as education and healthcare.

2 RELATED WORK

We focus our related work on three categories: (1) designing information in AR headsets for aiding task performance, (2) examining the presentation of textual information in AR headsets, and (3) using AR headsets with children.

2.1 Design of Information in AR Headsets for Task Performance

Prior work has started to explore using AR headsets for aiding in tasks due to its hands-free capabilities, and ability to provide real-time information over a user's environment without decreasing a user's awareness of their surroundings [6]. Several studies have started to explore the effect of AR headset design factors on task performance [5, 45, 46]. During a maintenance assembly task, Ariansyah et al. [5] compared using an AR headset to traditional paper-based instructions. In the AR headset, the participants could see textual instructions, and either 3D animation or video instructions. The authors found the participants had fewer errors when using the AR headsets. Also, for the AR headset, the authors found that displaying 3D animation instructions lowered task completion times compared to videos. The authors did not examine the design of textual information. Kim et al. [45] investigated different AR headset interface designs during a warehouse job simulation (i.e., finding order parts). The designs included text versus graphic-based designs, as well as always-on versus on-demand information. The authors found that graphic-based and always-on information reduced completion times and errors. However, prior work recommends that text should not always be removed [37].

Previous research has found some negative effects of AR headsets, such as slower completion times [10, 82] and higher cognitive workload [19], when compared to traditional methods (e.g., paper instructions). While AR headsets can help task performance through reducing searching, visualizing, and remembering [40], the negative effects show that simply applying AR may not result in task improvement. There is a need to examine different information designs in AR headsets for improving users' task performance. In addition, previous studies have only examined adults, no prior work to our knowledge has investigated how to design information in AR headsets for aiding children during tasks.

2.2 Presentation of Textual Information in AR Headsets

Previous studies have started to examine the presentation of textual information in AR headsets. Rzayev et al. [72] examined how text should be displayed for reading in an AR headset while the user is walking and sitting. The authors compared three text positions (top-right, center, and bottom-center) and two presentation types, line-by-line scrolling and Rapid Serial Visual Presentation (RSVP). RSVP presents text word-by-word in a fixed location. In general, presenting the text in the top-right increased cognitive workload and reduced text comprehension; there was no significant difference between the center and bottom-center locations. RSVP had higher comprehension during sitting, while line-by-line scrolling had higher comprehension during walking. Prior work has examined how text design affects readability in AR headsets and recommended using white text with a blue background [20, 24]. However, prior work has also recommended transparent backgrounds [2]. Albarelli et al. [2] conducted a study, in which participants stocked items in a test grocery store while product information was shown in an AR headset. The participants preferred the information in the center with no background due to readability and being able to easily switch between the information and environment. While these studies have begun to examine textual design in AR headsets, they do not examine how both critical and secondary textual information can affect task performance, and do not consider children.

2.3 Using AR Headsets with Children

Although most previous studies have focused on traditional AR platforms with children, such as tablets and smartphones [22, 34, 69], AR headsets are beginning to increase in popularity. For example, AR headsets are being used as educational tools for children (e.g., games [3, 43], virtual field trips [78]), to help children relax during medical procedures [15], and as aids for children with autism [26, 73]. Juan et al. [43] created an AR headset game focused on learning about endangered animals. For the game, children (ages 7 to 12) interacted with tangible cubes to discover facts about endangered animals. For using AR headsets to aid in children's disabilities, Jones et al. [42] investigated using monocular AR headsets to help facilitate sign language in learning environments. Prior work has also started to examine different interaction methods in AR headsets with children [61, 62]. Munsinger et al. [62] examined three selection methods (voice, gesture, controller) during a hidden object game in an AR headset with children (ages 10 to 13). The authors found higher input errors with voice compared to gesture, and a slower time with voice compared to the controller. Previous research has also explored children's expectations with AR headsets. Woodward et al. [85] conducted participatory design sessions with a group of children (ages 7 to 12) on using AR headsets for tasks. The authors found that children expect highly intelligent systems, and that children have several different expectations than adults.

For instance, the children did not consider using interactive gesture commands, although this is common in existing AR headsets [94].

While these studies start to examine children's expectations and interaction behaviors in AR, the current literature identifies no prior studies that have directly examined how children's interaction behaviors differ from adults in AR headsets. In addition, these prior studies did not examine the design of information, rather just application and interaction methods. It is important to examine how to design information in AR headsets for children, and to analyze how children may require different designs to meet their specific expectations, conceptual models, and needs.

3 EXPERIMENT 1: ADULTS

For our adult study, we analyzed a combination of different locations of critical information and presentation styles of secondary information during a procedural food assembly task. The critical information (e.g., food order) was shown in one of three locations: top-center, center, and bottom-center. For the secondary information (e.g., time), we displayed the information either locked to the display (*Display*) or situated in the environment (*Environment*).

3.1 Method and Design

Participants had to complete food orders listed in an AR headset using fake felt food while monitoring additional secondary information in the headset (Figure 1). While making the orders, the participants had a recipe menu on a screen in front of them to see what food items go in each order. We conducted the study in a room with consistent lighting, and the study took approximately 45 to 60 minutes. Participants either received extra credit for a course they were enrolled in or voluntarily participated without compensation. Our protocol was approved by our Institutional Review Board.

The critical information included the food order in text (e.g., "turkey sub"), which was always present in the headset, as well as an emergency warning that would appear briefly in the headset. The emergency warning consisted of a red triangle that would appear under the food order and represented that the food was on fire. The secondary information included the number of plates remaining, the time countdown, and a random word (Figure 1B and 1C). The secondary information ranged in levels of importance for the task, from necessary, to supplementary, and then irrelevant, respectively. During the task, the participants hit physical buttons when they finished completing the current food order, when the emergency warning symbol appeared, and when the number of plates ran out. For instance, the participant in Figure 1B is hitting the physical button because the emergency warning appeared (i.e., red triangle).

At the start of the study, participants filled out a demographic questionnaire, and then completed a practice session for 4 minutes with the AR headset. The practice session was used for the participants to get familiar with the task and the information being displayed in the headset and was not used in any analysis. After the practice, participants then began the main part of the study. In total, there were four different study blocks (5 minutes each). The study was a between-subjects study, in which each participant only saw the critical information in one location and the secondary information in one display style. Therefore, each participant had consistent designs for each study block. Also, each participant was instructed that the focus is not on how many food orders they complete, but if the food orders are correct. In the second and fourth study block, the information disappeared in the headset during the task and the participants were asked to recall the last information presented in the headset. We did not explain that we would randomly ask for the information presented in the headset, which allowed us to examine any differences in perceptibility. After the four study blocks, the participants completed a weighted NASA TLX [27] to determine their perceived cognitive workload.

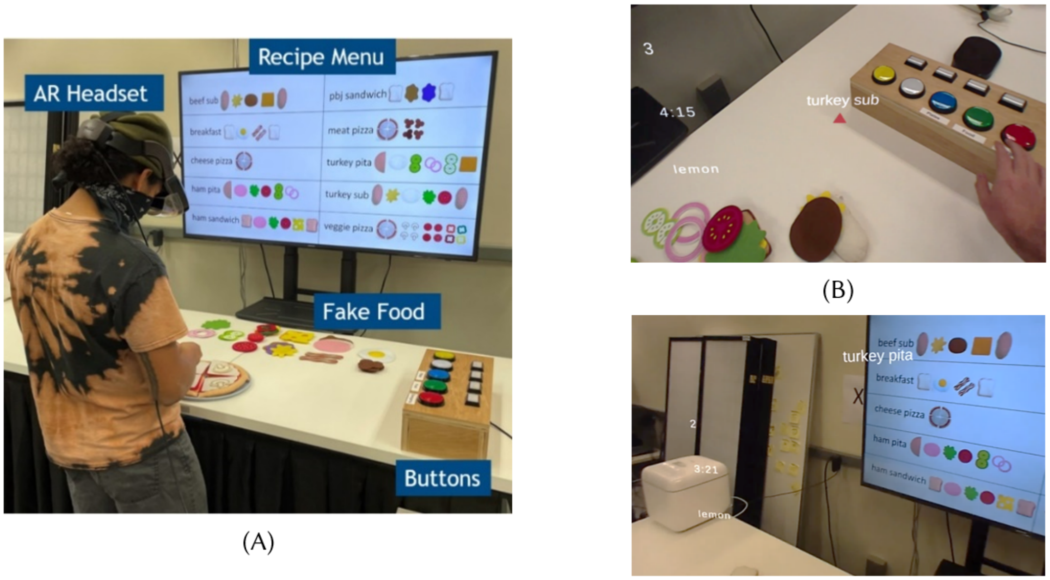
3.1.1 *Critical Information Design.*

The critical information consisted of the food orders and the emergency warning (i.e., red triangle). For food orders, there were 10 possible options: "beef sub", "breakfast", "cheese pizza", "ham pita", "ham sandwich", "pbj sandwich", "meat pizza", "turkey pita", "turkey sub", and "veggie pizza". Presentation of the food orders was originally randomized for each study block and then the same order was used for every participant. The same food order never occurred twice in a row. Only one food order would be shown at a time, and would be located at the top-center, center, or bottom-center of the headset field-of-view. The text height was 5 mm and white, which is aligned with Meta AR design recommendations [59]. Also, we used Liberation Sans font since it is recommended for readability [70]. The participant was instructed to hit the green button labeled "food" when they finished a food order, which would move on to the next order.

The emergency warning was a red triangle that would appear briefly under the food order (Figure 1B) and represented that the food was on fire. We chose a red triangle because people can more easily detect color and shapes [29, 38] and triangles are utilized in ISO 7010, an International Organization for Standardization technical standard for graphical symbols [93], to represent warnings. The emergency warning would randomly appear and remain visible in the headset for a time interval (6-9 seconds) before disappearing. The participant was instructed to hit the red button labeled "emergency" as soon as they noticed the emergency warning. If the participant pressed the emergency button it would immediately disappear. An emergency warning appeared two times in the first block, four times in the second and third blocks, and then five times in the fourth block (a total of 15 times). The specific times the warning appeared in the headset were generated randomly, and then used for every participant.

3.1.2 *Secondary Information Design.*

The secondary information included the number of plates, the time countdown, and a random word. The number of plates started at "5" and decreased by one each time the participant completed a food order. The participant was instructed to monitor the number, and to hit the blue button labeled "plates" when it was "0" to increase it back to "5". Nothing in the task was dependent on the number of plates; therefore, when the number became "0" nothing occurred and would remain at "0" until the button was hit. The time countdown started at "5:00" minutes and was presented in minutes and seconds. When it hit "0:00" the information would disappear, and the study block would end. The random word would randomly cycle between: "apple", "banana", "lemon", and "orange". We used the random word as a proxy for information that might not be directly related to the main task but still necessary for maintaining awareness. The current word would



(A) (B) (C)

Figure 1: Mockup of the food assembly task during AR headset study (A). Adult participants' views during the study. The secondary information is in the Display style and the critical information (i.e., food order, emergency warning) is in the center location (B). The secondary information is in the Environment style and the critical information is in the top-center (C).

remain visible in the headset for a random time (20-40 seconds) before switching to the next word.

The secondary information was either locked to the display (*Display*) or situated in the environment (*Environment*). We placed the secondary information on the left-hand side of the field-of-view due to people exhibiting a leftward visual and spatial bias known as *pseudoneglect* [11, 80]. Pseudoneglect leads to advantages in the left visual field, such as faster motion processing, greater detection accuracy, and higher contrast sensitivity [17, 57, 80], and has been shown to extend to elements on computer screens [57]. For the *Display* presentation style, the textual information was locked to the left-hand side of the field-of-view and superimposed over the users' environment. The font, height, and color of the textual information was the same as the food orders. In the *Environment* presentation style, the text appeared 500 mm away from the participant with a height of 10 mm, which is consistent with design recommendations [59]. The text was superimposed and fixed in the environment to the left of the participant. If the participant looked down at the table or turned their head to the right, they would not be able to see the text since it was in a fixed location in the environment. Figure 1C shows when the participant is looking at the text. The font and color were consistent with the *Display* style.

3.2 Equipment

The AR application was created using Unity [96] and run on a Meta 2 AR headset [13]. The headset features a 90-degree field-of-view with a 2560 x 1440 resolution. We used a rectangular wooden box (431.8 mm x 177.8 mm x 101.6 mm) as a base for the buttons, and each button had a 50.8 mm diameter.

3.3 Participants

The participants included 60 adults [M = 23.08 years, SD = 4.49, N = 59 (one participant did not report their age)]. Twenty-one participants were female, and one participant identified as non-binary; three participants were left-handed. Out of the 60 participants, 11 of them self-reported having previous experience with an AR headset. All the participants had normal or corrected-to-normal vision, and we did not recruit participants who were color-blind or dyslexic. None of the participants self-reported any negative physical effects from using the AR headset during the study.

3.4 Data Analysis and Results

To analyze the location of critical information and presentation style of secondary information, we calculated common task performance metrics, including information recall, error rate, response time, and perceived cognitive workload (e.g., [5, 31, 45]). More specifically, we examined the participants' accuracy of recalled information, emergency warning response time and error rate, plates response time, and perceived cognitive workload; Table 1 shows the results. For each metric, unless noted, there was not a significant interaction effect between secondary information presentation style and critical information location, a Levene's test found that the data met the assumption of equal variances, and a Shapiro-Wilks test showed that the data was normal. We used R [98] to calculate the statistics and the conditions were balanced.

3.4.1 Information Recall. During the second and fourth study block, the information in the AR headset disappeared during the task and the participants were asked to recall the last presented textual information (i.e., food order, number of plates, countdown

Table 1: Results for adults' task performance metrics (M [SD]) separated by secondary information presentation style and critical information location. Significant main effect (*) and interaction effect (†).

Metrics	Secondary Information Presentation Style		Critical Information Location		
	Display	Environment	Top-Center	Center	Bottom-Center
First Response Recall Accuracy	31.7% [17.3%]	43.3% [26.2%]	32.5% [18.3%]	45.0% [25.1%]	35.0% [23.5%]
Habituated Response Recall Accuracy	35.8% [19.3%]	42.5% [19.9%]	37.5% [22.2%]	42.5% [20.0%]	37.5% [17.2%]
Emergency Response Time	2.8s [0.8]	2.4s [0.5]	2.7s [0.6]	2.7s [1.0]	2.4s [0.5]
Emergency Error Rate	18.2% [16.6%]	14.2% [14.4%]	19.0% [13.7%]	17.0% [18.4%]	12.7% [14.2%]
Plates Response Time	6.6s [5.0]	5.0s [3.9]	6.0s [4.3]	5.9s [3.9]	5.4s [5.6]
Perceived Cognitive Workload †	46.0 [12.8]	44.8 [13.3]	47.0 [13.8]	44.3 [12.0]	44.9 [13.6]

time, random word). We did not inform the participants that we would ask them to recall the information before the start of the study. Therefore, we split analysis into two sections: *first response* recall (second study block) and *habituated response* recall (fourth study block). *First response* recall captures the raw perceptibility of the presentation styles, while *habituated response* recall coincides with real-world settings in which the users are aware of the task. We calculated the proportion of correct answers for each participant. A participant's answer was correct if it exactly matched the last information presented in the headset. A Shapiro-Wilks test showed that the data was severely skewed for *first response* recall ($W = 0.87$, $p < 0.0001$) and *habituated response* recall ($W = 0.85$, $p < 0.0001$).

When examining *first response* recall, a Levene's test found that the data for secondary information presentation style did not have equal variances ($p < 0.05$). Therefore, we conducted a Kruskal-Wallis test for secondary information presentation style and found no significant effect on recall accuracy ($H(1) = 0.17$, *n.s.*). We applied an Aligned Rank Transform [84] for the data on critical information location. A one-way ANOVA found no significant effect of critical information location on recall accuracy ($F_{2,57} = 1.40$, *n.s.*). When the participants were unaware of having to recall the information in the headset, there was no significant difference in recall accuracy between the secondary information presentation styles, as well as the critical information locations. For *habituated response* recall, a two-way ANOVA found no significant effect of secondary information presentation style ($F_{1,54} = 2.66$, *n.s.*) or critical information location ($F_{2,54} = 0.32$, *n.s.*) on recall accuracy. Even when participants were aware that they would have to recall the information, there was no significant difference in recall accuracy between the presentation styles and locations (Table 1).

3.4.2 Emergency Warning Metrics. A Shapiro-Wilks test showed that the emergency warning data for response time ($W = 0.84$, $p < 0.0001$) and error rate ($W = 0.88$, $p < 0.0001$) were severely skewed; therefore, we applied the Aligned Rank Transform to both [84]. We determined response time by calculating the time it took a participant to press the red button after the red triangle appeared in the AR headset. When calculating response time, we did not include any misses (i.e., not recognizing the triangle before it disappeared). A two-way ANOVA found no significant effect of secondary information presentation style ($F_{1,54} = 3.85$, *n.s.*) or critical information location ($F_{2,54} = 0.59$, *n.s.*) on participants' response time.

For emergency warning error rate, we calculated a participant's proportion of misses (i.e., when the participant did not notice the triangle before it disappeared). Similar to response time, a two-way ANOVA found no significant effect of secondary information presentation style ($F_{1,54} = 0.47$, *n.s.*) or critical information location ($F_{2,54} = 1.02$, *n.s.*) on participants' emergency error rate. In general, the presentation style of secondary information and location of critical information did not significantly affect the response time or error rate for the emergency warning.

3.4.3 Plates Response Time. During the study, the participants monitored the number of plates and hit the blue button when the number of plates was "0" to increase it back to "5". We analyzed the participants' response time by calculating the time it took a participant to press the button after the number turned "0". We did not include the times when the participant failed to notice that the number of plates ran out and did not hit the button before the end of the study block. Although participants were instructed to wait until the number of plates equaled "0" before hitting the button, one participant repeatedly hit the button when the number of plates was "1" or "2". Therefore, we had a total of 59 participants for analysis. A Shapiro-Wilks test showed that the data for response time was not normal ($W = 0.87$, $p < 0.001$); therefore, we applied the Aligned Rank Transform [84]. A two-way ANOVA found no significant effect of secondary information presentation style ($F_{1,53} = 1.57$, *n.s.*) or critical information location ($F_{2,53} = 0.04$, *n.s.*) on participants' response time (Table 1).

3.4.4 Perceived Cognitive Workload. Using the NASA TLX [27] scores, we analyzed the participants' cognitive workload. A two-way ANOVA found no significant effect of secondary information presentation style ($F_{1,54} = 0.13$, *n.s.*) or critical information location ($F_{2,54} = 0.26$, *n.s.*) on cognitive workload. There was no significant

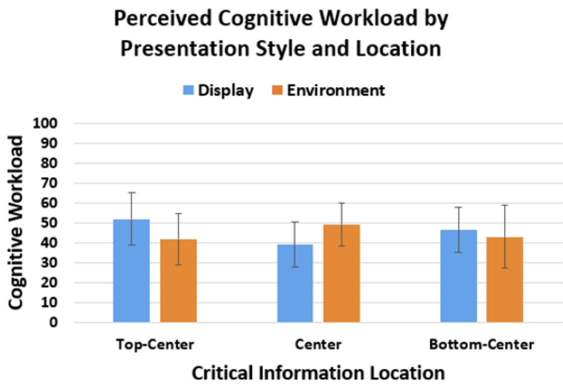


Figure 2: Adult participants' perceived cognitive workload by secondary information presentation style and critical information location. Error bars represent 95% confidence interval.

difference in cognitive workload between the two presentation styles, and the three critical information locations. However, there was a significant interaction effect between secondary information presentation style and critical information location ($F_{2,54} = 3.38$, $p < 0.05$), with a large effect ($\eta^2 = 0.11$) [65]. Figure 2 illustrates the cognitive workload values by combinations of presentation style and location, in which there is an inverse relationship. When the secondary information was locked to the display, participants' cognitive workload was lower when the critical information was in the center but higher when it was in the top-center or bottom-center. Also, when the secondary information was situated in the environment, participants had a lower cognitive workload when the critical information was in the top-center or bottom-center but higher when it was in the center. Although there was no direct significant effect of secondary information presentation style or critical information location on participants' cognitive workload, there was a significant interaction between the two design factors (Table 1).

3.5 Discussion

In general, we did not find any significant differences in task performance between the two presentation styles of secondary information (*Display* vs. *Environment*) or the locations of critical information in the AR headset field-of-view. Therefore, in the context of displaying visual information in AR headsets for aiding adults' procedural task performance, secondary information can be either locked to the display or situated in the environment, and critical information can be located at the top-center, center, or bottom-center of the field-of-view.

Our finding on the secondary information presentation styles is consistent with prior work [89], in which there was no significant difference in users' information recall between having information locked to an AR headset display or situated in the environment during a simple math task. The results from our study show that the findings translate from a math task to a real-world task of assembly. Designers can utilize either the *Display* or *Environment* styles for secondary information in terms of aiding users' task performance.

For critical information, we did not find any significant difference in participants' task performance between the top-center, center, and bottom-center locations. Our findings are consistent with prior studies that found that center area locations result in faster response times, higher text comprehension, and lower cognitive workload. Rzayev et al. [72] found higher text comprehension and lower cognitive workload for textual information in the center and bottom-center locations of an AR headset, compared to the top-right. Prior work in virtual reality also found that virtual content placed at eye-level or below (i.e., center, below-center) can result in faster context switching times, compared to top-left and bottom-right locations [36]. In examining center locations, Rzayev et al. [71] found that notifications placed in the direct center of the AR headset field-of-view were perceived as urgent and intrusive. Therefore, we recommend that designers place critical information in the center area of the AR headset display (top, middle, or bottom) for improving procedural task performance, and utilize the middle center location for urgent messages.

Overall, the critical and secondary information designs did not affect adults' task performance; however, we did find a significant interaction effect between the two design factors for perceived cognitive workload. When the secondary information was displayed in the *Environment* style, which was in the periphery, the participants had a lower cognitive workload when the critical information was also in the periphery (i.e., top-center and bottom-center). Also, in vice-versa, when the secondary information was locked to the display and more centralized, the participants had a lower cognitive workload when the critical information was also more centralized in the center location. Prior work recommends listing and organizing related elements together on a computer interface [12, 14]. In visual short-term memory, spatial configuration forms the basis of relational encoding; people immediately perceive information in relation to other information [41]. In addition, presenting objects at different positions helps people's working memory to distinguish between the objects more clearly [67]. For our study, when examining the conditions that had a lower cognitive workload, the information was consistently located to aid with spatial configuration and still in distinct locations to help people distinguish between the information. Therefore, we recommend that designers keep the secondary information display style and critical information location consistent, either in the periphery or centralized.

4 EXPERIMENT 2: CHILDREN

Since children's interaction behaviors can differ from adults, we replicated our previous study with children (ages 9 to 12). Although the children completed the same task, we made several design changes to how the information was presented based on children's conceptual models of AR headsets [85]. The critical information location was kept the same, but the secondary information remained locked to the display on the left- or right-hand side of the field-of-view. We describe the design changes and how they connect to children's conceptual models of AR headsets below.

4.1 Method and Design

Same as the adult study, the children had to complete food orders listed in the AR headset using fake felt food while monitoring

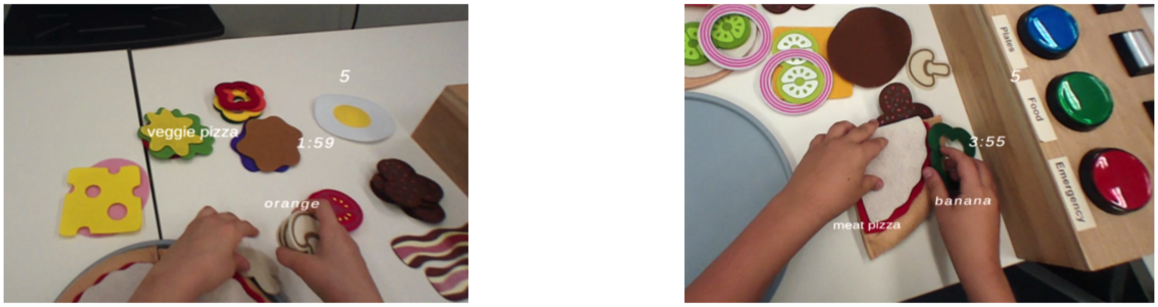


Figure 3: A child's view during the AR headset task study. The secondary information is located on the right-hand side of the headset field-of-view, and the critical information is in the center location (left). Another child's view during the AR headset task study, with the critical information in the bottom-center location (right).

secondary information in the headset. The children saw the same recipe menu and type of critical and secondary information as the adults. The food orders (e.g., "ham pita") are in the recommended Lexile Framework for Reading [60] range for children in the third grade [74] (i.e., the youngest grade level of the children in our study). We conducted the study in a room with consistent lighting, and the study took approximately 45 to 60 minutes. The children earned a small prize for participating (e.g., stickers), as well as $20 cash. Our protocol was approved by our Institutional Review Board, and we collected both parental consent and child assent.

At the start of the study, the researcher asked the children demographic questions (e.g., age, grade level), and then the children completed a practice session for 3 minutes with the AR headset to get familiar with the task; the practice was not used for analysis. After the practice, the children began the main part of the study. In total, there were four different study blocks, and each study block was 4 minutes instead of 5 minutes. The task was shortened to keep the children engaged and to prevent the children from becoming tired from wearing the headset. Like the adult study, the study was a between-subjects study, in which each child only saw the critical information in one location and the secondary information on one side of the field-of-view. In the second and fourth study block, the information disappeared in the headset during the task and the researcher asked the children to recall the last information presented in the headset. We did not explain that we would randomly ask for the information presented in the headset. After the four study blocks, the children completed an adapted NASA TLX to determine their perceived cognitive workload. Prior work has adapted the NASA TLX to children (ages 6 to 11), which includes child-appropriate wording and a simplified task [49, 50].

4.1.1 Applying Children's Conceptual Model. We made several design changes based on children's conceptual model of AR headsets [85] to match the children's expectations, increase usability, and improve task performance. Prior work has found that in children's conceptual model, information (e.g., mini-maps, text) is always present and locked to the AR headset display [85]; therefore, we kept the secondary information in the *Display* presentation style to meet their expectations. Although the secondary information was always locked to the display, we either placed it on the left- or right-hand side of the headset field-of-view (Figure 3). Children expect elements to be on the right-hand side of the headset field-of-view [85]. In our previous study with adults, we placed the information on the left-hand side due to people exhibiting a leftward visual bias, known as pseudoneglect [11, 80]. While pseudoneglect is an established bias with adults, there are mixed results with children [23, 28, 76]. Hausmann et al. [28] found that during a line bisection task on paper, children (ages 10 to 12) showed a leftward bias when using their left hand and a rightward bias when using their right hand, compared to only a leftward bias for adults. Sireteanu et al. [76] examined visual bias during a line length judgement task on a computer screen with adults, dyslexic children, and non-dyslexic children (ages 8 to 12). The authors found that dyslexic children had a rightward bias and non-dyslexic children showed a leftward bias, but not to the extent as adults. These studies show mixed results regarding visual bias with children. Therefore, we wanted to examine both the left- and right-hand side of the headset display for secondary information with children, especially since children expect elements to be on the right side [85]. We kept the critical information the same as in the adult study (i.e., top-center, center, bottom-center).

4.2 Equipment

The AR application was created using Unity [96] and run on the same Meta 2 AR headset as the adult study. However, due to children's smaller head circumference, we added a foam piece to the back of the headset. The foam piece was 25.4 mm thick to allow for a minimum head circumference of 482.6 mm on the tightest setting; nine-year-old children have an average head circumference of 520 mm [63]. The rectangular wooden button box was the same as in the adult study.

4.3 Participants

The participants included 24 children [M = 10.54 years, SD = 0.93], 16 males and 8 females. Two of the children were left-handed. The children's grade levels ranged from 3rd to 7th, with a majority being in 4th (n = 10) and 5th grade (n = 7). We did not recruit children who were color-blind or dyslexic due to the visual information in the headset, and all the children had normal or corrected-to-normal vision. Out of the 24 children, 19 had experience with VR headsets, but only 1 had experience with AR headsets. None of the

Table 2: Results for children's task performance metrics (M [SD]) by secondary information and critical information locations. Emergency error rate values were calculated after one outlier was removed. Significant main effect (*) and interaction effect (†).

Metrics	Secondary Information Location		Critical Information Location		
	Left-Side	Right-Side	Top-Center	Center	Bottom-Center
First Response Recall Accuracy	35.4% [22.5%]	45.8% [25.7%]	40.6% [32.6%]	37.5% [18.9%]	43.8% [22.2%]
Habituated Response Recall Accuracy *	41.7% [19.5%]	43.8% [26.4%]	37.5% [26.7%]	31.1% [17.7%]	59.4% [12.9%]
Emergency Response Time	2.9s [0.8]	2.7s [0.8]	3.2s [0.9]	2.4s [0.6]	2.8s [0.8]
Emergency Error Rate *	25.6% [17.7%]	22.2% [24.2%]	30.8% [19.8%]	8.6% [6.3%]	27.5% [24.8%]
Plates Response Time	19.3s [34.7]	12.2s [14.5]	9.4s [12.4]	11.6s [13.5]	27.1s [42.7]
Perceived Cognitive Workload	42.6 [16.3]	37.6 [15.0]	41.4 [17.7]	40.0 [9.9]	39.1 [19.5]

children self-reported any negative physical effects from using the AR headset.

4.4 Data Analysis and Results

We analyzed the information using the same metrics as in the adult study. Table 2 shows the results, broken up by location. There were no significant interaction effects between secondary information and critical information locations. Also, unless mentioned, a Levene's test found that the data met the assumption of equal variances and a Shapiro-Wilks test showed that the data was normal. We used R [98] to calculate the statistics and the conditions were balanced.

4.4.1 Information Recall. Similar to our adult study, during the second and fourth study block we asked the children to recall the last presented information. A Shapiro-Wilks test showed that the data was not normal for *first response* recall ($W = 0.89$, $p < 0.05$) and *habituated response* recall ($W = 0.86$, $p < 0.01$); therefore, we applied the Aligned Rank Transform [84].

Regarding *first response* recall, a two-way ANOVA found no significant effect of secondary information location ($F_{1,18} = 0.48$, *n.s.*) or critical information location ($F_{2,18} = 0.16$, *n.s.*). When the children were not aware they would be asked to recall the information, the location of the secondary information and critical information did not affect information recall. For *habituated response* recall, a two-way ANOVA did not find a significant effect of secondary information location ($F_{1,18} = 0.068$, *n.s.*). However, there was a significant effect of critical information location ($F_{2,18} = 4.97$, $p < 0.05$), with a large effect ($\eta^2 = 0.36$) [65]. A Bonferroni post-hoc comparison showed that the children had a significantly higher *habituated recall* accuracy when the critical information was located at the bottom-center [M = 59.4%, SD = 12.9%] when compared to the center [M = 31.1%, SD = 17.7%] (Figure 4 left); there was no significant difference between the bottom-center and top-center locations [M = 37.5%, SD = 26.7%]. We examined each information type separately (i.e., food order, number of plates, countdown time, random word), and did not find any significant effects on *habituated recall* accuracy. Therefore, the bottom-center location led to a higher recall accuracy in general, not only for specific information types.

4.4.2 Emergency Warning Metrics. A Shapiro-Wilks test showed that the emergency warning data for error rate ($W = 0.86$, $p < 0.01$) was not normal, so we applied the Aligned Rank Transform [84]. The data for emergency warning response time was normal.

A two-way ANOVA found no significant effect of secondary information location ($F_{1,18} = 0.65$, *n.s.*) or critical information location ($F_{2,18} = 1.65$, *n.s.*) on children's response time. For emergency warning error rate, initially, a two-way ANOVA found no significant effect of secondary information location ($F_{1,18} = 0.15$, *n.s.*) or critical information location ($F_{2,18} = 1.92$, *n.s.*). However, when examining the error rate by critical information location, we found one outlier. We calculated outliers as two standard deviations above or below the mean. The child outlier experienced the critical information in the center location and had difficulty understanding the task to monitor for the emergency warning, resulting in a high error rate. After removing the outlier, a two-way ANOVA found a significant effect of critical information location on children's error rate ($F_{2,17} = 3.99$, $p < 0.05$), with a large effect ($\eta^2 = 0.32$) [65]. A Bonferroni post-hoc comparison showed that the children had a significantly lower error rate when the critical information was located at the center [M = 8.6%, SD = 6.3%] when compared to the top-center [M = 30.8%, SD = 19.8%] (Figure 4 right). There was no significant difference between the center and bottom-center locations (Table 2). The children were able to notice the emergency triangle in the center location more often, when compared to the top-center. Overall, the location of secondary information and critical information did not significantly affect the children's response time for the emergency warning triangle. However, the location of the critical information did significantly affect the children's error rate.

4.4.3 Plates Response Time. Similar to adults, we did not include the times when the children failed to notice that the number of plates was "0" and did not hit the button before the end of the study block. Two children either did not reach "0" or failed to notice when it became "0" before the end of the study blocks; therefore, we had a total of 22 children for analysis. A Shapiro-Wilks test showed that the response time for plates was not normal ($W = 0.57$, $p < 0.0001$); therefore, we applied the Aligned Rank Transform [84]. A two-way ANOVA found no significant effect of secondary information

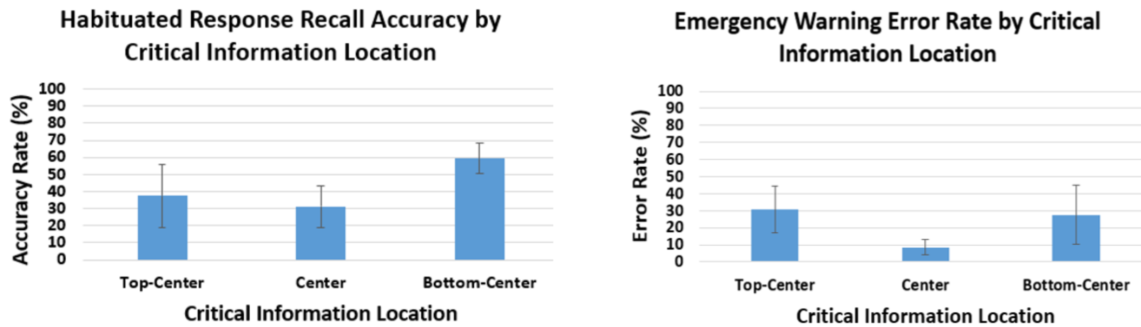


Figure 4: Habituated response recall accuracy rate by critical information location (left). Emergency warning error rate by critical information location with one outlier removed (right). Error bars represent 95% confidence interval.

location ($F_{1,16}$ = 0.95, *n.s.*) or critical information location ($F_{2,16}$ = 0.32, *n.s.*) on children's response time. The location of the critical and secondary information did not affect the children monitoring the number of plates (Table 2).

4.4.4 Perceived Cognitive Workload. We used an adapted NASA TLX [49, 50] that was designed for children to calculate the children's perceived cognitive workload. A two-way ANOVA found no significant effect of secondary information location ($F_{1,18}$ = 0.52, *n.s.*) or critical information location ($F_{2,18}$ = 0.04, *n.s.*) on cognitive workload. There was no significant difference in cognitive workload between the two secondary locations and the three critical information locations (Table 2).

4.5 Discussion

Overall, we did not find any significant differences between having the secondary information on the left-hand side or right-hand side for children's procedural task performance. For the location of critical information (top-center, center, bottom-center), we found significant differences for *habituated response* recall accuracy and emergency error rate.

We examined having the secondary information on the left-hand or right-hand side of the headset display because children expect elements to be on the AR headset right-side [85] and prior work has shown mixed results on pseudoneglect (i.e., left-ward bias) with children [23, 28, 76]. In our study, we did not find any significant effect of secondary information location on aiding task performance. Therefore, since we did not find any effect of location (left-side vs. right-side) on task performance, we recommend that designers place secondary information on the right-hand side of the AR headset display, to match the children's expectations and increase usability.

In addition, we found that when the critical information was located at the bottom-center of the headset, compared to the center location, the children's *habituated response* recall accuracy was higher. This is most likely due to the children constantly looking down at the table to complete the food orders, which decreased their eye movements when the critical information was in the bottom-center (Figure 3 right). Prior work has shown that eye movements can disrupt working memory [33, 79], which is a part of short-term memory that is concerned with immediate perceptual processing and information recall [7]. For instance, eye movement desensitization and reprocessing (EDMR), has been used to help treat posttraumatic stress disorder for both adults and children [1, 33]. EDMR increases eye movements during the recall of traumatic memories, which reduces their vividness and emotionality due to taxing the working memory. Children may benefit more from EDMR treatment, due to having lower central executive spans which is responsible for working memory processing [25]; therefore, the children's working memory is more affected by eye movements. Also, children are still developing working memory [56], and the ability for voluntary eye movements and stable eye fixations [55].

In result, when the critical information was in the center location it likely increased the children's eye movements and disrupted their working memory. When the critical information was in the center location, the children had to shift their eye movements up to see the recipe menu and down to complete the food order. The children's higher recall accuracy most likely occurred for *habituated response* recall, and not *first response* recall, since the children were aware of being asked to recall the information, which would increase their eye movements because they would be looking at the information more often. We most likely did not see a significant difference in *habituated response* recall accuracy between the top-center and bottom-center locations, because the children already had to look up for the recipe menu.

Although we found that the children's *habituated response* recall accuracy was lower when the critical information was in the center when compared to the bottom-center, we also saw that the children's emergency error rate was lower for the center when compared to the top-center. While the center location disrupted the children's working memory due to increasing eye movements, it also increased noticeability of the emergency warning triangle. The children noticed the triangle more often when it was in the center, when compared to the top-center. Having the red triangle appear directly in the center of the headset field-of-view caught the children's attention. We recommend that designers place critical information in the AR headset field-of-view in the direction the children are expected to look during the majority of the task, in order to reduce eye movements and increase working memory. However, for urgent information that needs to be immediately perceptible, we recommend that designers place the information in the center of the field-of-view.

5 DESIGN RECOMMENDATIONS

The location of critical information had a significant effect on children's *habituated response* recall accuracy and emergency warning error rate, while it did not affect adults' task performance. Since children's working memory is still developing [56] there is more of an effect of their eye movements disrupting their working memory and recall [33, 79]. Adults' working memory is more developed, which enables them to process more information at once. Also, children take longer to recognize words [8] and have more difficulty tracking multiple visual elements at once compared to adults [21]. For secondary information, we did not see any significant effect on task performance for children based on the left-hand or right-hand side, while prior work has shown that adults are more prone to a left-ward bias. Also, children expect virtual objects to be locked to the right-hand side of the AR headset display [85]. For adults, we did not find any significant differences in task performance between the two presentation styles of secondary information (*Display* vs. *Environment*). When analyzing critical and secondary information combined, we found that adults had lower cognitive workload when the location of the information was consistent (i.e., periphery or centralized). We provide design recommendations on designing AR headset content, in the context of procedural task performance, for both adults and children:

- Critical Information: For adults, designers can place critical information in any center location of the AR headset field-of-view (top, middle, or bottom); however, for children, designers should make sure to place the critical information in the direction the children are expected to look during the majority of the task. Urgent information that needs to be immediately perceived should be placed in the center location of the field-of-view for children.
- Secondary Information: Designers should place secondary information on the left-hand side of the AR headset field-of-view for adults and can either lock it to the display (*Display* style) or situate it in the environment (*Environment* style). For children, designers should keep the secondary information locked to the display on the right-hand side to match children's current expectations.
- Combined: For adults, when displaying both critical and secondary information in the field-of-view, we recommend that designers keep the secondary information presentation style and critical information location consistent, either in the periphery or centralized.

Our findings are beneficial for researchers and designers developing AR headset experiences for task-based activities in contexts such as healthcare and maintenance. Also, our work provides a foundation of knowledge for designing AR headset experiences for children, such as for AR headset educational activities. Overall, our work provides an understanding of how the design of textual information in AR headsets can affect users' task performance.

6 LIMITATIONS AND FUTURE WORK

There are some limitations to our work. We only examined the design of visual information within the context of a stationary procedural task (i.e., food assembly). Procedural tasks might not encompass all possible task demands, and the task was mainly stationary. Also, we only focused on textual information. Future work should investigate different graphical representations of information, as well as other design factors. Furthermore, the visual design of the textual information may have impacted our results. For example, the text in our studies was white, which is aligned with Meta AR design recommendations [59]. However, this could have impacted readability when shown against the white table in our studies. One thing to note is, while pseudoneglect has been shown to occur in both right-handed and left-handed people, it is not prominent in cultural groups that read right-to-left [77]. Therefore, our results are specific to certain cultural groups. Another limitation is that our recommendations are based on children's current expectations of AR headsets, which may change in the future. Also, only 24 children participated in our study. The number may seem small, but it is consistent with prior research with children (e.g., [61, 75, 86, 91]). Although we had a mix of gender per condition, prior work has shown that for ages 3-12, females are better at shifting visual attention [47]. Future work should further examine how to design critical and secondary information in AR headsets for children, such as the effect of gender and using eye tracking in AR headsets to determine any disruption in working memory.

7 CONCLUSION

While AR headsets are being applied in a wide range of contexts, little work has focused on how visual information should be designed. It is essential to study how visual information should be presented in AR headsets to maximize task performance for both adults and children. Like adults, children are increasingly being presented with AR headsets in different contexts. We aimed to understand how to design textual information in AR headsets for aiding task performance for both adults and children. We conducted two studies (adults vs. children) that focused on analyzing multiple design factors, such as the presentation style of secondary information and the location of critical information. While the design of information did not affect adults' task performance, the location of information had a direct effect on children's task performance (i.e., information recall, error rate). We provide new understanding and design recommendations on how to design visual information in AR headsets to aid in adults' and children's procedural task performance.

ACKNOWLEDGMENTS

This work is partially supported by the National Science Foundation Grant Award #IIS-1750840 and the National Science Foundation Graduate Research Fellowship under Grant No. DGE-1842473. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect these agencies' views. We thank Reecha Khanal and Daniel Delgado for their help in participant recruitment.

SELECTION AND PARTICIPATION OF CHILDREN

Children (ages 9 to 12) were recruited from a local elementary school and a local history museum, with appropriate permission from the school and museum. For the school, parents and guardians were approached during pick-up by researchers to describe the study and distribute informational packets. The study was also listed in the school weekly newsletter sent out to parents. For the museum, families were approached at the front of the museum by researchers to describe the study and distribute informational packets. Parents who were interested reached out to the researchers by email to schedule a time to bring their child to our institution. The researcher conducting the study went over the parental informed consent with the parents, and if they consented, the child was taken to a separate area in the room and asked to assent to the research. During the assent process, the researcher explained AR, the task, and informed the child that they could take as many breaks as they want, and they could stop at any time. If the child verbally assented, the researcher started the study. During the study, the researcher asked the child if they wanted to take a break between each of the study blocks. Parents were allowed to stay in the room but were in a separate area to not distract the children. All data was anonymized and stored in secure locations only accessible to the researchers.

REFERENCES

[1] Abdulbaghi Ahmad and Viveka Sundelin-Wahlsten. 2008. Applying EMDR on Children with PTSD. *Eur Child Adolesc Psychiatry* 17, 3 (April 2008), 127–132. DOI:https://doi.org/10.1007/S00787-007-0646-8

[2] Andrea Albarelli, Augusto Celentano, Luca Cosmo, and Renato Marchi. 2015. On the Interplay between Data Overlay and Real-World Context using See-through Displays. In *Proceedings of the Biannual Conference on Italian SIGCHI Chapter (CHItaly'15)*, ACM Press, New York, New York, USA, 58–65. DOI:https://doi.org/10.1145/2808435.2808455

[3] Troels L. Andersen, Sune Kristensen, Bjørn W. Nielsen, and Kaj Grønbæk. 2004. Designing an Augmented Reality Board Game with Children: The BattleBoard 3D Experience. In *Proceedings of the International Conference on Interaction Design and Children (IDC '04)*, ACM Press, New York, New York, USA, 137–138. DOI:https://doi.org/10.1145/1017833.1017858

[4] Lisa Anthony, Quincy Brown, Jaye Nias, Berthel Tate, and Shreya Mohan. 2012. Interaction and Recognition Challenges in Interpreting Children's Touch and Gesture Input on Mobile Devices. In *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces (ITS '12)*, ACM Press, New York, New York, USA, 225–234. DOI:https://doi.org/10.1145/2396636.2396671

[5] Dedy Ariansyah, John Ahmet Erkoyuncu, Iveta Eimontaite, Teegan Johnson, Anne Marie Oostveen, Sarah Fletcher, and Sarah Sharples. 2022. A Head Mounted Augmented Reality Design Practice for Maintenance Assembly: Toward Meeting Perceptual and Cognitive Needs of AR Users. *Appl Ergon* 98, (2022), 103597. DOI:https://doi.org/10.1016/J.APERGO.2021.103597

[6] Susanna Aromaa, Antti Väätänen, Iina Aaltonen, Vladimir Goriachev, Kaj Helin, and Jaakko Karjalainen. 2020. Awareness of the Real-World Environment When Using Augmented Reality Head-Mounted Display. *Appl Ergon* 88, (2020), 103145. DOI:https://doi.org/10.1016/J.APERGO.2020.103145

[7] Alan Baddeley. 1992. Working Memory. *Science 255*, 556–559. DOI:https://doi.org/10.1126/SCIENCE.1736359

[8] Ranka Bijeljac-Babic, Victor Millogo, Fernand Farioli, and Jonathan Grainger. 2004. A Developmental Investigation of Word Length Effects in Reading Using a New On-line Word Identification Paradigm. *Read Writ* 17, 4 (June 2004), 411–431. DOI:https://doi.org/10.1023/B:READ.0000032664.20755.AF

[9] Mark Billinghurst and Andreas Duenser. 2012. Augmented Reality in the Classroom. *Computer* 45, 7 (2012), 56–63. DOI:https://doi.org/10.1109/MC.2012.111

[10] Jonas Blattgerste, Benjamin Strenge, Patrick Renner, Thies Pfeiffer, and Kai Essig. 2017. Comparing Conventional and Augmented Reality Instructions for Manual Assembly Tasks. In *Proceedings of the International Conference on Pervasive Technologies Related to Assistive Environments (PETRA '17)*, ACM Press, New York, New York, USA, 75–82. DOI:https://doi.org/10.1145/3056540.3056547

[11] Dawn Bowers and Kenneth M. Heilman. 1980. Pseudoneglect: Effects of Hemispace on a Tactile Line Bisection Task. *Neuropsychologia* 18, 4–5 (January 1980), 491–498. DOI:https://doi.org/10.1016/0028-3932(80)90151-7

[12] C. Marlin Brown. 1999. Dialogue Design. In *Human-computer Interface Design Guidelines*. Intellect Books, 93–120.

[13] Rory Brown. Meta 2: Full Specification. *VRcompare*. Retrieved May 25, 2022 from https://vr-compare.com/headset/meta2

[14] Catherine M. Burns. 2000. Putting it All Together: Improving Display Integration in Ecological Displays. *Hum Factors* 42, 2 (September 2000), 226–241. DOI:https://doi.org/10.1518/001872000779656471

[15] Thomas J. Caruso, Martine Madill, Douglas Sidell, Kara Meister, Ellen Wang, Maria Menendez, Madison N. Kist, and Samuel Rodriguez. 2021. Using Augmented Reality to Reduce Fear and Promote Cooperation During Pediatric Otolaryngologic Procedures. *Laryngoscope* 131, 4 (April 2021), E1342–E1344. DOI:https://doi.org/10.1002/LARY.29098

[16] Mon-Chu Chen and Roberta Klatzky. 2007. Displays Attentive to Unattended Regions: Presenting Information in a Peripheral-Vision-Friendly Way. *International Conference on Human-Computer Interaction (HCII'07)* 4551, (2007), 23–31.

[17] Stephen D. Christman and Christopher L. Niebauer. 1997. The Relation Between Left-Right and Upper-Lower Visual Field Asymmetries: (Or: What Goes Up Goes Right While What's Left Lays Low). *Advances in Psychology* 123, (1997), 263–296. DOI:https://doi.org/10.1016/S0166-4115(97)80076-3

[18] Leslie Cunningham-Sabo and Barbara Lohse. 2014. Impact of a School-Based Cooking Curriculum for Fourth-Grade Students on Attitudes and Behaviors Is Influenced by Gender and Prior Cooking Experience. *J Nutr Educ Behav* 46, 2 (March 2014), 110–120. DOI:https://doi.org/10.1016/J.JNEB.2013.09.007

[19] Dragoş Datcu, Stephan Lukosch, and Heide Lukosch. 2013. Comparing Presence, Workload and Situational Awareness in a Collaborative Real World and Augmented Reality Scenario. *IEEE ISMAR Workshop on Collaboration in Merging Realities (CiMeR '13)* (2013), 6pp. DOI:https://doi.org/https://research.tudelft.nl/

[20] Saverio Debernardis, Michele Fiorentino, Michele Gattullo, Giuseppe Monno, and Antonio Emmanuele Uva. 2014. Text Readability in Head-Worn Displays: Color and Style Optimization in Video versus Optical See-Through Devices. *IEEE Trans Vis Comput Graph* 20, 1 (2014), 125–139. DOI:https://doi.org/10.1109/TVCG.2013.86

[21] Matthew W.G. Dye and Daphne Bavelier. 2010. Differential Development of Visual Attention Skills in School-Age Children. *Vision Res* 50, 4 (February 2010), 459. DOI:https://doi.org/10.1016/J.VISRES.2009.10.010

[22] Lizbeth Escobedo, Monica Tentori, Eduardo Quintana, Jesus Favela, and Daniel Garcia-Rosas. 2014. Using Augmented Reality to Help Children with Autism Stay Focused. *IEEE Pervasive Comput* 13, 1 (2014), 38–46. DOI:https://doi.org/10.1109/MPRV.2014.19

[23] Christina v. Failla, Dianne M. Sheppard, and John L. Bradshaw. 2003. Age and Responding-Hand Related Changes in Performance of Neurologically Normal Subjects on the Line-bisection and Chimeric-faces Tasks. *Brain Cogn* 52, 3 (2003), 353–363. DOI:https://doi.org/10.1016/S0278-2626(03)00181-7

[24] Michele Gattullo, Antonio E. Uva, Michele Fiorentino, and Joseph L. Gabbard. 2015. Legibility in Industrial AR: Text Style, Color Coding, and Illuminance. *IEEE Comput Graph Appl* 35, 2 (March 2015), 52–61. DOI:https://doi.org/10.1109/MCG.2015.36

[25] Raymond W. Gunter and Glen E. Bodner. 2008. How Eye Movements Affect Unpleasant Memories: Support for a Working-memory Account. *Behaviour Research and Therapy* 46, 8 (August 2008), 913–931. DOI:https://doi.org/10.1016/J.BRAT.2008.04.006

[26] Nick Haber, Catalin Voss, and Dennis Wall. 2020. Upgraded Google Glass Helps Autistic Kids "See" Emotions. *IEEE Spectrum*. Retrieved August 16, 2021 from https://spectrum.ieee.org/upgraded-google-glass-helps-autistic-kids-see-emotions/particle-8

[27] Sandra G. Hart. 2006. Nasa-Task Load Index (NASA-TLX); 20 Years Later. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 50, 9 (2006), 904–908. DOI:https://doi.org/10.1177/154193120605000909

[28] Markus Hausmann, Karen E. Waldie, and Michael C. Corballis. 2003. Developmental Changes in Line Bisection: A Result of Callosal Maturation? *Neuropsychology* 17, 1 (January 2003), 155–160. DOI:https://doi.org/10.1037/0894-4105.17.1.155

[29] Christopher Healey and James Enns. 2012. Attention and Visual Memory in Visualization and Computer Graphics. *IEEE Trans Vis Comput Graph* 18, 7 (2012), 1170–1188. DOI:https://doi.org/10.1109/TVCG.2011.127

[30] Steven Henderson and Steven Feiner. 2011. Exploring the Benefits of Augmented Reality Documentation for Maintenance and Repair. *IEEE Trans Vis Comput Graph* 17, 10 (2011), 1355–1368. DOI:https://doi.org/10.1109/TVCG.2010.245

[31] Steven J. Henderson and Steven K. Feiner. 2011. Augmented Reality in the Psychomotor Phase of a Procedural Task. In *IEEE International Symposium on Mixed and Augmented Reality (ISMAR '11)*, IEEE, 191–200. DOI:https://doi.org/10.1109/ISMAR.2011.6092386

[32] Md Shafaeat Hossain and Carl Haberfeld. 2020. Touch Behavior Based Age Estimation Toward Enhancing Child Safety. In *International Joint Conference on Biometrics (IJCB '20)*, IEEE, 8pp. DOI:https://doi.org/10.1109/IJCB48548.2020.9304913

[33] Marcel A. van den Hout, Iris M. Engelhard, Marleen M. Rijkeboer, Jutte Koekebakker, Hellen Hornsveld, Arne Leer, Marieke B.J. Toffolo, and Nienke Akse. 2011. EMDR: Eye Movements Superior to Beeps in Taxing Working Memory and Reducing Vividness of Recollections. *Behaviour Research and Therapy* 49, 2 (February 2011), 92–98. DOI:https://doi.org/10.1016/J.BRAT.2010.11.003

[34] Tien Chi Huang, Chia Chen Chen, and Yu Wen Chou. 2016. Animating Eco-Education: To See, Feel, and Discover in an Augmented Reality-Based Experiential Learning Environment. *Comput Educ* 96, (May 2016), 72–82. DOI:https://doi.org/10.1016/j.compedu.2016.02.008

[35] María Blanca Ibáñez and Carlos Delgado-Kloos. 2018. Augmented Reality for STEM Learning: A Systematic Review. *Comput Educ* 123, (August 2018), 109–123. DOI:https://doi.org/10.1016/j.compedu.2018.05.002

[36] Samat Imamov, Daniel Monzel, and Wallace S. Lages. 2020. Where to Display? How Interface Position Affects Comfort and Task Switching Time on Glanceable Interfaces. In *IEEE Conference on Virtual Reality and 3D User Interfaces*, 851–858. DOI:https://doi.org/10.1109/VR46266.2020.00110

[37] Natalia Irrazabal, Gastón Saux, and Debora Burin. 2016. Procedural Multimedia Presentations: The Effects of Working Memory and Task Complexity on Instruction Time and Assembly Accuracy. *Appl Cogn Psychol* 30, 6 (2016), 1052–1060. DOI:https://doi.org/10.1002/ACP.3299

[38] Yoshio Ishiguro and Jun Rekimoto. 2011. Peripheral Vision Annotation: Noninterference Information Presentation Method for Mobile Augmented Reality. In *Proceedings of the Augmented Human International Conference (AH'11)*, ACM Press, New York, New York, USA, 1–5. DOI:https://doi.org/10.1145/1959826.1959834

[39] Elizabeth Jarpe-Ratner, Stephanie Folkens, Sonika Sharma, Deborah Daro, and Neilé K. Edens. 2016. An Experiential Cooking and Nutrition Education Program Increases Cooking Self-Efficacy and Vegetable Consumption in Children in Grades 3–8. *J Nutr Educ Behav* 48, 10 (November 2016), 697-705.e1. DOI:https://doi.org/10.1016/J.JNEB.2016.07.021

[40] Nor Farzana Syaza Jeffri and Dayang Rohaya Awang Rambli. 2021. A Review of Augmented Reality Systems and Their Effects on Mental Workload and Task Performance. *Heliyon* 7, 3 (2021), e06277. DOI:https://doi.org/10.1016/J.HELIYON.2021.E06277

[41] Yuhong Jiang, Ingrid R. Olson, and Marvin M. Chun. 2000. Organization of Visual Short-Term Memory. *J Exp Psychol Learn Mem Cogn* 26, 3 (2000), 683–702. DOI:https://doi.org/10.1037/0278-7393.26.3.683

[42] Michael Jones, M. Jeannette Lawler, Eric Hintz, Nathan Bench, Fred Mangrubang, and Mallory Trullender. 2014. Head Mounted Displays and Deaf Children: Facilitating Sign Language in Challenging Learning Environments. In *Proceedings of the International Conference on Interaction Design and Children (IDC '14)*, ACM Press, New York, NY, USA, 317–320. DOI:https://doi.org/10.1145/2593968.2610481

[43] M. Carmen Juan, Giacomo Toffetti, Francisco Abad, and Juan Cano. 2010. Tangible Cubes Used As The User Interface In An Augmented Reality Game for Edutainment. In *IEEE International Conference on Advanced Learning Technologies (ICALT '10)*, 599–603. DOI:https://doi.org/10.1109/ICALT.2010.170

[44] Min Kyong Kim, Stefania Druga, Shaghayegh Esmaeili, Julia Woodward, Alex Shaw, Ayushi Jain, Jaida Langham, Kristy Hollingshead, Silvia B. Lovato, Erin Beneteau, Jaime Ruiz, Lisa Anthony, and Alexis Hiniker. 2022. Examining Voice Assistants in the Context of Children's Speech. *Int J Child Comput Interact* 34, 100540 (2022). DOI:https://doi.org/10.1016/j.ijcci.2022.100540

[45] Sunwook Kim, Maury A. Nussbaum, and Joseph L. Gabbard. 2019. Influences of Augmented Reality Head-Worn Display Type and User Interface Design on Performance and Usability in Simulated Warehouse Order Picking. *Appl Ergon* 74, (January 2019), 186–193. DOI:https://doi.org/10.1016/J.APERGO.2018.08.026

[46] Naohiro Kishishita, Kiyoshi Kiyokawa, Jason Orlosky, Tomohiro Mashita, Haruo Takemura, and Ernst Kruijff. 2014. Analysing the Effects of a Wide Field of View Augmented Reality Display on Search Performance in Divided Attention Tasks. *IEEE International Symposium on Mixed and Augmented Reality (ISMAR '14)* (November 2014), 177–186. DOI:https://doi.org/10.1109/ISMAR.2014.6948425

[47] Liisa Klenberg, Marit Korkman, and Pekka Lahti-Nuuttila. 2010. Differential Development of Attention and Executive Functions in 3- to 12-Year-Old Finnish Children. *Dev Neuropsychol* 20, 1 (2010), 407–428. DOI:https://doi.org/10.1207/S15326942DN2001_6

[48] D.W.F. van Krevelen and Ronald Poelman. 2010. A Survey of Augmented Reality Technologies, Applications and Limitations. *The International Journal of Virtual Reality* 9, 2 (2010), 1–20. DOI:https://doi.org/10.1155/2011/721827

[49] Cynthia Laurie-Rose, Lori M. Curtindale, and Meredith Frey. 2017. Measuring Sustained Attention and Perceived Workload. *Hum Factors* 59, 1 (February 2017), 76–90. DOI:https://doi.org/10.1177/0018720816684063

[50] Cynthia Laurie-Rose, Meredith Frey, Aristi Ennis, and Amanda Zamary. 2014. Measuring Perceived Mental Workload in Children. *Am J Psychol* 127, 1 (2014), 107–125. DOI:https://doi.org/10.5406/AMERJPSYC.127.1.0107

[51] David Liu, Simon A. Jenkins, Penelope M. Sanderson, Perry Fabian, and W. John Russell. 2010. Monitoring with Head-Mounted Displays in General Anesthesia: A Clinical Evaluation in the Operating Room. *Anesth Analg* 110, 4 (2010), 1032–1038. DOI:https://doi.org/10.1213/ANE.0b013e3181d3e647

[52] David Liu, Simon A. Jenkins, Penelope M. Sanderson, Marcus O. Watson, Terrence Leane, Amanda Kruys, and W John Russell. 2009. Monitoring with Head-Mounted Displays: Performance and Safety in a Full-Scale Simulator and Part-Task Trainer. *Anesth Analg* 109, 4 (October 2009), 1135–1146. DOI:https://doi.org/10.1213/ANE.0b013e3181b5a200

[53] Silvia B. Lovato, Anne Marie Piper, and Ellen A. Wartella. 2019. "Hey Google, do unicorns exist?": Conversational Agents as a Path to Answers to Children's Questions. In *Proceedings of the International Conference on Interaction Design and Children (IDC '19)*, ACM Press, New York, NY, USA, 301–313. DOI:https://doi.org/10.1145/3311927.3323150

[54] Silvia Lovato and Anne Marie Piper. 2015. "Siri, is this you?": Understanding Young Children's Interactions with Voice Input Systems. In *Proceedings of the International Conference on Interaction Design and Children (IDC '15)*, ACM Press, New York, New York, USA, 335–338. DOI:https://doi.org/10.1145/2771839.2771910

[55] Beatriz Luna, Katerina Velanova, and Charles F. Geier. 2008. Development of Eye-movement Control. *Brain Cogn* 68, 3 (December 2008), 293–308. DOI:https://doi.org/10.1016/J.BANDC.2008.08.019

[56] Caitlin E.V. Mahy, Louis J. Moses, and Matthias Kliegel. 2014. The Development of Prospective Memory in Children: An Executive Framework. *Developmental Review* 34, 4 (December 2014), 305–326. DOI:https://doi.org/10.1016/J.DR.2014.08.001

[57] Aristides Mairena, Carl Gutwin, and Andy Cockburn. 2019. Peripheral Notifications in Large Displays: Effects of Feature Combination and Task Interference. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'19)*, ACM Press, New York, New York, USA, 12pp. DOI:https://doi.org/10.1145/3290605.3300870

[58] Haley Marshall and Jaclyn Albin. 2021. Food as Medicine: A Pilot Nutrition and Cooking Curriculum for Children of Participants in a Community-Based Culinary Medicine Class. *Matern Child Health J* 25, 1 (January 2021), 54–58. DOI:https://doi.org/10.1007/s10995-020-03031-0

[59] Paul Mealy. 2018. Planning Your Augmented Reality Project. In *Virtual & Augmented Reality For Dummies*. John Wiley & Sons, Inc. , 159–161.

[60] MetaMetrics. 2022. Understanding Lexile®Measures. *Lexile*. Retrieved July 5, 2022 from https://lexile.com/educators/understanding-lexile-measures/

[61] Brita Munsinger and John Quarles. 2019. Augmented Reality for Children in a Confirmation Task: Time, Fatigue, and Usability. In *Proceedings of the ACM Symposium on Virtual Reality Software and Technology (VRST '19)*, ACM Press, 5 pages. DOI:https://doi.org/10.1145/3359996.3364274

[62] Brita Munsinger, Greg White, and John Quarles. 2019. The Usability of the Microsoft Hololens for an Augmented Reality Game to Teach Elementary School Children. In *Proceedings of the International Conference on Virtual Worlds and Games for Serious Applications (VS-Games '19)*, IEEE, 1–4. DOI:https://doi.org/10.1109/VS-Games.2019.8864548

[63] Gerhard Nellhaus. 1968. HEAD CIRCUMFERENCE FROM BIRTH TO EIGHTEEN YEARS: Practical Composite International and Interracial Graphs. *Pediatrics* 41, 1 (January 1968), 106–114. DOI:https://doi.org/10.1542/PEDS.41.1.106

[64] Austin Olney. 2019. Augmented Reality | All About Holograms. In *Beyond Reality: Augmented, Virtual, and Mixed Reality in the Library*, Kenneth J. Varnum (ed.). American Library Association, 1–16.

[65] Julie Pallant. 2020. *SPSS Survival Manual: A Step by Step Guide to Data Analysis Using IBM SPSS* (7th ed.). Allen & Unwin. DOI:https://doi.org/10.4324/9781003117452

[66] Michael T. Pascale, Penelope Sanderson, David Liu, Ismail Mohamed, Birgit Brecknell, and Robert G. Loeb. 2019. The Impact of Head-Worn Displays on Strategic Alarm Management and Situation Awareness. *Hum Factors* 61, 4 (2019), 537–563. DOI:https://doi.org/10.1177/0018720818814969

[67] Yoni Pertzov and Masud Husain. 2014. The Privileged Role of Location in Visual Working Memory. *Atten Percept Psychophys* 76, 7 (2014), 1914–1924. DOI:https://doi.org/10.3758/S13414-013-0541-Y

[68] Jean Piaget. 1983. Piaget's Theory. In *Handbook of Child Psychology*, P. Mussen (ed.). Wiley & Sons, New York, NY, USA. DOI:https://doi.org/10.1007/978-3-642-46323-5_2

[69] Iulian Radu, Betsy McCarthy, and Yvonne Kao. 2016. Discovering Educational Augmented Reality Math Applications by Prototyping with Elementary-School Teachers. In *IEEE Virtual Reality (VR '16)*, IEEE, 271–272. DOI:https://doi.org/10.1109/VR.2016.7504758

[70] Luz Rello and Ricardo Baeza-Yates. 2017. How to Present More Readable Text for People with Dyslexia. *Univers Access Inf Soc* 16, 1 (March 2017), 29–49. DOI:https://doi.org/10.1007/s10209-015-0438-8

[71] Rufat Rzayev, Susanne Korbely, Milena Maul, Alina Schark, Valentin Schwind, and Niels Henze. 2020. Effects of Position and Alignment of Notifications on AR Glasses during Social Interaction. In *Proceedings of the Nordic Conference on Human-Computer Interaction (NordiCHI '20)*, ACM Press, New York, NY, USA, 11pp. DOI:https://doi.org/10.1145/3419249

[72] Rufat Rzayev, PawełW. Wozniak, Tilman Dingler, and Niels Henze. 2018. Reading on Smart Glasses: The Effect of Text Position, Presentation Type and Walking. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'18)*, ACM Press, New York, New York, USA, 9pp. DOI:https://doi.org/10.1145/3173574.3173619

[73] Ned Sahin, Neha Keshav, Joseph Salisbury, and Arshya Vahabzadeh. 2018. Safety and Lack of Negative Effects of Wearable Augmented-Reality Social Communication Aid for Children and Adults with Autism. *J Clin Med* 7, 8 (July 2018), 188. DOI:https://doi.org/10.3390/jcm7080188

[74] Scholastic Inc. 2022. Guided Reading Leveling Resource Chart. *Scholastic*. Retrieved July 5, 2022 from https://teacher.scholastic.com/education/guidedreading/leveling_chart.htm

[75] Gavin Sim, Brendan Cassidy, and Janet C. Read. 2013. Understanding The Fidelity Effect When Evaluating Games With Children. In *International Conference on Interaction Design and Children (IDC '13)*, 193–200. DOI:https://doi.org/10.1145/2485760.2485769

[76] Ruxandra Sireteanu, Ralf Goertz, Iris Bachert, and Timo Wandert. 2005. Children with Developmental Dyslexia Show a Left Visual "Minineglect." *Vision Res* 45, 25–26 (November 2005), 3075–3082. DOI:https://doi.org/10.1016/J.VISRES.2005.07.030

[77] Austen K. Smith, Izabela Szelest, Trista E. Friedrich, and Lorin J. Elias. 2014. Native Reading Direction Influences Lateral Biases in The Perception of Shape From Shading. *Laterality* 20, 4 (July 2014), 418–433. DOI:https://doi.org/10.1080/

1357650X.2014.990975

[78] Kiley Sobel. 2019. *Future of Childhood Immersive Media and Child Development*. Retrieved August 16, 2021 from https://files.eric.ed.gov/fulltext/ED598949.pdf

[79] Jan Theeuwes, Artem Belopolsky, and Christian N.L. Olivers. 2009. Interactions Between Working Memory, Attention and Eye Movements. *Acta Psychol (Amst)* 132, 2 (October 2009), 106–114. DOI:https://doi.org/10.1016/J.ACTPSY.2009.01.005

[80] Nicole A. Thomas, Oliver Schneider, Carl Gutwin, and Lorin J. Elias. 2012. Dorsal Stream Contributions to Perceptual Asymmetries. *J Int Neuropsychol Soc* 18, 2 (March 2012), 251–259. DOI:https://doi.org/10.1017/S1355617711001585

[81] Sergei Vardomatski. 2021. Augmented And Virtual Reality After Covid-19. *Forbes*. Retrieved July 6, 2022 from https://www.forbes.com/sites/forbestechcouncil/2021/09/14/augmented-and-virtual-reality-after-covid-19/?sh$=$1b886d882d97

[82] Eswara Rao Velamkayala, Manuel V. Zambrano, and Huiyang Li. 2017. Effects of HoloLens in Collaboration: A Case in Navigation Tasks. *Human Factors and Ergonomics Society Annual Meeting* 61, 1 (2017), 2110–2114. DOI:https://doi.org/10.1177/1541931213602009

[83] M. D. Vernon. 1961. The Development of Perception in Children. *Educational Research* 3, 1 (January 1961), 2–11. DOI:https://doi.org/10.1080/0013188600030101

[84] Jacob O. Wobbrock, Leah Findlater, Darren Gergle, and James J. Higgins. 2011. The Aligned Rank Transform for Nonparametric Factorial Analyses Using Only Anova Procedures. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'11)*, ACM Press, New York, New York, USA, 143–146. DOI:https://doi.org/10.1145/1978942.1978963

[85] Julia Woodward, Feben Alemu, Natalia E López Adames, Lisa Anthony, Jason C Yip, and Jaime Ruiz. 2022. "It Would Be Cool to Get Stampeded by Dinosaurs": Analyzing Children's Conceptual Model of AR Headsets Through Co-Design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '22)*, ACM Press, New York, NY, USA, 13pp. DOI:https://doi.org/10.1145/3491102

[86] Julia Woodward, Lisa Anthony, Germaine Irwin, Alex Shaw, Annie Luc, Brittany Craig, Juthika Das, Phillip Hall, Akshay Holla, Danielle Sikich, and Quincy Brown. 2016. Characterizing How Interface Complexity Affects Children's Touchscreen Interactions. In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI'16)*, ACM Press, New York, New York, USA, 1921–1933. DOI:https://doi.org/10.1145/2858036.2858200

[87] Julia Woodward, Jahelle Cato, Jesse Smith, Isaac Wang, Brett Benda, Lisa Anthony, and Jaime Ruiz. 2020. Examining Fitts' and FFitts' Law Models for Children's Pointing Tasks on Touchscreens. In *ACM International Conference on Advanced Visual Interfaces (AVI '20)*, ACM Press, New York, NY, USA, 1–5. DOI:https://doi.org/10.1145/3399715.3399844

[88] Julia Woodward, Alex Shaw, Aishat Aloba, Ayushi Jain, Jaime Ruiz, and Lisa Anthony. 2017. Tablets, Tabletops, and Smartphones: Cross-Platform Comparisons of Children's Touchscreen Interactions. In *Proceedings of the ACM International Conference on Multimodal Interaction (ICMI'17)*, ACM Press, New York, New York, USA, 5–14. DOI:https://doi.org/10.1145/3136755.3136762

[89] Julia Woodward, Jesse Smith, Isaac Wang, Sofia Cuenca, and Jaime Ruiz. 2020. Examining the Presentation of Information in Augmented Reality Headsets for Situational Awareness. In *ACM International Conference on Advanced Visual Interfaces (AVI '20)*, ACM Press, 1–5. DOI:https://doi.org/10.1145/3399715.3399846

[90] Philip David Zelazo, Ulrich Muller, Douglas Frye, and Stuart Marcovitch. 2003. The Development of Executive Function in Early Childhood. *Monogr Soc Res Child Dev* 68, 3 (December 2003), vii–viii. DOI:https://doi.org/10.1111/j.0037-976X.2003.00260.x

[91] Kening Zhu, Xiaojuan Ma, Gary Ka Wai Wong, and John Man Ho Huen. 2016. How Different Input and Output Modalities Support Coding as a Problem-Solving Process for Children. In *International Conference on Interaction Design and Children (IDC '16)*, Association for Computing Machinery, Inc, 238–245. DOI:https://doi.org/10.1145/2930674.2930697

[92] Zhiwei Zhu, Vlad Branzoi, Michael Wolverton, Glen Murray, Nicholas Vitovitch, Louise Yarnall, Girish Acharya, Supun Samarasekera, and Rakesh Kumar. 2014. AR-Mentor: Augmented Reality Based Mentoring System. In *IEEE International Symposium on Mixed and Augmented Reality (ISMAR '14)*, IEEE, 17–22. DOI:https://doi.org/10.1109/ISMAR.2014.6948404

[93] 2011. ISO 7010:2011 Graphical symbols. *International Organization for Standardization*. Retrieved April 23, 2019 from https://www.iso.org/standard/54432.html

[94] 2019. Mixed Reality Start Gesture. *Microsoft Docs*. Retrieved August 9, 2021 from https://docs.microsoft.com/en-us/windows/mixed-reality/design/system-gesture

[95] 2021. Overcooked | Cooking Video Game . *Team17*. Retrieved February 8, 2021 from https://www.team17.com/games/overcooked/

[96] 2022. Unity. *Unity Technologies*. Retrieved May 31, 2022 from https://unity3d.com/

[97] Nickelodeon Cooking Contest Game: Free Online Nick Culinary Arts Educational Video Game for Kids. *Culinary Schools*. Retrieved March 29, 2023 from https://www.culinaryschools.org/kids-games/nickelodeon-cooking-contest/

[98] R: The R Project for Statistical Computing. *The R Foundation*. Retrieved March 29, 2023 from https://www.r-project.org/