The Effect of Close Proximity Prior Experience on Visual Working Memory Decay in High School Seniors

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Dating as far back as Ancient Greece, human memory has remained an extensively studied subject, having been analyzed by figures such as Aristotle who noted in his treatise, "On Memory", that humans are unique in their ability to recall memory (Aristotle, 1930). Over time, it has become evident that memory is not perfect as it may be inaccurate, fabricated, or even unattainable. Although human memory comes in various forms, the primary purpose of this research is to examine visual working memory. To better understand erroneous memory recall, studies have been conducted gauging the malleability of memory, resulting in the contemporary understanding that memories can be altered by misinformation (Loftus & Hoffman, 1989). Errors in recall have also been associated with one more factor, forgetfulness; German psychologist Hermann Ebbinghaus found an exponential relationship between time and memory lost (Murre & Dros, 2015). Ebbinghaus conducted a seven-month experimental study with himself as the subject, using "thirteen nonsense syllables" as stimuli, concluding in 1880 that there was a power function and in 1885 that there was a logarithmic function to memory loss after employing a "savings measure" (Murre & Dros, 2015, p. 3). From his study arose the question of "how stimuli at different serial positions were learned and how these were forgotten over time" (Murre & Dros, 2015, p. 3). Addressing the absence of a clear answer to these questions, theories arose seeking to explain the learning process, as well as forgetfulness.

One proposed theory on forgetting is the decay theory of memory, wherein memory deviates from its original state due to the passage of time. John Brown found that memory decays faster with more time between the presentation and recall period, and the similarity factor correlated positively with the correctness of recall (1958). Brown also noted the effects of rehearsal improving the correctness of recall (1958), a finding reflected in a study by Lloyd R. Peterson and Margaret Jean Peterson (1959) that attributed this improvement in recall to “serial learning” (p. 198). Critics of decay theory often look towards interference theory as a means to explain forgetfulness. A study conducted criticizing the Petersons’ use of only single characters in gauging short-term memory, found proactive inhibition and interference to be the cause of forgetfulness (Keppel & Underwood, 1962). The discovery of interference’s involvement in the forgetting process directly conflicted with the decay theory pushed by the Petersons, as forgetting could no longer be attributed solely to the passage of time. The conversation between proponents and opponents of decay theory remains relevant in the modern day with studies continuing to be conducted to prove and disprove decay theory (Ricker, Vergauwe, & Cowan, 2016). Furthermore, Brown (1958) stated that “the merit of the decay hypothesis lies in its simplicity and its ability to explain the results without arbitrary auxiliary hypotheses” (p. 20). This explanation of the decay hypothesis, however, overlooked interference as a cause of forgetting since it attributed forgetfulness only to the process of time as opposed to what happens within that time.

Recent studies using decay theory proposed two main theories on the process of visual memory decay: one that suggested that the process of decay occurs randomly—memory of visual stimuli randomly deviates from the actual stimuli over time—and another that suggested that decay occurs in the same way every time (Ricker, Vergauwe, & Cowan, 2016). One study using “psychophysical noise-masking methods” to uncover the root of short-term visual memory decay found that the latter of the two theories applied to subjects (Gold et al., 2005). Previous studies also indicated the likely existence of memory decay but were unable to discern the process of decay (Ricker, Vergauwe, & Cowan, 2016). These findings showed that decay may be observed in its most basic form, but the process of decay remains unclear. Discussions around the existence and exact processes of decay leave more information to be desired, thus allowing decay theory to be used as a foundation for this study.

As aforementioned, there is a specific form of memory called working memory which is defined as "the small amount of information that can be held in mind and used in the execution of cognitive tasks" (Cowan, 2014, p. 197). Working memory has long pertained to "intelligence, information processing,…and learning" (Cowan, 2014, p. 197), but its capacity varies from study to study with no contemporary consensus between "discrete and continuous models" (Fukuda et al., 2010, p. 181). The current discrete model roughly limits the number of items retained within working memory capacity to four items, whereas the continuous model attributed a different portion of working memory to each item—larger and more detailed items exhausted more resources (Fukuda et al., 2010). Although neither model agrees with the other, it can be noted from this that decay studies observing working memory should utilize item sets of four at maximum, and refrain from using a large array of items.

Related to working memory is the effect of prior experience on subsequent learning. Studies found that prior knowledge could allow individuals to strategically commit items to memory by looking back at unfamiliar words (McGillivray & Castel, 2017). "Prior brain states" and emotional stimuli could also cause biased memory or increased retention ability (Tambini & Davachi, 2019, p. 885). This means that emotional stimuli should be avoided to obtain more accurate results and a neutral brain state should be promoted to decrease memory bias. Furthermore, combining the concept of prior experience with working memory, it would be beneficial to test the effect of prior experience in closer proximity to task completion with caution to the capacity limits of working memory as well as interference.

Literature Review

This study aims to acquire data on the effect that simulated prior experience has on working memory decay and thus, in furtherance of understanding the purpose of this study, it is necessary to consider the existing research concerning the subject. There have been many studies seeking to prove and disprove the existence and impact of decay, with several focused on the matter of decay versus distinctiveness. One study conducted by Souza and Oberauer (2014), found that "absolute time" was non-causal in visual working memory and "relative spacing of trials" held a larger impact when analyzing experimental results utilizing a continuous color recall task (p. 156). This study directly contradicted results found in a study conducted by Ricker, Spiegel, and Cowan (2014), published in the same year, where it was found that "trace decay" was an important predictor of forgetting and that research that did not find evidence of impact caused by "trace decay" were conducting experiments in a different manner (p. 1521). The methods and variables used in both studies were similar, but not the same. The difference in study designs—the former's use of colors and the latter's use of unrecognizable symbols—indicated that neither of the two studies may serve as a concluding remark on the decay versus distinctiveness conversation. Additionally, studies used retention and inter-trial intervals as their independent variables to explain time-based forgetting. These studies were limited in that they did not experiment with other variables that may increase or decrease decay, such as prior experience. Instead, these studies reduced the impact of interference and other factors that may influence time-based forgetting.

Nevertheless, it is important that this study does not overlook the impact that interference may have on memory. A study conducted by McConnell and Quinn (2000) determined that "to cause interference, the [visual] percept must be maintained in the [visual] store by a change that will counteract the process of decay" (p. 65). The study concluded that the passive visual store "has both temporal and capacity characteristics" and that "interference with the recall of the words by…visual noise is…caused by the direct access of the noise field into the passive visual store" (McConnell & Quinn, 2000, p. 65-66). This understanding of interference theory allowed future research to understand that the reduction of visual noise present during a task would lead to less interference in memory. Later, Oberauer and Lin (2017) conducted several experiments in a study describing an interference model in comparison with the "Slot-Averaging model" and the "Variable-Precision model" (p. 23). Oberauer and Lin's proposed interference model was found to be more flexible in making predictions regarding the process of working memory (2017) showing that interference theory has noticeable merit as an explanation to the function of forgetting. Several studies also specifically looked at proactive interference which, unlike retroactive interference, is the psychological phenomena where previously learned material interferes with the ability to retain or recall presently or newly learned material. These studies have found that the presence of spatial information restrained the effects of proactive interference and that proactive interference took great effect in estimating the visual working memory capacity of experiment participants (Hartshorne, 2008; Makovski, 2016). From this, it is evident that, in the future, researchers should take extra caution to ensure that interference does not hamper studies that do not consider interference by minimizing its occurrence. However, studies that may result in an explanation related to interference theory do not require lengthy precautions, especially if the method is unknown to cause interference.

While most studies dealing with decay theory continued to dispute the existence of decay and studies on interference theory attempt to prove its accuracy, studies focusing on prior experience have not yet tested simulated prior experience in working memory. Rather, studies on prior experience in relation to memory have researched the impact of prior experimentation and prior knowledge in long-term memory (Lustig & Hasher, 2002; Parsons, 2017). One study conducted by Lustig and Hasher found there to be proactive interference present when analyzing university students' working memory span (2002). The study looked at the effect that "prior laboratory experience" had on working memory span and found that "the working memory scores of experimentally experienced participants relative to similar participants who lacked those same experiences" were lower (Lustig & Hasher, 2002, p. 93). Lustig and Hasher's experiment accounted only for scenarios where participants undergo three-day long studies and failed to account for scenarios where participants underwent other experiments a substantial time before the trial. Furthermore, this study did not consider prior experience in the short-term relative to working memory soon after prior experience tasks. Another study conducted by Bellana et al. analyzed the effect that prior knowledge holds on the recollection of famous and non-famous faces (2019). Bellana et al. asserted that prior knowledge improved recollection and not familiarity (2019). While both of these studies related to the effect of prior experiences on memory, they were limited as they both dealt with experience over a long time. The data from these studies more accurately contributed to the effect that prior experience in the long-term has on working memory.

As noted, previous studies conducted on memory decay theory primarily focus on proving its existence, and studies on the effect of prior experience on memory mainly observed the effect that prior experience has in the long-term. Research is, however, still lacking regarding the effect that prior experience has in the short-term along with the process of decay. Furthermore, participants in previous studies did not fit within the adolescent age range thus further limiting the application of their results—participants may have also varied in individual experience prior to experimentation. Given the limitations of previous studies, a gap in knowledge could be established as a decay study within a smaller time frame has yet to be conducted with the variable of prior experience. To bridge said gap, future research should look to simulate prior experience in the short-term to test the working memory recall of adolescents with respect to memory decay. Few studies have been conducted that simulate prior learning in close proximity to testing and fewer of these studies use adolescents as the subjects of their study. Further advocating for the use of young participants in a narrow age group, a study on interference in visual short-term memory found that as people grow older, their pattern separation ability decreases (Smith, McKeown, & Bunce, 2017). This showed that to reduce the variability in pattern separation ability, a group of adolescents such as high school seniors would be close to ideal to prevent pattern separation ability from being a confounding variable. Thus, to attempt to bridge this gap in knowledge, the following study addressed the question: To what extent does prior experience in close proximity to testing impact working memory recall in high school seniors through memory decay?

This study attempted to simulate the effect of prior experience in closer proximity through a learning memory task, structured differently from an experimental memory task, to procure quantitative data regarding the accuracy of recall. Furthermore, the study focused on high school seniors, a specific group within the adolescent age range that limited variance in brain development and new data that did not use university students. Subjects were asked for consent in their participation and were not mentioned by name for the sake of confidentiality. The test subjects were split into a control group and an experimental group to gauge any differences that may have arisen.

This study's research aimed to add to the conversation surrounding the effect of prior experience on memory as well as working memory decay, providing data from a group that is not often gauged. The results of this study served to show the limits of human memory and how soon and effectively new material may be learned and applied in everyday life. Moreover, findings may help explain the process of decay in working memory or advocate for interference theory. In understanding how memory functions, science may one day reach the point of reducing memory loss or help retrieve lost memories. As a whole, the data from this study helped contribute to the existing pool of knowledge surrounding human memory and allows for future studies to confirm the results it produced.

Hypothesis

Conclusions drawn from studies on both memory decay theory and the effect of prior experience led to the belief that prior experience positively impacted the working memory recall of high school seniors through short-term memory decay. Since the participants were given spatial information, proactive interference was expected to take less effect. Studies on the effect of prior experience used methods involving the English language—as opposed to new material to be learned—citing interference as the cause of lower working memory span (Lustig & Hasher, 2002). The new material used in this study minimized the possibility of interference from knowledge prior to the experiment and it was hypothesized that the learning memory task would increase recall performance in high school seniors.

Method

Design

An experimental study conducted by Ricker, Spiegel, and Cowan was altered and employed to gauge the effectiveness of prior experience. The study design was originally purposed to observe the effects of memory decay using the inter-trial interval and the retention interval as independent variables (Ricker, Spiegel, & Cowan, 2014). The experiment split its participants into two groups: a control group and an experimental group. Due to the purpose of this study being to measure the impact of prior experience in closer proximity to testing, two groups were necessary to help observe changes in the accuracy of recall. The two groups each underwent a memory task simulating close-proximity prior experience that preceded a test task. The memory task used for this study was a game of Concentration where the control group and experimental group differed in the cards they played with. The test task following the memory task used unfamiliar material to test the visual working memory of participants and avoid the impact of proactive interference. After the experimental procedure, quantitative data was then extracted and compared through one-variable statistics and inferential statistics.

Participants

Twenty randomly selected high school seniors from a local high school participated in this study and were randomly assigned to the control and experimental groups. All participants had normal vision at the time of their participation and consented to their participation and the use of their results as part of this study. No participants had prior knowledge or experience with the characters or figures used in the experiment. In addition, no participants were in conditions that impaired their memory at the time of the exam and all participants were healthy as well.

Materials

A quiet, barren corner of a classroom was used to reduce visual and auditory stimuli present in the testing environment. A stark table was used to conduct both parts of the study. The control group used two packs of standard playing cards, and the experimental group used cards made from paper cut into identical sizes, with 40 characters from the test stimulus printed on each card. The test stimulus consisted of 40 characters created for this experiment, not resembling characters in any language known to the participants. The characters were created with respect to Makovski's (2018) study on object size in relation to visual short-term memory which found that "only the size representation of open objects is inflated" (p. 1136). The characters being printed on identically sized cards allowed participants to maintain a grasp of the symbol's size relative to the card, which was considered to be a closed object. This allowed the experiment to avoid the possible size representation inflation of open objects as the characters created would be considered as open objects. The test task was presented in black and in sets of four over a gray background on a laptop at full brightness. Each character was centered in a 540 by 540-pixel quadrant when shown. The full size of the display was 1080 by 1080-pixels.

Procedure

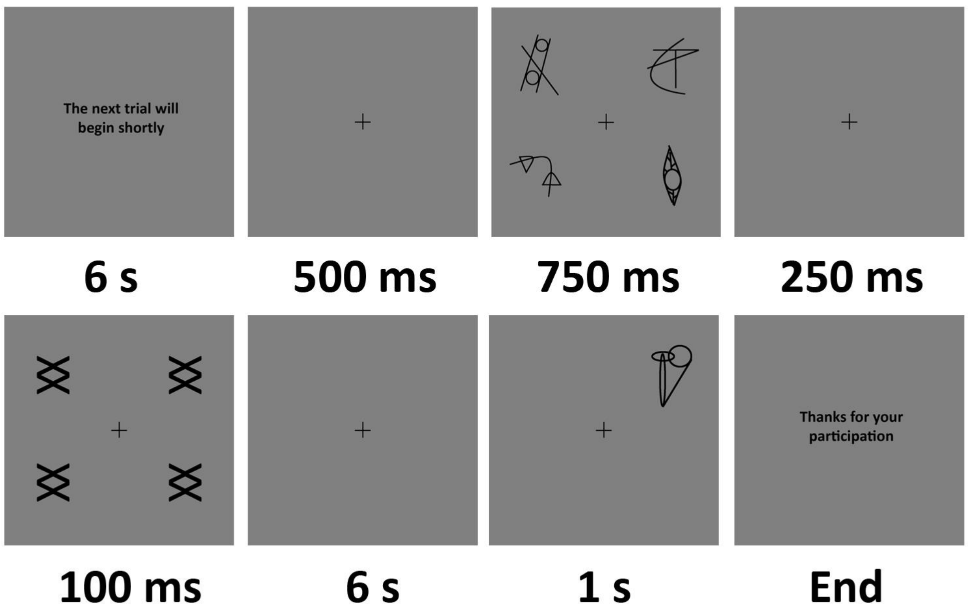
The control group and experimental group were first asked to participate in a game of Concentration, the memory task. The rules of Concentration are most accurately explained by Eskritt and Lee (2002) in their study as follows:

> In Concentration, cards are placed face down in an array randomly. A player turns over any card and then turns over a second card to look for the first card's match. If the cards match, the player removes these cards from the array and then repeats the procedure. If the cards do not match, they are turned back over and the turn ends (p. 255).

The study slightly altered these rules by removing the final element of ending one's turn as participants played with themselves. Each participant was made aware that their completion of the memory task was not timed nor recorded for results. These measures were taken to ensure that no gamification or competition could positively skew the visual working memory results produced as both gamification and competition have proven to increase memory performance (DiMenichi & Tricomi, 2015; Ninaus et al., 2015). This further ensured that participants would not over-perform on the memory task due to confounding effects. The control group played with regular playing cards while the experimental group played with cards made with the created characters. For the control group, 40 cards were randomly removed from one deck and the same 40 cards were then removed from the second deck to create 40 pairs of matching cards. The joker cards were removed prior to the draw. The experimental group played Concentration using the character cards instead. Immediately following the memory task, a laptop was set on the table in front of the participants. The participants were then informed of how the test task would proceed and given warning that the images would appear and disappear quickly. An example of one interaction of the test task was given to the participants that contained simple shapes in place of the characters. This measure was taken to ensure that participants did not spend time processing the speed at which the test task was presented. Participants would thus be more focused on completing the task and less time would be taken to grow accustomed to the procedure. After this, the test task was presented.

Figure 1

The Test Task



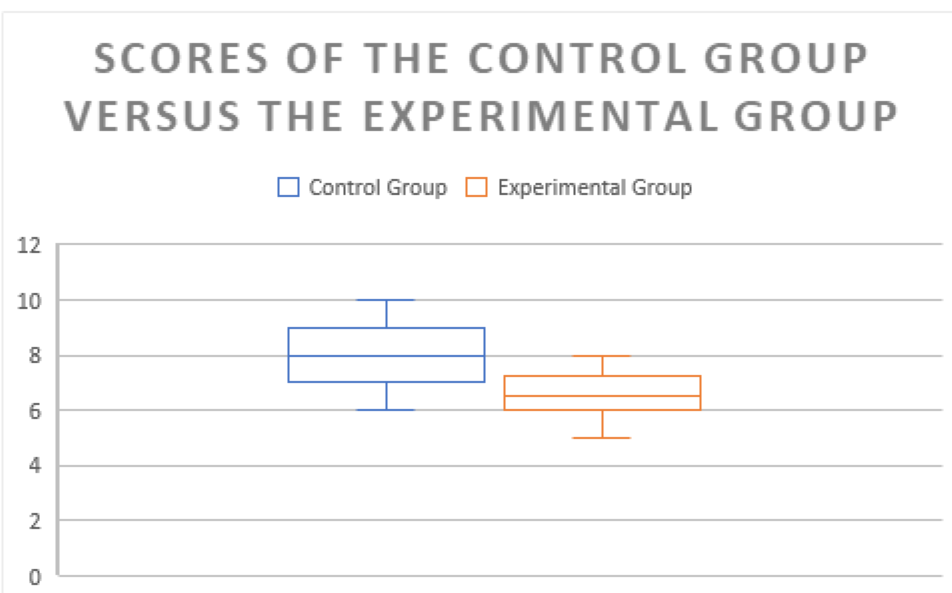
Note. From left to right, this figure shows an example of one iteration of the memory task presented. The "End" slide was not shown until 10 iterations had passed and the experiment had concluded.

Unlike the study conducted by Ricker, Spiegel, and Cowan, both the inter-trial interval and retention intervals were held at 6 seconds as the purpose of this study was not to determine the impact of temporal distinctiveness versus decay. Each participant was given a paper and a pen to record their answers. The test task consisted of an inter-trial interval, a fixation period, a memory array, a delay, a mask, a retention interval, and a test as shown in Figure 1. Each memory array contained 4 characters, one in each quadrant of the 1080 by 1080-pixel display. Trials commenced with a 6s inter-trial interval followed by a 500 ms fixation period, 750 ms memory array, 250 ms delay, 100 ms mask, 6s retention interval, and a 1s test. Each character from the memory array was replaced in the mask in the same position by the symbol shown in Figure 1 to avoid participants' use of sensory memory (Ricker, Spiegel, & Cowan, 2014). Each test showed a character in one quadrant. Half of the time the character was different from the original character in the quadrant and participants were asked to write a check if they thought the test character was the same as the original and a cross if they thought the test character was different from the original. Test characters different from the original were randomly chosen from the 40 characters created. The process shown in Figure 1 was repeated 10 times in succession for each participant with different sets of characters.

Data Analysis

Figure 2

Box-plot of Score Distributions



For this study, one-variable statistics were used to determine a sample mean and sample standard deviation, as well as a two-sample one-sided t-test for means with 0.05 significance to produce a P-value. The P-value statistic "quantifies the probability of obtaining data equal to or more extreme than the ones observed, given the assumption that the null hypothesis is true" (Lytsy, 2018, p. 1). To ensure that a two-sample one-sided t-test for means was appropriate the following conditions were checked: a simple random sample was taken, both samples were independent of each other, each population is 20 times the sample size—there are over 200 seniors at the selected high school, and the distributions were normal ("Hypothesis", n.d.) as shown in the box plots in Figure 2. With μ_1 and μ_2 representing the means of the control and the test group respectively, the null hypothesis (H_0) of μ_1=μ_2 was used with the alternative hypothesis (H_a) of μ_1<μ_2 with 17.2309 degrees of freedom.

Results

Table 1

One-Variable Statistics.

	Mean	sx	n
Control Group	7.9	1.19722	10
Experimental Group	6.6	0.966092	10

With respect to the 0.05 significance level, this study failed to reject the H_0. It was apparent there was no statistically significant evidence to suggest that the mean number of correct recall was higher in the experimental group than the control group through the resulting P-value of 0.992026, calculated with regards to Table 1.

Limitations

Prior to discussion, it must be acknowledged that the data presented in this study was susceptible to possible limitations, most notably, its small sample size. The lack of a sizable sample size resulted in a low significance of findings as well as a higher chance to mistake the magnitude of impact. A larger sample size would produce results with higher statistical power as well as reduce the chance for statistical error. The small sample used was prone to pre-existing differences in individual memory ability in the participants. With a larger sample, this difference would be more negligible as the influence of outliers decreases with sample size. Additionally, it proved difficult to convince randomly sampled high school seniors to commit their time to contribute to a study without incentive; it was disclosed to each randomly selected individual that the study would take around half an hour to complete. Although this reduced participation bias—participants did not skew results due to incentivization—the lack of an incentive could also mean that participants were less engaged in performing tasks adequately. Inadequate performance includes behavior such as participating in the study without focusing on completing the task, rather focusing on how the task is presented and making random guesses to exert less effort during the test task. The study was further limited by the inability to run multiple trials at once since it was necessary to ensure that participants completed the tasks correctly. The researcher could only be in a room with one participant at a time to reduce any possibility of competition between two participants participating in two separate memory tasks. The ability to run multiple trials at once would allow for a higher sample size as less time would have to be spent to acquire data.

Errors may also be found in the initial creation of the special characters. The characters may have been too similar to one another, two characters may be hard to differentiate from one another as their structures are too similar. It is equally possible that some characters resembled distinct objects or symbols from participants' obscure personal experiences, thus making the characters more familiar. Both of these limitations would have resulted in higher scores on the memory task, positively skewing results.

Moreover, participants may have been subject to proactive interference as all characters, even the ones that appeared in iterations where the correct answer was a cross, were shown to participants during the memory task. Although this allowed for a complete and authentic prior experience with the characters, it means that this study risked the possibility that participants with slower reflexes may record answers that were false negatives. This study was unable to examine the reflexes of each participant as the study it was modeled off of had done (Ricker, Spiegel, & Cowan, 2014) meaning that participants with slower reflexes may have recorded a check when the correct answer was a cross. This would have been caused by said participants recognizing that they saw the character in the memory task, but mistaking this memory for having seen the character in the same position in the memory array of the current iteration. In this way, prior learning of the characters actually impeded participant memory accuracy.

Discussion

From the experiment conducted in this study, it can be concluded through inferential statistics that the working memory of high school seniors does not benefit from prior experience in closer proximity to memory retrieval. This study took several precautions to eliminate confounding variables and was able to limitedly prove, using a small sample size, that the hypothesis was incorrect. This means that close proximity prior experience hinders memory performance, most likely as a result of proactive interference or the lack of reflex speed examination in the design of this study.

Thus, the future of research on prior experience in relation to memory sees several implications as a result of this study. Primarily, there appears to be an inverse relationship between the proximity of experience and accuracy of memory retrieval. Prior studies conducted showed improved recollection as a result of prior experience spanning longer periods of time whereas this study, when simulating prior experience in closer proximity, showed that prior experience actually detriments recollection. The reduced accuracy of the experimental group also suggests the existence of interference as a factor limiting memory retrieval. The control group stimulus was less likely to interfere with the test task as the special characters bear no similarity to numbers or card suits.

Future studies focusing on the role prior experience plays in relation to decay should do several things to remedy the shortcomings of this study. A larger sample is necessary to ensure that results are more accurate and reflex examination is necessary to ensure that all results only take into account the participants whose reactions were within an acceptable threshold as slow-reacting participants may end up guessing using a study design such as the one used in this study. Further research on this subject area may also seek to explain why some individuals are unable to differentiate between experiences in close proximity to one another such as the memory task and test task. The answer may not solely be reflex and reaction speed as there may be a phenomenon similar to that of memory distrust syndrome. Additionally, future studies may wish to study the validity of this study's results by replicating this study and using other experimental designs to answer the question posed by this study.

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