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Determining Age-Related Visual Memory and Line Length Perception in Children and Adults

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Dear Professor Steigman,

I am pleased to inform you that Katie Exline successfully defended her thesis on Monday, May 4, 2020. Her committee included Dave Sheridan and Louise Captein. The committee was quite impressed with Katie's original work—she undertook a project related to her interests in optometry. Consequently, Katie very much took the lead on the project. In addition to the typical background research of her topic and the writing of the paper, Katie spent countless hours programming two detailed experiments—that task required an abundance of creativity and persistence. She also dealt with the hurdles of recruiting young children from a local school. Katie's work has prepared her well for her next challenge—next fall she will be attending OSU's School of Optometry.

Sincerely,

Cynthia Laurie-Rose

DETERMINING AGE-RELATED VISUAL MEMORY AND LINE LENGTH PERCEPTION IN CHILDREN AND ADULTS

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Submitted in partial fulfillment of the requirements for graduation with Honors

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I'd first like to thank Dr. Laurie-Rose for her investment in me and this study. I would not have been able to complete this work without her support, and I'm grateful for her time and effort over these past two years working together. I'd also like to thank Dr. Sheridan for cultivating my knowledge of anatomy and physiology as I prepare to enter optometry school, but mostly for challenging me, encouraging me, and believing in me during this thesis and throughout other classes at Otterbein. Thank you to Professor Captein for your patience and support of this project, and thanks to Dr. Steigman and the Honors Program for your faith and encouragement.

Abstract

There is little research in the field of visual memory and perceptual abilities of children as compared to adults. This thesis seeks to understand and provide new perspectives to this field with potential implications in the fields of optometry and education. Through two basic experiments, this thesis evaluates the abilities of individuals to perceive a visual stimulus and compare it other visual stimuli, while also observing their abilities to learn and remember various visual stimuli. Through experimentation using line length as the visual stimulus, the method of constant stimuli (MCS) evaluates subjects' visual perception and the method of single stimuli (MSS) evaluates subjects' visual memory. In addition, a test called the Letter-Digit Substitution Test assesses cognitive abilities in an effort to determine if there is any connection between visual memory and cognitive abilities. The MCS demonstrated no significant difference in performance between children and adults as whole groups, but there were significant differences for specific trial lengths. Alternatively, the MSS showed a significant difference between children and adults for the whole groups as well as for individual trial lengths. Interestingly, children performed equally well on the two experiments, indicating that the child's visual memory for comparison was as good as comparing two lines one directly after another. These results indicate adults and children likely do not have a significant difference in perceptual abilities but do have a significant difference in visual memory.

Introduction

Optometry seeks to examine and treat various conditions of the eye and the visual system; from diseases to disorders, optometrists act as primary healthcare providers for the eye (American Optometric Association, 2012). With a future career in optometry in mind, this paper provides insight into two important fields of study regarding vision: perceptual abilities and visual memory. This project specifically focuses on better understanding these abilities in children in order to better serve them in optometry offices and school classrooms. With more knowledge about the visual memory and perceptual abilities of children, teachers and optometrists might work together to improve the conditions for children to best learn. Past studies have demonstrated connections between visual memory and cognitive abilities, so providing more insight regarding the relationship between these abilities might help to enhance classroom experiences (Wood, Black, Hopkins, and White, 2018; Kulp, Edwards, and Mitchell, 2002).

Before delving into visual memory and perception, it is important to first understand the physiology of sight. The visual pathway begins as light enters into the eye through the pupil and reflects off the retina, the main organ of vision. Composed of thousands of tiny cells called rods and cones, the retina receives light energy and translates it into electrical impulses perceivable by the brain. The rods and cones act as the photoreceptors that translate light energy into electrical energy that can be fired as action potentials through nerve cells which, in turn, release neurotransmitters to affect ganglion cells. Ganglion cells are the last step before visual information exits the eye into the brain, and they compile electrical impulses at the optic disc. The optic disc is where the optic nerve attaches to the retina and carries the transmitted energy into the brain. The optic radiation orients the image in the brain before the impulses finally end in the primary visual cortex and visual association cortex in the occipital lobe (Sheridan, 2019; Dragoi, 2020). Through understanding the anatomical and physiological processes relevant to visual perception, the important concept of perceptual abilities is also easier to comprehend.

Psychophysics combines the concepts of the physical world and perception, resulting in a field of study that measures how individuals sense and perceive physical stimuli (Woodruff, 2002). Considering both the concepts of perceptual abilities and visual memory, psychophysics is an idea central to the research completed in this study. One's ability to perceive and differentiate a specific stimulus revolves around the perceptual threshold point: the minimum intensity of a stimulus necessary to achieve a specific level of performance (Manning, Jones, Dekker, and Pellicano, 2018). The ability to distinguish a visual threshold is known to improve throughout childhood development (Ellemberg, Lewis, Liu, and Maurer, 1999; Hadad, Maurer, and Lewis, 2011; Hayward, Truong, Partanen, and Giaschi, 2016; Manning, Dakin, Tibber, Pellicano, 2014). Therefore, children are typically worse at differentiating visual thresholds as compared to adults. Witton, Talcott, and Henning found children to be worse at assessing visual trials than adults, answering incorrectly 19% of the time, compared to the adults' typical 5% error rate (2017; Wichmann and Hill, 2001a; Wichmann and Hill, 2001b). Manning et al. discusses factors that could affect children's performance such as inattentiveness, reduced motivation, and response bias (2018). In addition, Witton et al. mention further factors such as the ability to maintain vigilance throughout the entirety of a task and the ability to consistently judge stimuli (2017). Psychophysics characterizes perceptual abilities, helping to describe how children and adults compare when assessing visual, or other sensory, stimuli.

Visual memory consists of two main components: first, the ability to discriminate stimuli and, second, the ability to recall visual information when it is no longer present (Whisler, 1974).

Researchers have completed many studies regarding visual memory, especially in adults, utilizing various visual stimuli in order to determine how effectively individuals can differentiate visual stimuli. In 1981, Riege and Inman completed a study that asked younger, middle-aged, and older adults to learn and remember geometric art patterns. Participants then had to recall the patterns a minute later, thus testing their visual memory. There was a significant effect such that as people increased in age into later adulthood, their performance worsened. When considering children, studies have shown that visual memory can be improved through practice with recognizing visual stimuli such as letters (Whisler, 1974). This study seeks to compare children and adults' visual memory using the same stimuli and programs in order to determine the abilities of the two groups to learn and recall visual stimuli.

In 2002, Kulp, Edwards, and Mitchell completed a study to learn about whether or not visual memory is connected to cognitive abilities. Researchers administered the Test of Visual-Perceptual Skills to students in second through fourth grade at an elementary school in order to learn about the students' visual memory. Then, the researchers compared the scores of the visual memory test to scores on standardized tests. Kulp et al. found a significant connection between visual memory and cognitive abilities on both reading and math tests, further demonstrating the importance of understanding visual memory (Kulp et al., 2002). With more research into the visual memory and cognitive abilities of students, schools might be able to better understand a student's needs in the classroom. Also, this might be helpful to learn early on if students need additional support by giving them a visual memory test at the beginning of the school year.

Although there are numerous studies evaluating adults' abilities to perceive and remember visual stimuli, there is considerably less literature discussing the same evaluation of children's abilities. In 2011, Norman, Holmin, and Bartholomew completed a study that compared the perception and visual memory abilities of younger adults with those of older adults to better understand how visual memory changed over time. They determined no significant differences between the abilities of young adults and older adults in terms of visual memory and perception (Norman et al., 2011), but this begs the question of whether there is a difference between children and young adults. This thesis will evaluate and compare the perception abilities of adults with children as well as the visual memory abilities of these two groups.

Children are constantly learning and developing, and few experiments- in comparison to the multitude of studies dedicated to adults' visual memory- have been completed to evaluate and understand their abilities to perceive a given stimulus and then to remember and evaluate the stimulus in comparison to other stimuli. Thus, this thesis seeks to explore these questions through two simple experiments proven to evaluate these abilities (Morgan et al., 2000; Norman et al., 2011). The first of the two experiments is the method of constant stimuli (MCS), which evaluates an individual's ability to perceive differences between an explicit standard and a given stimulus. The explicit standard is a known and predetermined stimulus that is clearly presented to test subjects. This standard is important as it allows researchers to understand whether a person can effectively evaluate differences in visual stimuli. For this thesis specifically, that standard will be a line of a specific length.

The alternative to the method of constant stimuli, and the second of the two experiments used in this thesis, is the method of single stimuli (MSS). In the MSS, individuals learn an implicit standard and compare various stimuli to this standard. This differs from MCS as an implicit standard is never actually presented to individuals. Rather, they learn the stimulus through practice trials presented before experimentation (Morgan et al., 2000). This type of experiment allows researchers to understand a person's abilities to learn and remember a visual stimulus, thus evaluating visual memory.

This thesis seeks to provide insights with exciting implications in the field of optometry as well as in the field of education due to the lack of research regarding children's abilities in perception and visual memory. With better understanding of perception, optometrists may be able to better service patients based on the tests they complete during visual exams. Also, with better understanding of the connection between visual memory and cognitive abilities, educators might be able to better assist students in learning via new or better understood visual learning techniques in the classroom. Teachers might also recognize specific cognitive patterns that, with more knowledge, they can connect to visual memory to better serve students in class.

Method

Participants

This experiment was completed in Westerville, Ohio at Otterbein University and at Saint Michael School, a local elementary school. The participants included in the study consisted of seven college-aged adults ranging from 20 years and 5 months to 22 years and 8 months as well as a group of 22 third-grade students from 8 years and 6 months to 9 years and 10 months old. The Institutional Review Board (IRB) granted approval for the study on human participants. Adults signed consent forms prior to testing, and parents signed consent forms before their children participated. Each parent received explicit information and detailed goals of the project before signing the consent form to ensure their understanding of the project on behalf of the youth participants. Children also gave verbal assent on the day of testing before the experiment began. They were given the option to end the testing at their discretion, and incomplete experiments were not counted in final results.

Prior to testing, adult observers and the parents of youth observers completed a demographic form. The form asked for the individual's name, age, year in school, and gender. The form also asked for the most recent eye exam in order to ensure that inadequate vision would not misconstrue the data. Each individual was asked whether or not they had normal (i.e. 20/20) vision without corrective measures such as prescription glasses or contact lenses and, if not, if their vision was corrected to normal using corrective measures. Finally, the form inquired as to whether or not the individual had been diagnosed with attention or behavioral disorders but encouraged participation regardless of the response to that question.

Measures

Letter-Digit Substitution Test. This test accurately and reliably examines the cognitive abilities of individuals in a very short time frame of only sixty seconds, demonstrated by Van der Elst et al. in 2006. Van der Elst et al. completed a study in order to produce a normative set of letter-digit substitution test results for adults between 24 and 81 years old, providing a comparable scale for other studies to utilize the test to measure cognitive abilities (Van der Elst et al., 2006). In 2012, Van der Elst et al. created another study using the same test as the 2006 research in order to normalize data for school-aged children, ranging from eight to fifteen years old (Van der Elst et al., 2012). Based on Van der Elst et al.'s work, both child and adult participants completed this test in order to measure their reasoning abilities as well as their working memory. Observers were instructed to match the letter in the chart with the matching number based on the key provided at the top of the page, depicted in Figure 1. Following the procedure in Van der Elst et al., the first ten letter-number pairings were used as practice, and individuals were then given sixty seconds to finish as many pairings as possible (Van der Elst, 2006). The test score was represented by the number of correctly matched letter-number pairs at the end of the sixty second period.

Stimulus and Apparatus

The stimuli for both the MCS and MSS experiments were identical in order to maintain consistency throughout experimentation. All trials displayed on a black screen with a white line stimulus created on Adobe Software and integrated into programming completed on SuperLab 4.5. The participants used a Cedrus RB-830 response pad to respond throughout the MCS and

MSS tasks, selecting either a button labeled, "shorter," or a button labeled, "longer," for each trial. Based on the experiments done by Norman et al. (2011) the line stimulus "standard" was 9.0 cm long, and it subtended 5.2° of the visual angle. Four trial length stimuli were created—two shorter and two longer—that varied from the standard by intervals of 4.8% and 8.0%. Thus the longer stimuli measured 9.432 cm or 9.720 cm for longer stimuli, and these trial lengths were labeled 3 and 4 respectively. Thus the shorter stimuli measured 8.280 cm or 8.568 cm for shorter stimuli, and these trial lengths were labeled 1 and 2 respectively. Each trial length as well as the stimulus was presented in one of four orientations: horizontal, vertical, left oblique, and right oblique. With a total of 96 trials presented, each trial length showed up equally often in each orientation. For example, 24 of the 96 trials would be devoted to trial length 1, and six of the 24 presentations would be in the horizontal orientation. There would also be six vertical, six left oblique, and six right oblique presentations for trial length 1, totaling 24 trials of the same length but varying orientations. The same is true for trial lengths 2, 3, and 4. The program randomized the order of the 96 trials in both the MCS and MSS blocks to reduce bias and confounding variables such as diminished focus throughout testing.

Tasks

Method of Constant Stimuli (MCS). The MCS testing helps to explain individuals' ability to *perceive* visual differences in line length, thus addressing the portion of the thesis that seeks to compare perceptual abilities of children and adults. During the MCS experiment, the individual was shown a white line of a predetermined length on a black background on the computer screen. This white line could be either the standard line stimulus or one of four trial lengths, varying from the 9.0 cm standard in length and, depending on the random trial, orientation. All other qualities of the lines such as color and visual angle remained the same. In

MCS testing, there is typically a single "standard" stimulus compared directly with a comparison stimulus trial. In this experiment, observers compared the first line stimulus presented with the comparison stimulus, either shorter or longer, using a simple two alternative forced-choice (2AFC). The order was varied as to whether the standard length stimulus appeared first or one of the comparison stimuli appeared first. Of the 96 trials in the MCS experiment, the standard appeared first for 48 of them and second for 48 of them.

During testing, the first stimulus, either the standard or a comparison, was presented on the screen for an interval of 2.0 seconds before disappearing. There was then a 1.5 second interstimulus interval period (ISI) in which the screen appeared blank. The second stimulus then appeared for 2.0 seconds. Following the second line presentation for the full 2.0 second period, the observer was then asked to determine whether the second line was shorter or longer than the first line by pressing one of two buttons labeled either "shorter" or "longer." Once the individual selected a choice, they then continued to the next line comparison trial at their own pace with each subsequent trial beginning after any response to the choice prompt. Each comparison of lines counted as one trial, and the individuals completed a total of 96 MCS trials in a block. This method was modeled after the MCS task in Norman et al. (2011).

Method of Single Stimuli (MSS). The MSS testing evaluated an individual's ability to *learn, remember, and compare* a line stimulus with subsequent stimuli, thereby demonstrating the visual memory component of the thesis. During the MSS experiment, the individual first completed a practice block of 20 trials in which they learned an implicit standard known to researchers but never actually shown to the observers (Morgan et al., 2000). The individual was shown a single line on the screen for 2.0 seconds before choosing whether the presented line was shorter or longer than the implicit standard. The individual listened for a feedback sound to indicate whether they responded correctly or incorrectly about the line being shorter or longer than the implicit standard. When correct, the observer heard a positive bell ringing response, confirming their correct response. When incorrect, the observer heard no audial feedback, confirming an incorrect response. After the 20 learning trials, participants began the main session that included 96 trials. During the 96 trial test block, observers continued to receive feedback each time as to whether they responded correctly or incorrectly. Past experiments determined no significant difference between the conditions of providing feedback throughout the main session for correct responses or not providing feedback (Morgan et al., 2000; Norman et al., 2011), so the response was included to engage participants and to promote effort to answer correctly. This method was modeled after the MSS task in Norman et al. (2011).

Procedure

Participants completed testing on a personal laptop computer provided by the researcher in quiet environments at Otterbein University or at Saint Michael School. Before testing began, the researcher explained the purpose of the testing and summarized the three tasks– the Letter-Digit Substitution Test, MCS Testing, and MSS Testing– to be completed. After describing the tasks and answering further questions, the researcher received verbal assent and written confirmation from the participant to confirm they were comfortable with the testing and environment. All participants had permission to withdraw from testing at any point.

After giving verbal assent, the participants first completed the brief Letter-Digit Substitution Test. Following the Letter-Digit Substitution Test, the participants began the MCS testing on the computer. Observers were prompted with on-screen instructions that explained the tasks, but the researcher supervised the experiment and answered all questions throughout testing. Following completion of the MCS experiment, the researcher explained the MSS experiment briefly again and remained available for questions during the MSS portion of testing.

W	B	T	P	V	D	G	C	J
1	2	3	4	5	6	7	8	9

T	W	C	G	J	V	B	D	P	V	P	T	D	C	B

Figure 1. Example of the key and a single line of matching trials for the Letter-Digit Substitution Test. Subjects matched the letter with the correlating number to demonstrate cognitive abilities.

Results

Method of Constant Stimuli (MCS). The number of correct answers was determined for each participant at each trial length presented. Means for the number of correct responses for each trial length are presented in Table 1, for each of the two groups of participants, “adults” and “children.” These data were submitted to a 2 (Group: Children, Adults) x 4 (Trial Lengths) mixed ANOVA with repeated measures on length. The main effect for trial length was significant (Wilks’ lambda = .286, F (3, 25) = 20.799, $p < .001$, $\eta_p^2 = .714$). This indicates that the number of correct responses varied across the trial lengths. Alternatively, the main effect for groups was not significant ($p > .05$), but the Length x Group interaction was significant (Wilks’ lambda = .605, F (3, 25) = 5.443, $p < .05$, $\eta_p^2 = .395$). This means that, as a whole, the children and adults did not perform significantly different, but for specific trial lengths two and four, the two groups did perform significantly different. This interaction appears in Figure 4 as a function of trial length, displaying the total number of correct responses.

Method of Single Stimuli (MSS). The number of correct answers was determined for each participant at each trial length presented. Means for the number of correct responses for each trial length are presented in Table 2, for each of the two groups of participants, “adults” and “children.” These data were submitted to a 2 (Group: Children, Adults) x 4 (Trial Lengths) mixed ANOVA with repeated measures on length. The main effect for trial length was significant (Wilks’ lambda = .440, F (3, 25) = 10.601, $p < .001$, $\eta_p^2 = .560$). Likewise, the main effect for groups was also significant (F (1, 27) = 20.868, $p < .001$, $\eta_p^2 = .436$). These significant main effects were modified by a significant Length x Group interaction (Wilks’ lambda = .626, F (3, 25) = 4.978, $p < .05$, $\eta_p^2 = .374$). This data analysis indicates that the children and adult groups performed significantly different on the MSS task as whole but that performance differences were more pronounced on specific trial lengths. This interaction appears in Figure 5 as a function of trial length, displaying the total number of correct responses.

Combined Method of Constant Stimuli vs Method of Single Stimuli for Children. This analysis was completed to compare how well children performed on the MCS task versus the MSS task. Means for the number of correct responses for each trial length are presented in Table 3, for the two tasks, "MCS" and "MSS." These data were submitted to a 2 (Task: MCS, MSS) x 4 (Trial Lengths) repeated measures ANOVA. The main effect for task was not significant, meaning children performed equally well on the MCS and MSS tasks as a whole (Wilks' lambda = .693, F (3, 40) = 5.901, $p < .05$, $\eta_p^2 = .307$). Alternatively, the main effect for Length x Task was significant (Wilks' lambda = .685, F (3, 40) = 6.125, $p < .05$, $\eta_p^2 = .315$). This indicates that task did make a difference when considering the performance on individual trial lengths. This interaction appear in Figure 6 as a function of trial length, displaying the total number of correct responses.

Descriptive Statistics for MCS				
	Group	**Mean # Correct Responses**	**Standard Deviation**	**N**
Trial Length 1	Children	13.000	2.7603	22
	Adults	13.286	1.8898	7
Trial Length 2	Children	13.227	2.7591	22
	Adults	17.143	1.8645	7
Trial Length 3	Children	13.318	2.3981	22
	Adults	13.857	1.8645	7
Trial Length 4	Children	9.136	3.1967	22
	Adults	5.143	1.7728	7

Table 1. Data from the Method of Constant Stimuli for the two groups analyzed, children and adults, summarized as the mean number of correct responses for each individual trial length.

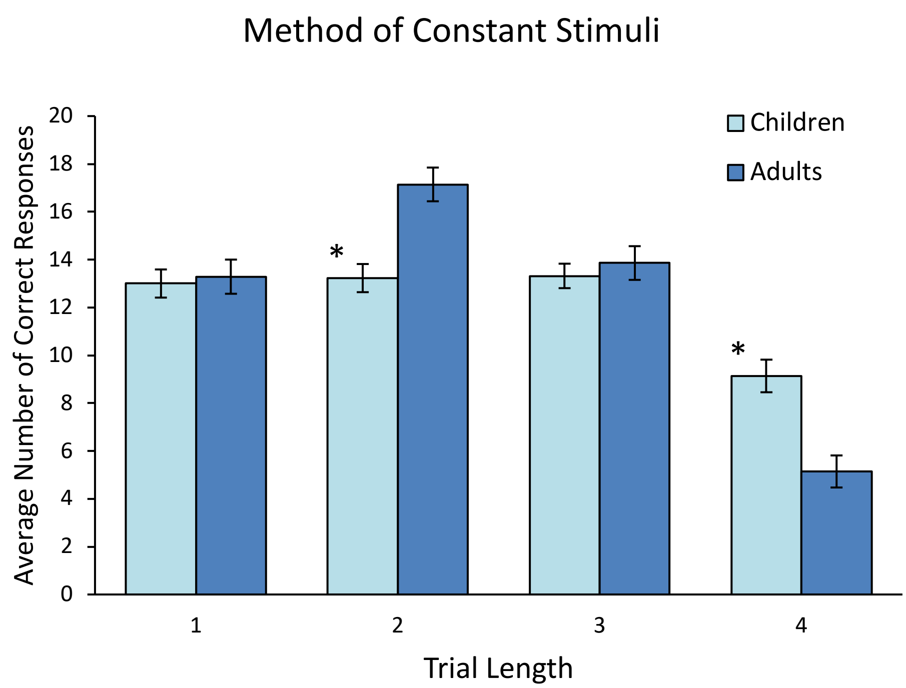

Figure 2. Graphical summary of the performance of children and adults on the Method of Constant Stimuli task. Trial lengths 2 and 4 (marked by *) were significantly different, but the main effect for the children vs adult group was not significantly different. Error bars represent standard error.

Descriptive Statistics for MSS				
	Group	**Mean # Correct Responses**	**Standard Deviation**	**N**
Trial Length 1	Children	12.36	2.838	22
	Adults	15.43	3.409	7
Trial Length 2	Children	12.95	3.498	22
	Adults	17.86	2.911	7
Trial Length 3	Children	11.14	2.376	22
	Adults	13.43	1.902	7
Trial Length 4	Children	11.77	2.927	22
	Adults	18.57	3.359	7

Table 2. Data from the Method of Single Stimuli for the two groups analyzed, children and adults, summarized as the mean number of correct responses for each individual trial length.

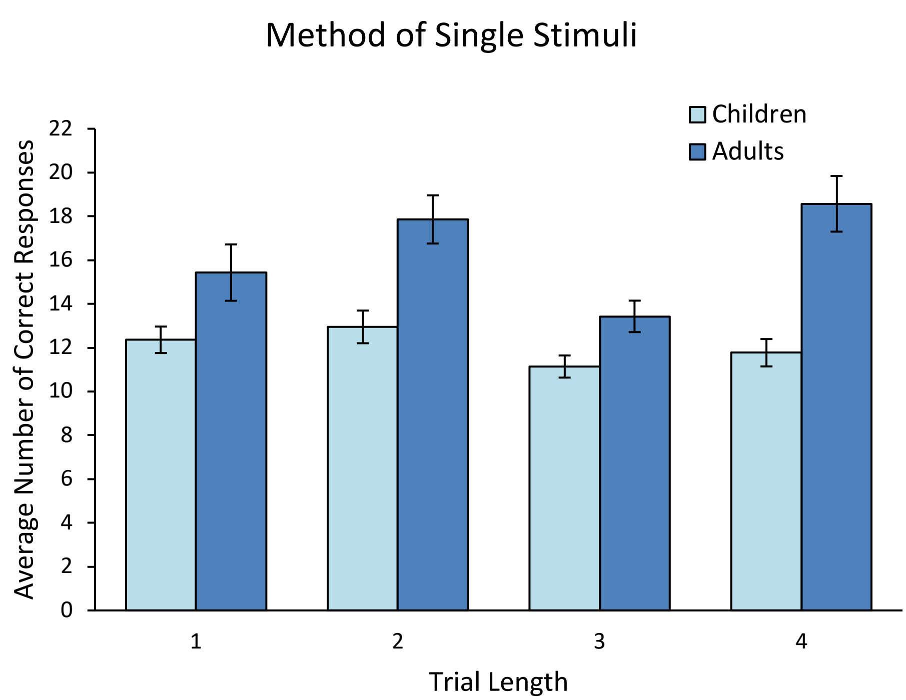

Figure 3. Graphical summary of the performance of children and adults on the Method of Single Stimuli task. The main effect for both length and group are significant. Error bars represent standard error.

Descriptive Statistics for Children's MCS vs MSS				
	Task	**Mean # Correct Responses**	**Standard Deviation**	**N**
Trial Length 1	MCS	13.000	2.7603	22
	MSS	12.364	2.8376	22
Trial Length 2	MCS	13.227	2.7591	22
	MSS	12.955	3.4980	22
Trial Length 3	MCS	13.318	2.3981	22
	MSS	11.136	2.3764	22
Trial Length 4	MCS	9.136	3.1967	22
	MSS	11.773	2.9266	22

Table 3. Data from the combined comparison of the children's performance on the Method of Constant Stimuli versus the Method of Single Stimuli. For the two tasks analyzed, MCS and MSS, summarized is the mean number of correct responses for each individual trial length.

Figure 4. Graphical summary of the compared performance of children on the Method of Constant Stimuli and the Method of Single Stimuli tasks. The main effect for task is not significant, but the main effect for length x task is significant. Error bars represent standard error.

Discussion

There were some intriguing findings regarding both perceptual abilities and visual memory, and not only when comparing children to adults but also when comparing children's performance on the two tasks. The Method of Constant Stimuli (MCS) and Method of Single Stimuli (MSS) help to describe differences in the visual capabilities between children and adults, providing a means of comparison for perceptual abilities and visual memory, respectively. The perceptual abilities of children and adults, as a whole, were not significantly different. Alternatively, in the case of visual memory, there was a significant difference between the performance of the adult and children groups, indicating a difference in the visual memory of adults and children. An interesting additional finding was uncovered when data analysis was ran on the children's performance on the MCS in comparison to the MSS. As a whole, the group performed equally well on both tasks, indicating that the measure of their perceptual abilities was likely accurate due to its consistency and that their visual memory did not affect their abilities to assess lines.

Children and adults performed equally well, as a whole, on the Method of Constant Stimuli as there was no significant main effect when considering groups. Much like Norman et al. discovered with younger and older adults, children were as adept at differentiating between line stimuli as adults (2011). This finding demonstrates that there was no difference between the perceptual abilities of the child and adult groups. In turn, it can be deduced that the perceptual abilities of a child improve throughout childhood as predicted by many previous studies (Ellemberg et al., 1999; Hadad et al., 2011; Hayward et al., 2016; Manning et al., 2014), and that by third grade, those perceptual abilities would be no different than the perceptual abilities of an adult. For specific trial lengths 2 and 4, there was a significant difference between the judgment of the two groups, meaning that children and adults did perform differently in the case of these two lines. Children were worse at differentiating trial length 2 from the stimulus as compared to adults, which is reasonable considering that the two stimuli varied by only .432 cm. This discrepancy could be attributed to a response bias such as deciding to consistently press, "longer," when they were uncertain about a judgment, a factor that Manning et al. discussed in the 2018 study. There was also a significant main effect when considering trial length, and this is an expected finding, simply describing that the groups were better at discriminating some trial lengths from the standard than other trial lengths from the standard. Norman et al. determined the difference threshold needed to accurately and consistently discriminate line length stimuli from a standard to be around 5-6%, thus agreeing with the finding that participants would be better at discriminating certain line lengths from the standard than others (2011).

The Method of Single Stimuli produced different results than the Method of Constant Stimuli, indicating an exciting difference in the visual memory of children and adults. As a whole, children and adults performed significantly different on the MSS, meaning that children were significantly worse at learning, remembering, and comparing line stimuli. This finding supports previous work showing that visual memory can be developed and improved due to the neural plasticity of the brain (Dosher and Lu, 2017). Also, when considering Whisler's work, there was a significant improvement in the visual memory of first-graders with training (1974). It follows that with more school and different experiences, the visual memory of children would continue to improve throughout childhood. Without many other studies comparing children and adults directly, this result of a different visual memory capacity indicates an opportunity for further research regarding when visual memory is fully developed and if there are differences between younger children and older children. Also, as in the MCS, there was a significant difference between the judgment of lines, again pointing to Norman et al.'s finding that individuals are better at differentiating between certain line stimuli than others (2011).

A serendipitous discovery was found when removing the adults' performance on the two tasks and comparing the performance of only children on the Method of Constant Stimuli and the Method of Single Stimuli. Interestingly, there was no significant main effect when comparing the two tasks, indicating that children performed equally well on the two different tasks. Two major understandings may be deduced from this fact: first, the children's perceptual abilities were consistent throughout both tasks and, second, the visual memory of the children did not affect their ability to discriminate the line stimuli. The consistency of the children's performance likely indicates an accurate determination about their perceptual abilities. In other words, the children were able to discriminate the lines at a specific visual threshold, and they remained consistently adequate at differentiating at that threshold (Manning et al., 2018; Norman et al., 2011). Also, this finding supports the idea that 20 practice trials prior to completing an MSS task fairly prepares participants (Morgan et al., 2000). Since the children performed equally well on both the MCS and MSS, it can be understood that they were able to learn the implicit line stimulus standard and judge trial lengths in comparison to the implicit standard. Most excitingly, considering children and adults performed equally well on MCS but significantly different on MSS; and considering that perceptual abilities did *not* affect the children's performance on the MSS, it can be concluded that the differences between the children's performance on the MSS and adult's performance on the MSS can be fairly attributed to differences in visual memory.

Limitations

Two random and yet challenging limitations occurred during this study: first, a cyber attack on Otterbein University and, second, the occurrence of COVID-19 when testing was being completed during early 2020. The cyber attack resulted in an inability to use school equipment which, in turn, greatly limited the adult sample size. Thus, with only seven adults, few conclusions regarding the performance of the adult group alone could be drawn. Likewise, COVID-19 caused a rapid change in the study's composition, forcing no further contact with adults outside of the immediate home of researchers, so further testing on computers could not be completed even after the cyber attack's resolution.

Trial Length 4 also presented some unusual data during the Method of Constant Stimuli (MCS) trials. After noticing the lower performance of both children and adults, the program used for experimentation was revisited to determine if an error existed. While the exact cause has not been determined, there appears to be a variance in the resolution of the stimuli for Trial Length 4 during the MCS trials. Based on the better performance of adults in the Method of Single Stimuli (MSS), the lower data can be attributed to an experimental error.

Future Directions

Based on the small adult sample size of seven individuals, no conclusions could be drawn about the adult group alone. Preliminary results showed there could be a significant correlation with cognitive abilities in the adult group, so further research with a greater sample size might give a better indication as to this finding. Further, it would be interesting to compare results with standardized tests rather than just the Letter-Digit Substitution Test (similar to Kulp et al., 2002). While we would expect to see similar results based on Van der Elst's work providing normative data (2012), it would be interesting to see if the cognitive results were the same.

In addition, the finding regarding a difference between the visual memory of children and adults provides an exciting starting point for new research. Perhaps comparing the visual memory of individuals younger than third grade, individuals in early adolescence, late adolescence, and adulthood would help to describe how visual memory develops over time. More research in this domain would be not only informational but also intriguing to see if similar results were achieved.

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