

Increasing Verbal Working Memory in Young-Old Adults  
by a Subtract-2 Span Task on Mobile Application

by

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## Abstract

Working memory is the ability to retain and manipulate information for several seconds up to a minute while maintaining other information. Verbal working memory is the verbal component of this ability and declines with age. This research was conducted to determine if training with the Reverse Digit Span task and Order Span Task could reverse this trend. Participants ranging from 65 to 75 years old were tested with the Reverse Digit Span task, Order Digit Span task, and Operation Span task before being split into two groups. The experimental group trained on the website five times a week for three weeks. Afterward, all participants were tested again to see if there was a significant improvement. The results were statistically insignificant, showing that this training method does not increase older adults' working memory in three weeks.

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# Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task on Mobile Application: Introduction 1

## Chapter 1: Introduction

Verbal working memory declines with age, but people between the ages of 65 and 75 could reverse this with the autonomous, weekly use of a mobile application digit span tasks. In a digit span task participants are given a series of numbers and asked to remember and recall them in a specified sequence, such as in their original order or in the reverse order that they were provided. This paper provides research to support digit span task brain training for older adults with the goal of positively affecting their working memory.

Working memory is the ability to retain and manipulate information for several seconds up to a minute while maintaining other information (Eriksson et al., 2015). This ability uses the prefrontal cortex, parietal cortex, and basal ganglia to form future goal-oriented behavior as well as hold attention (Eriksson et al., 2015; Zinke et al., 2013). It is suggested that the working memory of the average young adult is capable of holding three to four items meaning that older generations typically have reduced capacity due to the linear decline that occurs between the ages of 55- 60 and 75-80. This decline is believed to be the result of neurochemical, structural, and functional brain changes (Eriksson et al., 2015; Nyberg et al., 2012; Zinke et al., 2013). This age-related memory decline is important as working memory is a strong predictor of high order cognition such as fluid intelligence, abstract reasoning, and language abilities (Borella et al., 2017; Eriksson et al., 2015; Matysiak et al., 2019; Payne & Stine-Morrow, 2017). The ability to communicate, manage their finances, and medication and maintain social connections are necessary for older adults to remain independent. These activities require higher- level brain function and a solution to combat this natural decline is brain training. The availability of smart devices makes weekly training with an app an inexpensive, accessible and promising option to halt or reverse this cognitive decline, while supporting high-order cognitions will keep this population in a better mental condition and allow them to maintain a satisfying quality of life.

## Chapter 2: Older Adults and Their Characteristics

### **Defining Older Adults**

There are over 31 million people between the ages of 65 and 74 living in the United States (United States Census Bureau, 2020). This population is predicted to almost double by 2060 with people 65 and over becoming 23% of the U.S (Vespa et al., 2020). Currently, the majority of this population lives with their family, while roughly 22% live independently (Roberts et al., 2018). This is an educated populace with 61.5% of males and 55.2% of females having attended some college or achieved a degree, but still more than half of people over the age of 60 have low literacy, therefore simple natural language must be used to increase understanding when training or communicating (Czaja et al., 2019). These older adults have adopted technology as well, with one in three owning a tablet and two in five owning a smartphone (Anderson & Perrin, 2017). Their average leisure screen time is roughly 4 hours a day (Livingston, 2019). That said, older adults experience higher levels of computer anxiety and lower self-confidence levels, preventing them from trying new pieces of technology (Czaja et al., 2019; Dickinson et al., 2005; Gamberini et al., 2006). On top of that, they experience more frustration and anxiety when encountering challenges with mobile devices (Nurgalieva et al., 2019). As a result, designing technology specifically for this population will be needed for them to buy-in. Additionally, older adults state they do not learn new technology due to a lack of interest or skill, or if they perceive the technology as being too difficult to learn. Consequently, the digit span application is also more likely to be used by this population if they perceive it as useful to accomplish their desired tasks.

The remainder of this chapter will explore and explain the sensory abilities of older adult users, including their hearing, eyesight, and motor control, followed by an in-depth examination of this population's mental capabilities and limitations. Chapter 2 will also examine the attention and memory of older adult users, including their tendency towards positivity bias and why they avoid negative stimuli.



## **Senses and Mental Capabilities**

### **Hearing**

Hearing is a sense that dulls for the majority of people in their older years. By the age of 65, over half of men and 30% of women have experienced some hearing loss (Czaja et al., 2019). This means spoken conversational language has to be over 70 decibels. For comparison, that is as loud as a vacuum cleaner (Purdue University, 2003). In addition, as mentioned previously, many older people live in communal or family housing increasing the occurrence of background noise. Combine typical hearing loss with uncontrolled background noise and the use of sound or spoken word for training this population is difficult. Not to mention other household residents may discourage use of the device if the volume must be played at a vacuum cleaner level. That said, auditory information during app use can be a positive as it can help users retrieve semantic memories required for a task (Lu et al., 2017). Ultimately, sound may well provide useful feedback and secondary information to the user but it is best kept in a supporting role.

### **Eyesight**

Vision is another sense that begins to fade as people get older, but not quite to the extent of hearing loss. It goes beyond small font as bad eyesight makes it hard to understand text and pictures, thus severely affecting the comprehension and interaction of the interface (Dodd et al., 2017). Czaja et al. (2019) state that roughly 10% of people between the ages of 65 to 74 have vision impairment. Also, four out of five people get presbyopia, farsightedness caused by stiffening of the eye lens, by the time they are 55 years old (Farage et al., 2012; Zebardast et al., 2017). It is estimated that 16% of older adults in the U.S. are without adequate correction, over 5 million people in the U.S. alone. This means fonts should appear at 16 point or larger and bigger icons are necessary for the user to see and interpret them with ease (Aguirre & Abadia, 2017; Czaja et al., 2019; Dickinson et al., 2005). Participants in Lu et al.'s study stated they preferred even larger text with a font size of 26 points or bigger. It should be noted that their application was written in Chinese and was on an iPad hence had a more space for larger text (2017).

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The size discrepancy could be solved by adapting font sizes as recommended by Gamerbini et al. (2006) and Petrovčič et al. (2018). Other text elements to consider are fonts and weight. Aguiree and Abadia (2017) reviewed eight designer guidelines for older adults, all eight saying that sans serif is the recommended font agreeing with Farage et al. (2012) previous statement that decorative font should be avoided. Furthermore, the guidelines that Aguiree and Abadia review suggested using bold font for titles to catch the users' attention and make it easier to read. Nurgalieva et al. (2019) saw that 126 of the 434 reviewed guidelines concurred with Farage et al.'s (2012) recommendation of using capital letters for the same reasons.

In general, an increase in age leads to vision difficulty transitioning between dark and bright pages, a reduced functional field of view, and slower processing of information displayed on the screen (Czaja et al., 2019; Farage et al., 2012). This means it is best to keep the pages repetitive to put less strain on the eye and decrease the amount of information that has to be processed. This is critical as it takes almost a second for older adults to reorient their attention. Similarly, the reduced field of vision means that objects will have to be near the user's point of focus, otherwise the user will have to be specifically provided a cue near this focus point that informs them to look elsewhere. This design point will be crucial when developing for larger tablet screens versus a smaller screened smartphone. Finally, for objects like buttons, it is recommended they have a "raised" appearance with immediate feedback such as a color change to accommodate for the decreased visual sensitivity (Lu et al., 2017; Petrovčič et al., 2018). Overall, to use an application comfortably, this population needs large visuals with obvious, high-contrast markers guiding their eyes.

### **Motor Control**

Motor control is another element that starts to change as people grow older. Their movements and even initiation for said movements slows down in older adults (Czaja et al., 2019; Frolov et al., 2020). This decay in motor control also leads to less precise movements, decreased sensitivity to haptic cues, and less endurance. Based on their

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study, Lu et al. recommends extending the touch range of buttons 20 mm outside of the icon and limiting unnecessary movements when possible (2017). Interestingly, even with reduced sensitivity, the team still recommends incorporating haptic cues when designing for this population as using multiple senses helps older adults better navigate within games and apps (Gamberini et al., 2006). It is best to avoid using complicated hand gestures in said games and apps due to motor control decay and arthritis in their hands which leads to stiff movements and decreased range of motions (Mayo Clinic Staff, 2019).

### **Mental Capabilities**

Mental processes slow down and change in older adults presenting a unique challenge as the reduced capacity of working memory and attention makes it difficult to remember the steps taken to complete a task (Dodd et al., 2017; Gamberini et al., 2006). Attention can be divided into two categories: selective and divided. Dodd et al. defined selective attention as the piece that filters stimuli present in the user's environment (2017). The reduction of this attention type from aging can be minimized by increasing familiarity with the object or environment (Gamberini et al., 2006). Divided attention is used to manage multiple tasks or process several information sources at once (Dodd et al., 2017). This deficit of divided attention comes from the increasing complexity of the stimulus, but it can be minimized by having the older adult practice the task more frequently (Gamberini et al., 2006). These reductions in attention are likely a reason why older users have trouble picking up new tasks as they often result in task failure and thus frustration. If the older user can stick with the new task, their difficulty will decrease as practice and familiarity will minimize their attention deficit, resulting in an increased success rate.

Even with practice, it is best to use the same mental model as previous tasks the user has interacted with. Overlearning is defined as "the immediate continuation of practice beyond the criterion of one perfect instance" (Rohrer et al., 2005). This mental familiarity results in information that users pull with minimal effort, such as the order of

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the months or what happens when you turn a steering wheel. This overlearned information in older adults is a critical point to account for when designing for this audience. Procedural memory, when integrated correctly into an app design, can increase intuitiveness. This is especially true for older people as they take 1.5 to 2 times longer than young adults to complete an unfamiliar task (Czaja et al., 2019). More importantly, by relying on overlearned material, the designer can bypass the older user learning a new automatic process thus creating a more intuitive and enjoyable user experience. Apps should be familiar and reflect the user's life in its structure and interaction (Lu et al., 2017).

Another mental model that needs to be taken into account and designed for with this age group is their positivity bias. The effect of their positivity bias is twofold, with an attentional bias towards positive stimuli and an attentional avoidance of negative stimuli (Gronchi et al., 2018). The attentional bias to positive stimuli is an automatic process meaning the users are not aware they are seeking it. Handling this bias correctly during the development process will result in an app that older adult users are happier to interact with and encourage them to return to the app of their own volition. On the other hand, attentional avoidance of negative stimuli is a controlled mechanism; hence, the user will recognize their desire to avoid repeating the situation or experience. This likely explains the results of a 2004 study that saw older adults do better on a working memory task when positive emotional stimuli were used (Mikels et al., 2005). Knowing that the older adult user is aware and consciously choosing to avoid negative stimuli is valuable information during app development and as a result, negative app stimuli should largely be avoided.

With that said, one negative stimulus that is impossible to avoid is user error. An app can be carefully designed to reduce errors, such as minimizing necessary steps and scrolling, as well as providing environmental support (Czaja et al., 2019). Likewise, best practice design helps preclude errors by avoiding complex gestures such as pinching and multi-finger swiping. Furthermore, designers can pace the learning, encourage task

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practice, and provide immediate feedback to prevent operation errors on application tasks (Lu et al., 2017). However, despite these thoughtful design efforts errors will still occur, and it is best to allow the user to backtrack from their slip up with an “undo” option or conduct an error check before allowing them to continue. For a training application frequent initial user errors are to be expected and present a complex design challenge. The “undo” function or error check must be thoughtfully designed in order to encourage the user to return to the application and persevere with their training.

### Chapter 3: Working Memory

#### **Defining Working Memory**

The definition of working memory has changed over time as many researchers have adapted it to fit their agenda. An earlier definition was written by A. Newell and H. Simon in 1956 stating working memory is “a holding place for information to be held temporarily, with the possibility of many working memories being held concurrently” (Cowan, 2017). However, the most commonly used definition and the one used in this paper is generic working memory. This definition states that working memory is the ability to retain and manipulate information simultaneously (Cowan, 2017; Gazzaniga et al., 2013; Hynes et al., 2014; Lundqvist et al., 2010; Sommerfield et al., 2003; Westerberg et al., 2007).

Working memory can last from seconds to minutes, has a limited capacity of three to five items, and is lost primarily by decay (Cowan, 2001; Gazzaniga et al., 2013). The information it holds originates from sensory input or is retrieved from long term memory storage. Currently, it is believed that working memory uses an acoustic code rather than a semantic code meaning words that sound similar will interfere with each other, but not words with related meaning (Gazzaniga et al., 2013). This implies that when investigating working memory in older adults, it is best to use numbers or select words that sound dissimilar to avoid an unintentional increase in erroneous recall.

The ability to hold information in working memory is required for goal directed behavior as it selects task relevant information and is closely linked to fluid intelligence (Gazzaniga et al., 2013; Johansson and Tornmalm, 2012). Fluid intelligence is the ability to engage in creative abstract thinking, recognize patterns, and problem solve. One study suggests that working memory is a component of fluid intelligence, meaning increasing working memory may increase fluid intelligence. This is supported by several studies seeing increases in fluid intelligence after working memory training (Au et al., 2015; Jaeggi et al., 2008). Jaeggi et al. used the N-back task in their working memory training

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with 70 young adults. In N-back tasks, participants are presented with visual sequences such as letters and pictures. The participants are then asked yes or no questions about the previous visuals such as whether a specific letter or picture matches the letter or picture from  $n$  items ago (Coulacoglou and Saklofske, 2017). In Jaeggi et al., study participants were shown a picture of a cube with a spoken consonant for them to recall later. These participants were divided into four groups to complete eight to nineteen training sessions to see if fluid intelligence improved and when. All four groups showed improvement in fluid intelligence and the level of improvement was dependent on the number of training sessions. This finding was further supported by Au et al.'s meta-analysis on twenty studies focusing on the N-back task with participants ranging from 18 to 50 years of age. However, in a 2016 working memory study by Melby-Lervåg et al. (2016) no increase in fluid intelligence was found, so further research is needed.

Working memory involves several regions of the brain including, but not limited to the frontal cortex, lateral prefrontal cortex, parietal cortex, inferior parietal lobule, and intraparietal lobule (Akerlund et al., 2013; Takeuchi et al., 2010). This variety of brain activation allows working memory to be broken down into different components, typically called visuospatial and verbal. From previous studies of patients with lesions we can infer that the left supramarginal gyrus takes part in auditory-verbal working memory while the right parieto-occipital region helps complete non-verbal visuospatial working memory tasks (Gazzaniga et al., 2013).

Impaired working memory capacity is associated with neurological psychiatric disorders and normal aging (Takeuchi et al., 2010). These deficits lead to impaired attention, planning, organization, problem solving, and execution of actions (Akerlund et al., 2013; Gazzaniga et al., 2013). Thus, the result of normal aging is working memory deficits and memory disturbances that make it harder for people to recall and execute the sequencing necessary to complete daily tasks. That is, they forget what they were doing and what to do next.

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### **Training Working Memory**

Many studies have been conducted to see if training via N-back tasks or complex span tasks can improve working memory though the skill increase remains elusive (Blasiman & Was, 2018). Melby-Lervåg et al. reviewed 87 studies that used complex span tasks or N-Back tasks to train working memory and saw only short-term improvements in verbal and visuospatial working memory tasks. They did not see any far transfer effects or “convincing” improvements in real-world cognitive skills such as fluid intelligence. While the lack of far transfer has been noted multiple times, the same studies show benefits for small transfer effects such as increased attention (Borella et al., 2017; Matysiak et al., 2019; Teixeira-Santos et al., 2019). It only took three training sessions for participants to show verbal working memory improvement in the Borella et al.’s study (2017). Additionally, several studies focusing on verbal working memory show participants maintaining some benefit even after training has ended (Teixeira-Santos et al., 2019; Zinke et al., 2014).

Previous research shows that training on working memory tasks can improve trained and untrained tasks resulting in changes in brain activity (Takeuchi et al., 2010; Westerberg et al., 2007). Working memory training has been shown to increase the structural integrity of white matter in the parietal regions, regions adjacent to the body of the corpus callosum (Takeuchi et al., 2010). Brain activity and biochemistry in the frontal and parietal cortices are altered during untrained cognitive tasks after working memory training (Akerlund et al., 2013; Lundqvist et al., 2010; Takeuchi et al., 2010). Some studies have shown mixed results such as Hynes et al. (2014). This research was focused on training one participant who suffered brain damage after a stroke. The researchers stated they did not see cognitive gains but did see an improvement in time perception, which could be a sign of improved working memory. Conversely, the lack of improvement may have resulted from the researcher using only far transfer tasks rather than near or close transfer tasks. Far transfer tasks are improvements on tasks that measure abilities dissimilar or “far” from the trained ability (Teixeira-Santos et al., 2019)



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as opposed to “near” or close transfer tasks that are activities more similar to the training task.

Working memory training results might be inconsistent due in part to how easily influenced it is by several factors, including a user’s daily cup of coffee. Blasiman and Was reviewed 21 factors to examine their impact on working memory with only 11 of the 21 factors remaining consistent (2018). These 11 factors are intelligence, age, mental conditions, emotion, stress/anxiety, dieting, stereotype threat, bilingualism, drug use, and brain stimulation. Intelligence had a low impact on working memory and they did tend to go hand-in-hand but did not have an isomorphic relationship. Emotion was defined as having a medium impact on working memory, meaning even a user’s daily ups and downs could result in different test results. The study noted that all forms of anxiety such as math anxiety and lack of sleep have a negative effect on working memory, with lack of sleep having the highest impact. This means the users may would need encouragement to continue using the app on their own as they could do worse on some training days if they are in a state of stress or experiencing other negative emotions.

In 2014, Zinke et al. showed people between the ages of 65 and 95 could improve their verbal working memory using the subtract-2-span task. Eighty participants tested for noncorrected visual or auditory impairments and neurological or psychiatric disorders were divided into the control group and the training group. Each group completed pre-training and post-training assessments for comparison. The training task subtract-2-span task would be completed in 9 sessions over three weeks. In this task, an experimenter would read a random number sequence to the participant. The participant would subtract two from each number and read it back in sequential order. As each participant stated the correct number set another number would be added. If the participant were incorrect then the process would start over. This experiment’s results stood out as not only did participants see improvement, but the transfer of the skills developed in these sessions showed even after nine months. These gains were affected by baseline performance and

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age as shown in other studies (Borella et al., 2017; Teixeira-Santos et al., 2019).

Moreover, participants that started with a higher baseline showed the most improvement.

Payne and Stine-Morrow (2017) saw similar results when examining the effects of at-home computer-based training on verbal working memory. Forty-one people over age 65 completed one of two training programs by carrying out 15 training sessions over three weeks. These 30-minute sessions were completed on a program called iTrain that is designed for the iPad. The program involved three tasks designed to exercise verbal working memory: Category Span, Lexical Decision Span, and Sentence Span. In the Category Span task, participants are given a category and a list of words to judge if the word fits the category. For example, if they were given the category “weather,” then they would say no for “chocolate” but yes to “humidity.” For Lexical Decision Span, participants judge if a string of letters displayed for four seconds forms a word. In the final task, Sentence Span, participants judge the semantic prose of a sentence, such as “As the ship gets better, your child needs to develop this oven” and respond with a yes or no answer as to whether the sentence is complete and makes sense. This experiment showed promising results as the researchers saw improvements in untrained verbal memory measures. The experiment did not do a maintenance test but did show that the training worked to some extent for the short term.

Cogmed QM is another computer-based memory training program, developed at the Karolinska Institute and Cogmed Cognitive Medical System AB in Sweden (Lundqvist et al., 2010). This software program was created to train working memory using verbal and visuo-spatial working memory tasks (Johansson and Tornmalm, 2012; Lundqvist et al., 2010). Cogmed QM has been used in multiple experiments such as Akerlund et al. (2013) who used the software to train adult participants for five weeks resulting in improved working memory and higher cerebral function. Other experiments to see success using this software include Westerberg et al. (2007) and Johansson and Tornmalm (2012). It is a unique system as it is one of the few trainings to demonstrate far transfer impacts that affect participants everyday life (Weicker et al., 2016).

## Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task 13 on Mobile Application: Working Memory

### **Working Memory and Health**

#### **Hypertension**

Hypertension is commonly found in this older adult user base as 70% of older adults have hypertension and it often goes undiagnosed and untreated (Agarwala et al., 2020). This condition correlates with lower cognitive function, including memory and executive functions, and faster cognitive decline in old age (Gąsecki et al., 2003; Ihle et al., 2017; Saxby et al., 2003). The connection of hypertension to working memory is murky as studies such as Ihle et al. (2017) and Saxby et al. (2003) saw a decline, while Raz et al. (2004) did not see any difference between those with hypertension and those without in working memory span tasks. Other studies only see a relationship when subjects are over 70, indicating that it might be the length of the condition that correlates with decreased working memory (Fogari et al., 2003). This theory is supported by chronic elevation in blood pressure increases the likelihood of structural brain abnormalities (Raz et al., 2004).

Ihle et al. (2017) showed that the effects of hypertension on working memory in older adults could be nullified by them engaging in leisure activities that require greater cognitive function. These activities include but are not limited to, reading, playing card games or Scrabble, as well as doing crossword puzzles or sudoku. Participants had to complete such activities at least 35 minutes a day to nullify hypertension's effects on working memory.

The inconsistent connection of working memory and hypertension could be the result of hypertension treatment. This is due to a lack of consensus on the impact of antihypertensive drugs on cognitive performance, as some studies showed results being better while others saw no difference or a decrease (Fogari et al., 2003). It appears to be drug-dependent as centrally acting sympathetic nervous system blocking agents such as methyl dopa and Lipophilic beta-blockers as propranolol have a negative impact on cognitive performance (Fogari et al., 2003). Central acting agents make up 1.4% of hypertension treatment in the U.S. while Beta-blockers make up 19%. This medication

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has mixed results as atenolol is also a beta-blocker and did not significantly impact cognitive performance (Shah & Stafford, 2017). Finally, Losartan improves memory function, an angiotensin receptor blocker that makes up 22% of hypertension treatment.

### **Diabetes**

Diabetes refers to a group of diseases that affects how your body handles blood sugar or glucose. These diseases all lead to excess glucose in the patient's blood, but the cause varies upon the type. Patients are typically born with type 1 diabetes as their immune system attacks insulin producing cells leaving sugar to be built up in the bloodstream rather than transported to the cells. Type 2 diabetes occurs when a patient's body becomes resistant to insulin and cannot produce enough insulin to overcome said resistance (Mayo Clinic Staff, 2020). It is estimated that 12.7% to 15.9% of adults over 65 have diabetes, while another 42.3% to 51.0% are estimated to be prediabetic (Centers for Disease Control and Prevention, 2020). Patients are diagnosed with prediabetes when they have a higher than normal blood sugar level, yet it is not high enough to be considered type 2 diabetes.

Diabetes appears not to affect working memory if it is diagnosed early and treated. For example, Arvanitakis et al.'s (2006) study on older adults saw those with diabetes experienced a decrease in semantic or long-term memory and perceptual speed but not working memory. Sadanand et al. found the same conclusion after reviewing fifteen studies on older adults with type 2 diabetes. However, there are studies such as Ennis et al. (2020) who found a decrease in working memory. A possible explanation for the different conclusions is the blood sugar levels of the participants. Working memory was significantly altered in young adults with type 1 diabetes while hypoglycemic (Sommerfield et al., 2003). This research is supported by Cerasuolo and Izzo's (2017) study of hypoglycemia in zebrafish. They saw deficits in working memory after fourteen days of sustained hypoglycemia and the deficits continued even when the low glucose environment was corrected.

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Another explanation for the inconsistent relationship between working memory and diabetes is faster aging due to diabetes. Working memory has been proven to be age-related, and research such as Saczynski et al. (2009) and Arvanitakis et al. (2006) show that diabetes appears to age the brain as much as fourteen years. Older adults with type 2 diabetes have more brain atrophy, a lower percentage of gray matter and a high percentage of white matter lesions. The longer the duration of the disease, the lower percentage of brain volume and gray matter. Additionally, they are 1.5 times more likely to have a single cerebral infarct and almost 2.5 times more likely to have multiple infarcts.

### **Brain Damage**

Working memory deficits are common after brain injury, which can result from strokes to hits to the head (Akerlund et al., 2013; Hynes et al., 2014; Johansson and Tornmalm, 2012; Lundqvist et al., 2010). Such damage can impact daily life functioning as it degrades the ability to do multiple step tasks and results in increased forgetfulness and distractibility. (Westerberg et al., 2007). This not only results in loss of independence but also increased anxiety and feelings of inadequacy. Those with brain damage can decrease the noted consequences by completing working memory training. Johansson and Tornmalm (2012) saw significant improvement in working memory tasks after training participants with a recorded history of brain damage. They saw that those with lower baseline scores had the most improvement, which is a reversal of the neurotypical pattern of the highest baseline scores seeing the most improvement (Weicker et al.) Researchers saw improvement in participant's ability to manage daily activities after training as well. They did not see a correlation between training results, age, time post-injury, or diagnosis. Other studies to see success in working memory training after brain injury include Lundqvist et al. (2010) and Westerberg et al. (2007). Historically patients with brain injuries tend to benefit more from working memory training than healthy subjects (Weicker et al., 2016).

## Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task 16 on Mobile Application: Design Guidelines

### Chapter 4: Design Guidelines

#### Universal Design

Increasing web accessibility improves usability for older users, particularly those with slow connections or older technology (Aguirre & Abadia, 2017). Multiple guidelines have been developed since the creation of the internet, but few are known as well as Web Content Accessibility Guidelines (WCAG) which is based on Universal Design. The WCAG was developed by W3C, an international vendor neutral group that creates standards for the web, in 1999 and is now updated periodically (WebAIM Staff, 2020). The last update occurred in 2018 and is slated to be updated again in 2021. This protocol is made of four core components as shown in table 1.

Table 1

*The Core Components of Web Content Accessibility Guidelines*

Perceivable	Content is made available to the senses
Operable	Interface forms, controls, and navigation are operable
Understandable	Information and the operation of user interface must be understandable
Robust	Content must be robust enough that it can be interpreted by a wide variety of user agents, including assistive technologies

These components each have their own criteria that can be met with three levels of conformance: A, AA, AAA. Level A means the basic requirement for some users with disabilities to access the web content is met and is considered the bare minimum a website should achieve. Level AA indicates increased accessibility by removing significant barriers to accessing content. Finally, level AAA is the highest level a website can

## Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task 17 on Mobile Application: Design Guidelines

achieve and means the site has enhancements to improve web accessibility for some users with disabilities. Websites should be designed with AAA as the goal, but its criteria tend to need more complex coding resulting in AA being the common goal.

Gamberini et al. took usability a step further for their project Eldergames (2006.) The team completed research to create a game to increase older adults' cognitive, functional, and social skills by defining five characteristics important for their user's usability, as shown in table 2. Most characteristics can be seen as a more fleshed out version of WCAG's core component Understandable. Later, the team successfully created a prototype that improved users' divided attention, memory, reasoning, and selective attention (Gamberini et al., 2009). Gamberini et al. state, "the prototype proved to provide a pleasant social cognitive training because of its simplicity, usability of the interface ...."

Table 2

### *The Eldergame's Five Usability Characteristics*

Learnability	How difficult it is to learn to use a device, to understand and to integrate functioning instruction. Time needed to complete a task correctly and results obtained in a certain amount of time are possible measures of learnability.
Efficiency	The extent to which technological applications satisfy users needs, avoiding loss of time, frustration and dissatisfaction. It can be measured by an experienced user's performance on a specific task;

## Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task 18 on Mobile Application: Design Guidelines

Memorability	Elderly users' memorability of a device's functioning is very important in order to avoid frustration and loss of time. A simple measure of this characteristic can be obtained by considering the time needed to perform a previously experienced task;
Errors	How easily a product can induce errors for elderly users and how easily it recovers from them.
Satisfaction	Users' attitude and adoption of technological applications could be influenced by the pleasure derived from their usage.

### Designing the Prototype

The prototype memory training website will host two games based on working memory digit span tasks. These tasks were chosen for memory training as they present single digit numbers as the universally known factor and do not require participants to use their vocabulary or be familiar with the English language. This is important as English language skills vary widely in the U.S. older adult population with over 5.7 million older adults speaking another language at home increasing by 2.5 million from 2010 (United States Census Bureau, 2019). Based on this information using digits as the common factor will allow a broad range of users to access the app. The prototype app presents users with two digit-span tasks for memory training designated Reverse and Order. Both games begin by presenting users with three single-digit numbers. In the Reverse game, the participants begin with the three-digit sequence of single digit numbers, and their task is to enter the numbers in the reverse order that they appear (Figure 1). While in Order, participants will begin by typing the three one-digit numbers they see from the smallest value to the largest (Figure 2). If the user enters the numbers correctly, they are given a new sequence with one additional number. This additive



## Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task 19 on Mobile Application: Design Guidelines

number process continues until the user answers incorrectly and the training screen resets to the game start.

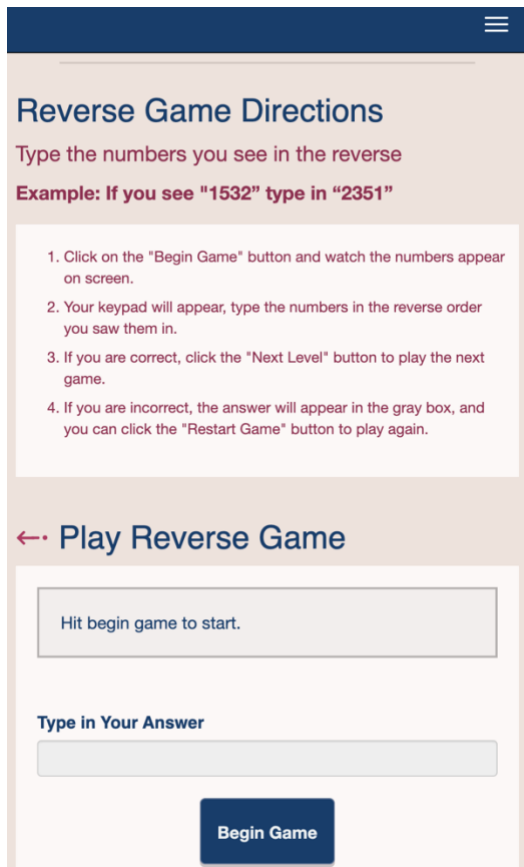


Figure 1. The Reverse Game Screen

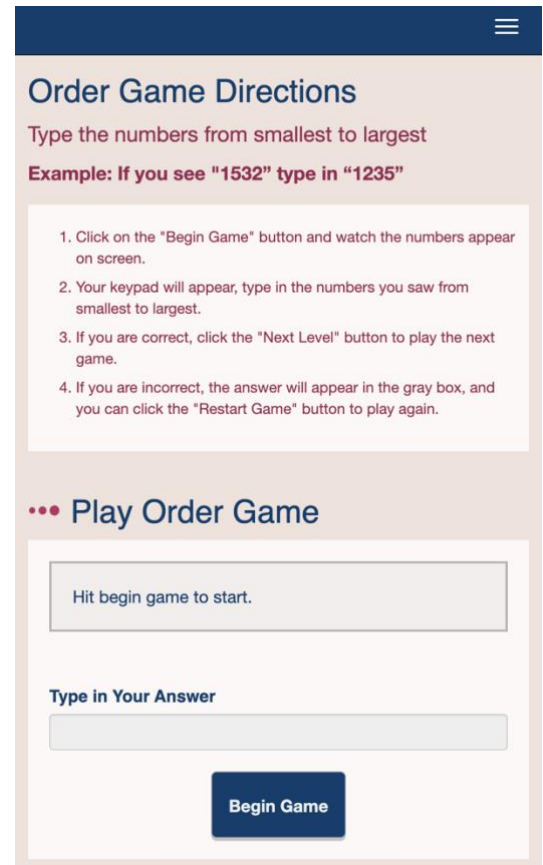


Figure 2. The Order Game Screen

The memory training design guidelines were generated by reviewing existing guides and advice found in studies, literature reviews, and established web design and web standards groups. These groups include the World Wide Web Consortium's WCAG and the National Library of Medicine (NNLM). Over 400 user guidelines were reviewed and summarized to determine best practices and use those as parameters for creating this application. The first rule of many layout guidelines is developing a clean and consistent design (Aguirre & Abadia, 2017; Dickinson et al., 2005; Gamberini et al., 2006). That

## Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task 20 on Mobile Application: Design Guidelines

includes minimal use of icons and graphic embellishments. This goes in hand with Díaz-Bossini & Moreno's (2014) recommendation to avoid irrelevant information that does not contribute to or clarify the message. Nurgalieva et al. (2019) and Díaz-Bossini & Moreno (2014) took it a step further saying the preliminary information should be centered on the screen. This guideline corresponds with Gamerbini et al.'s recommendation to minimize peripheral vision as all the information is in one area. Another near universal piece of advice recommends incorporating a high contrast background while avoiding a bright white background that can strain the user's eye (Aguirre & Abadia, 2017; Díaz-Bossini & Moreno, 2014; Dickinson et al., 2005; Gamberini et al., 2006; NNLM Middle Atlantic Region, 2017; Petrovčič et al., 2018). Additionally, Aguirre and Abadia (2017) and Díaz-Bossini & Moreno (2014) recommend minimizing the use of blues and greens as it becomes more difficult to differentiate various shades of these colors with age. If used correctly, colors can be used to categorize information visually, making it easier for users to read the screen (Aguirre & Abadia, 2017; Díaz-Bossini & Moreno, 2014; Nurgalieva et al., 2019).

Graphics are another essential element to consider when developing a site. Ideally, graphics should be simple, universal icons that convey a message rather than only be decorative (Petrovčič et al., 2018). Universally recognized icons and graphic elements can quickly direct users to the next steps, errors or other pertinent information. The useful effect of supporting graphics has been studied numerous times and shown they aid patients of all ages in understanding health related information such as about their medications (Houts et al., 2005; Katz et al., 2006). However, it is vital to support pictures with text and label them clearly with alt tags as this makes the image, and the information it conveys, accessible to everyone (Aguirre & Abadia, 2017).

The characteristics of the text on the screen are another critical element covered by the website standard guidelines. Many literature reviews report that users prefer larger text with NNLM, Dickinson et al. (2005), and Aguirre and Abadia (2017) asserting that the minimum website text size must be 14 points. Aguirre and Abadia make other key

## Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task 21 on Mobile Application: Design Guidelines

points about text and fonts in their web design literature review including that the text should be a sans-serif font like Arial and aligned left to make it easier to read. The two researchers also recommend a text line spacing of 1.5 for the same reason. Likewise, NNLM's guideline recommends using spacing between text to increase readability, such as breaking information into sections and using numbered instructions. When it comes to the written language of the text, it is best to keep it simple and minimize using technical terms (Díaz-Bossini & Moreno, 2014; Dickinson et al., 2005; NNLM Middle Atlantic Region, 2017; Petrovčič et al., 2018). Díaz-Bossini & Moreno's (2014) guideline states that using redundant language will decrease the workload of reading. The last rule comes from Nurgalieva et al.'s literature review (2019), which recommends using capital letters to highlight important text such as titles as it captures attention easily.

The fourth website and app element reviewed was how the user and device interacted with each other. For older adults, it is best to avoid double-clicking and complicated gestures such as dragging elements with a finger as there is a higher error rate with these actions (Díaz-Bossini & Moreno, 2014; Dodd et al., 2017). Multiple guidelines suggest minimizing scrolling or avoiding it altogether if possible, particularly side-scrolling, as this also results in a high error rate (Aguirre & Abadia, 2017; Díaz-Bossini & Moreno, 2014; Dickinson et al., 2005). Unique functions on the page, such as a built-in calculator should have a name that is easy to understand and recall (Petrovčič et al., 2018). According to Dickinson et al. (2005), there should be less than ten actions per screen, meaning functions should have limits on what they can do so the user is not overwhelmed. The directions for a function should be shown clearly and left on-screen to provide external cues for the user, thus reducing their workload (Gamberini et al., 2006). Nurgalieva et al. (2019) and Dodd et al. (2017) found that tasks should be in sequential order and the function should give a clear indication of progress to the user. This progress indication is also for giving users feedback and cementing their understanding of what went right or wrong during the interaction.

## Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task 22 on Mobile Application: Design Guidelines

Buttons are another common function on digital interfaces, and they have their own set of guidelines. Petrovčič et al. (2018) discovered that older adults prefer buttons with a raised appearance but require them to be visually distinguishable from each other to prevent errors. One way of doing this is to make the buttons larger with space in-between and use explicit text such as “Send Message” (Dickinson et al., 2005). Similarly, the button should give feedback when pressed, such as visually looking pushed in or providing a haptic cue.

The last element reviewed for this guide was navigation. Nurgalieva et al. (2019) saw that it was imperative that each screen have a “home” button and a visual indication of where the user is such as breadcrumbs. Menus can help users navigate the site, but it is best to keep it shallow. Older users encounter errors more frequently when interacting with nesting menus; as such it is best to leave them out of designs (Gamberini et al., 2006; Nurgalieva et al., 2019; Petrovčič et al., 2018). It is also recommended to avoid transparent menus as they are harder to read, particularly for older generations as their eyesight worsens and their ability to differentiate contrast and color contracts (Nurgalieva et al., 2019).

## Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task 23 on Mobile Application: Methodology

### Chapter 5: Methodology

The study was completed virtually using a between-groups designed experiment that included 18 participants ranging in age from 65 to 75. These participants were found via online postings on platforms such as Facebook and through personal and professional acquaintances. The participants were in a healthy or unhealthy state of aging as the only qualification necessary to participate was to have normal vision or corrected to normal vision. Due to the online nature of this experiment, the auditory component of most tasks was removed as audio quality would be highly varied amongst participants and their technology.

The participants met the researcher individually for an introductory 45-minute Zoom call where they answered a short survey asking for their age, level of education, and if they had ever been rendered unconscious from an injury or impact to the head. This was followed by three tasks to establish a baseline for their current working memory.

The first task was the reverse digit span task, where the researcher held up cards labeled with the numbers one through nine. The participants had to tell the researcher the numbers they saw in the opposite order that they were presented. The sequences started with two digits and increased by one number each time the participant answered correctly. The maximum number of digits for this study was eight. If the participant answered incorrectly, they were given another opportunity to complete the task by providing a new number sequence of the same length. If they answered this second number sequence incorrectly the trial would end.

Order digit span task was the second task. It was presented to the participant and performed in the same way as the reverse digit span task. That is, the researcher presented cards to the test subject displaying the numbers zero to nine, except this time participants were asked to relay the presented numbers back to the researcher in sequential order.

## Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task on Mobile Application: Methodology 24

The third and final exercise was Oswald et al.'s modified operation span task (2014) and it was completed using a web application designed by Luthra and Todd (2019). In this task, participants were presented with a simple math problem such as " $2 + 2 = 4$ " and were asked to judge if the arithmetic equation was true or false. After judging the equation, the participant was then given a letter set to recall. After being shown three to seven equations and letter set combinations the participant would be asked to recall the letter sets in the order the letters had been shown to them and type their response into a keypad. This operation span exercise included 17 trials and participants were scored by the number of letter sets that they correctly recalled.

From there, the participants were split into two groups, control and experimental. The experimental group was asked to complete ten-minute training sessions with the website five times a week for three weeks, while the control group waited during this time. After three weeks, all the control and experimental participants performed the reverse digit span task, the order digit span task, and the operation span task using the same parameters and methods as in the initial testing. The researcher recorded the results after the three-week testing time frame to compare and measure the degree of transfer.

## Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task on Mobile Application: Results 25

### Chapter 6: Results

The comparability of the training and control group was tested by completing t-tests on the performance of the baseline tasks. The results indicated no significant differences in the pretrained tasks (all  $P > .3$ ), suggesting that randomization had been successful. The first set of analyses were focused on the changes in the task, followed by a deeper look into possible correlations with the recorded variables.

#### Reverse Digit Span Task

In the Reverse Digit Span task, the control group's average increased by 1.5, while the experimental group average increased by 0.75 as shown in figure 3. The results were not statistically significant ( $P > 0.3$ ), meaning the training did not have an impact on the experimental groups' scores. Interestingly, participants who improved the most were those with the lowest scores initially, both overall and for the experimental group.

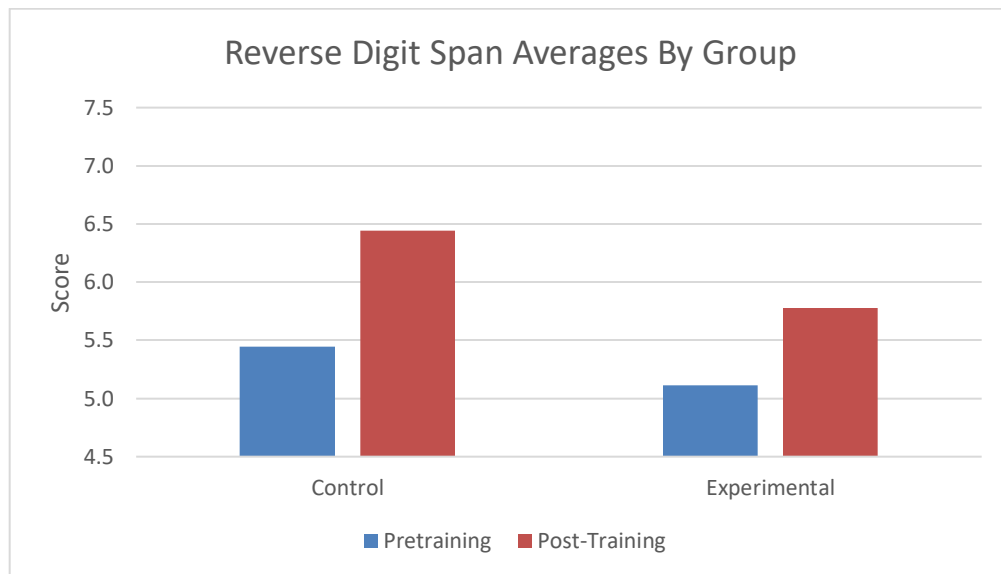
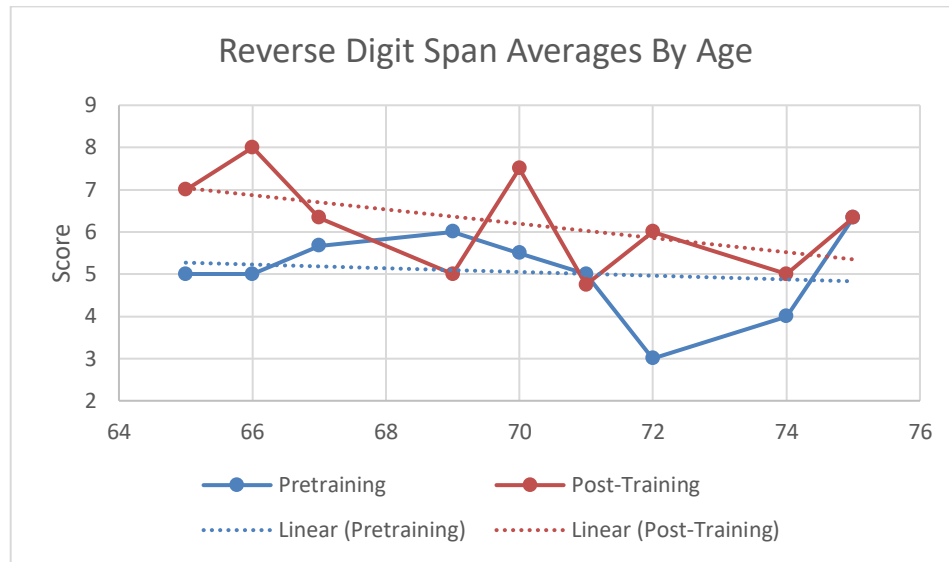


Figure 3. The average scores for the Reverse Digit Span task by group.

Reverse Digit Span task scores show a negative trend with age for pretraining and post-training, while scores increased with education post-training; the trend reversed in

## Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task 26 on Mobile Application: Results

post-training as shown in figure 5. In pretraining, those who report losing consciousness due to a head impact scored lower than those who did not experience this (Figure 6). The participants who reported the occurrence of a head impact saw the most improvement regardless of which group they were in.



*Figure 4.* The average scores for the Reverse Digit Span task by age.



Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task on Mobile Application: Results 27

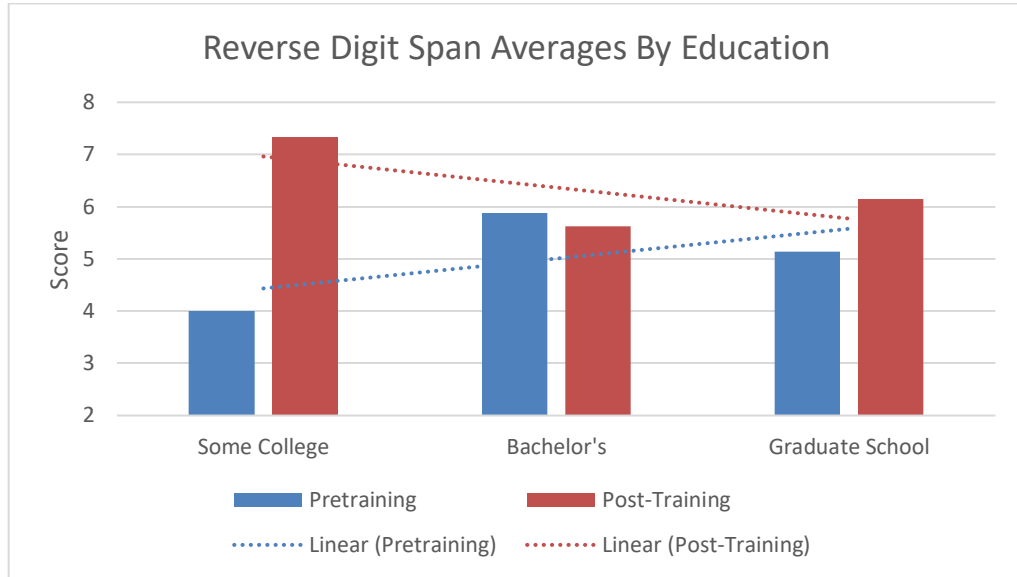


Figure 5. The average scores for the Reverse Digit Span task by education.

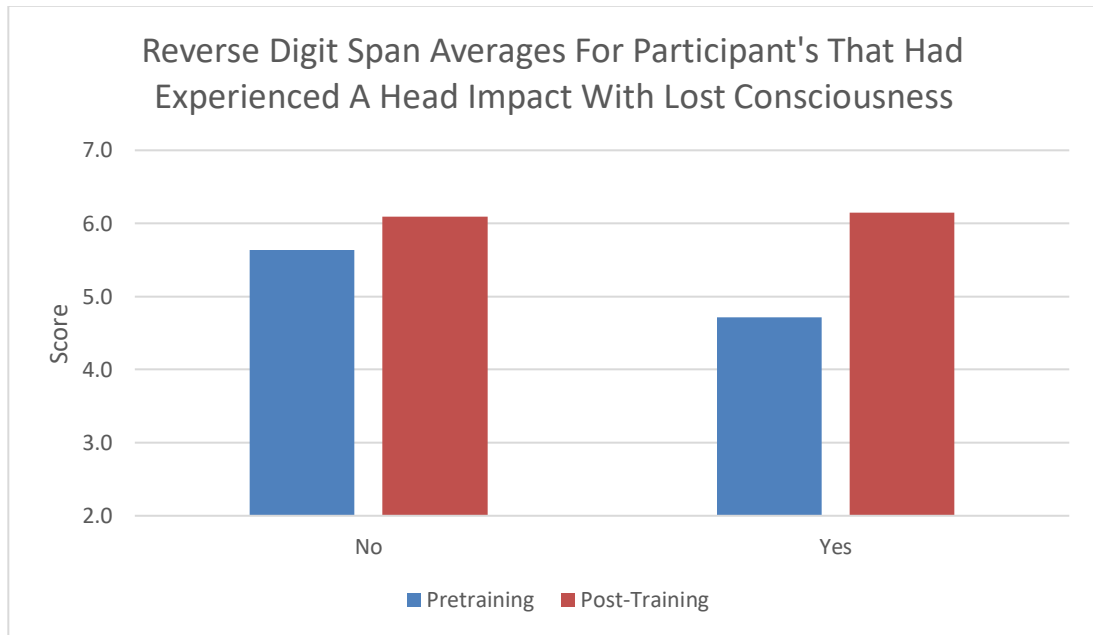
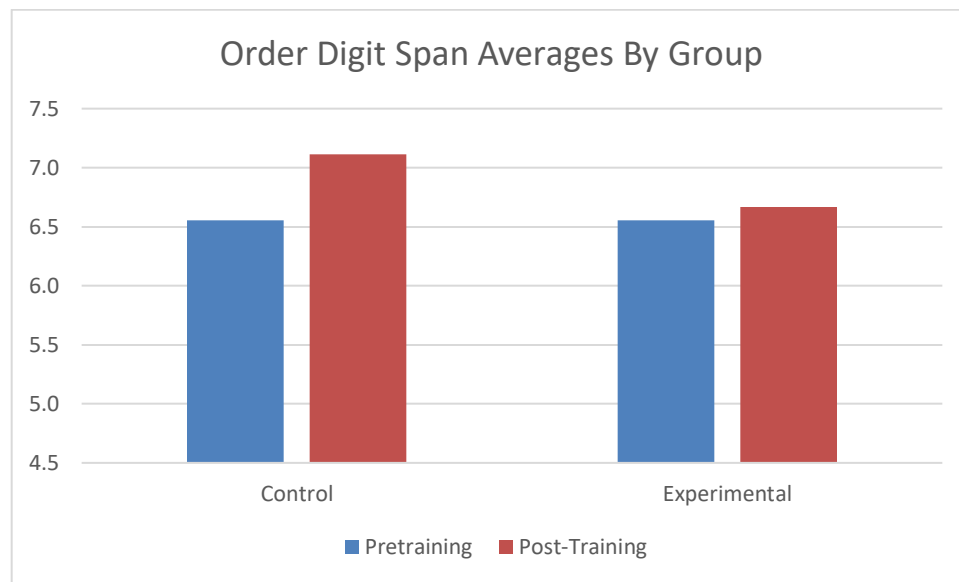


Figure 6. The average Reverse Digit Span task scores for study participant's that had experienced a head impact with lost consciousness.

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### Order Digit Span Task

The Order Digit Span scores showed similar results to the Reverse Digit Span task as the numbers were not statistically significant ( $P > 0.1$ ). The experimental group saw a score increase of 0.1, while the control group had an increase of 0.6 (Figure 7). Participants scored 1.3 points higher on the Order Digit Span task than on the Reverse Digit Span task indicating the first span task acted as a warm-up.



*Figure 7.* The average scores for the Order Digit Span task by group.

There was a universal negative trend with score and age, as shown in figure 8. The trend between education and score followed this negative trend as well, which is opposite the Reverse Digit Span task scores. Finally, participants that had not hit their head and lost consciousness had a lower baseline but saw a higher gain post-training.

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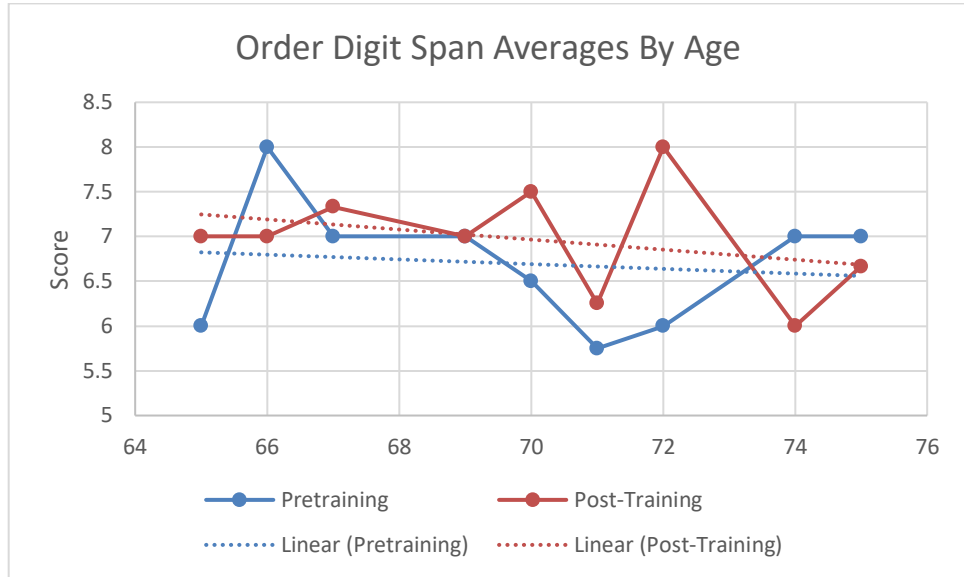


Figure 8. The average scores for the Order Digit Span task by age.

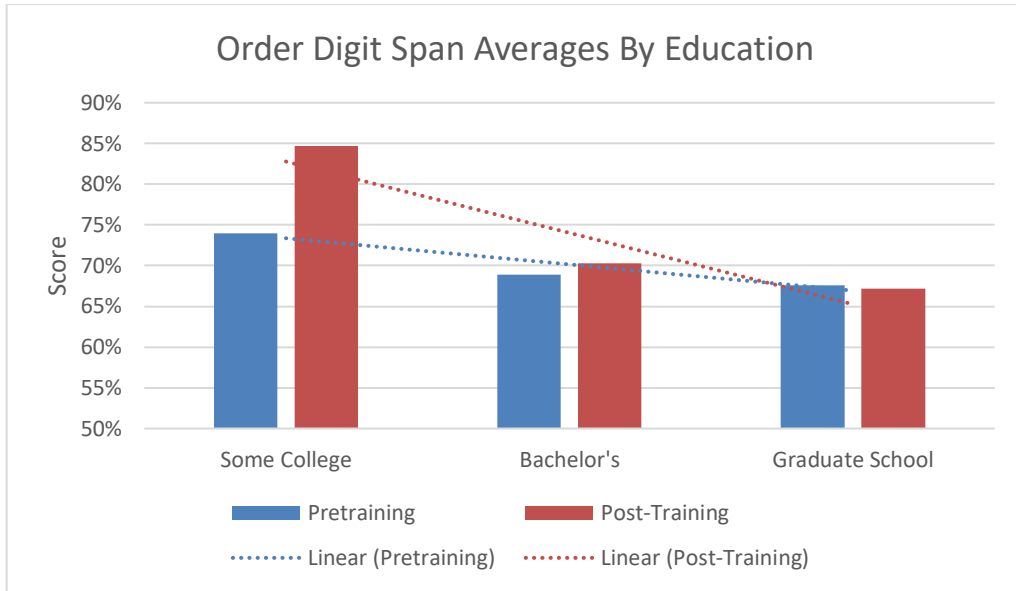
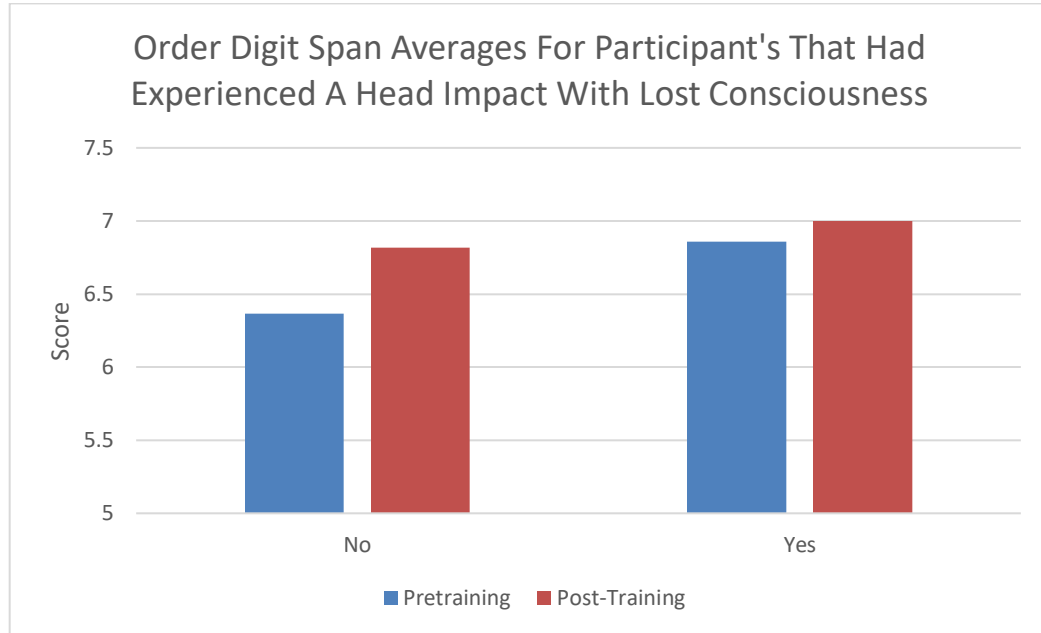


Figure 9. The average scores for the Order Digit Span task by education.

## Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task on Mobile Application: Results 30

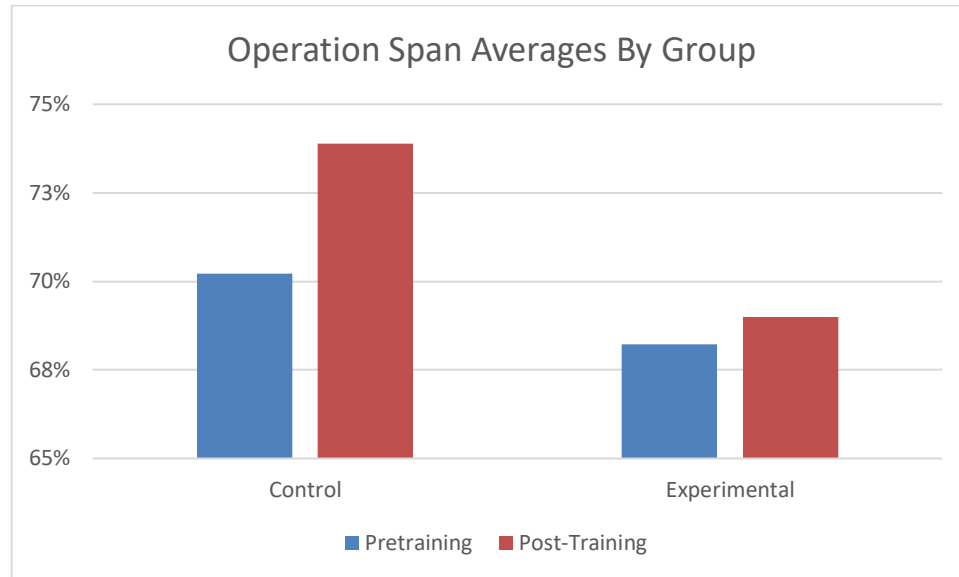


*Figure 10.* The average Order Digit Span task scores for study participant's that had experienced a head impact with lost consciousness.

### Operation Span Task

In the last task, the Operation Span scores continued the pattern of the Order Digit Span task and the Reverse Digit Span task and did not show any statistical significance ( $P > 0.1$ ). The experimental group saw an improvement of 1%, while the control group had a gain of 4%.

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*Figure 11.* The average scores for the Operation Span task by group.

As with the other two tasks, there was a negative correlation between the score and age for both trials. Education displayed the same negative trend for pretraining and post-training trials as well. Finally, participants that hit their head had a higher score than the other participants in pretraining, but their score decreased in the post-training, as shown in figure 14.

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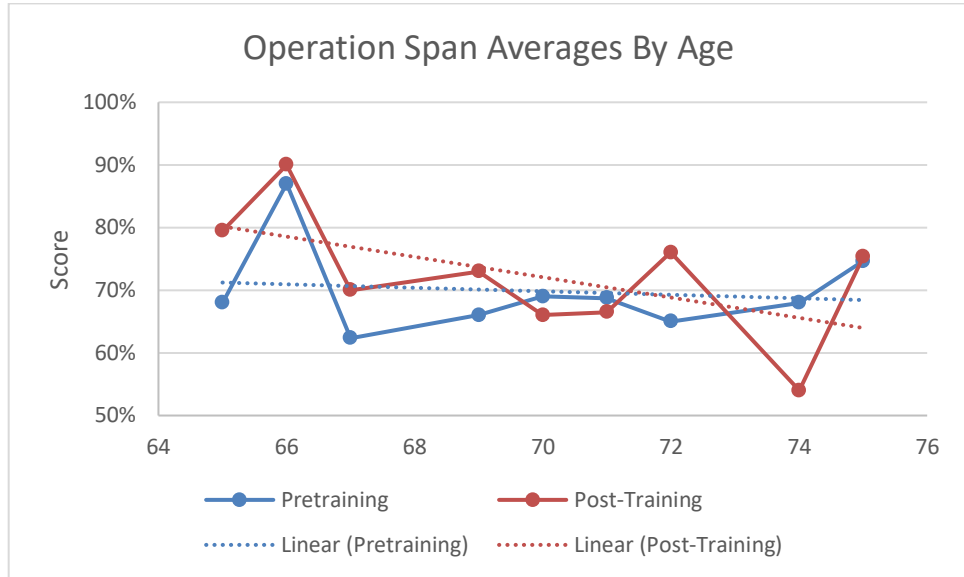


Figure 12. The average scores for the Operation Span task by age.

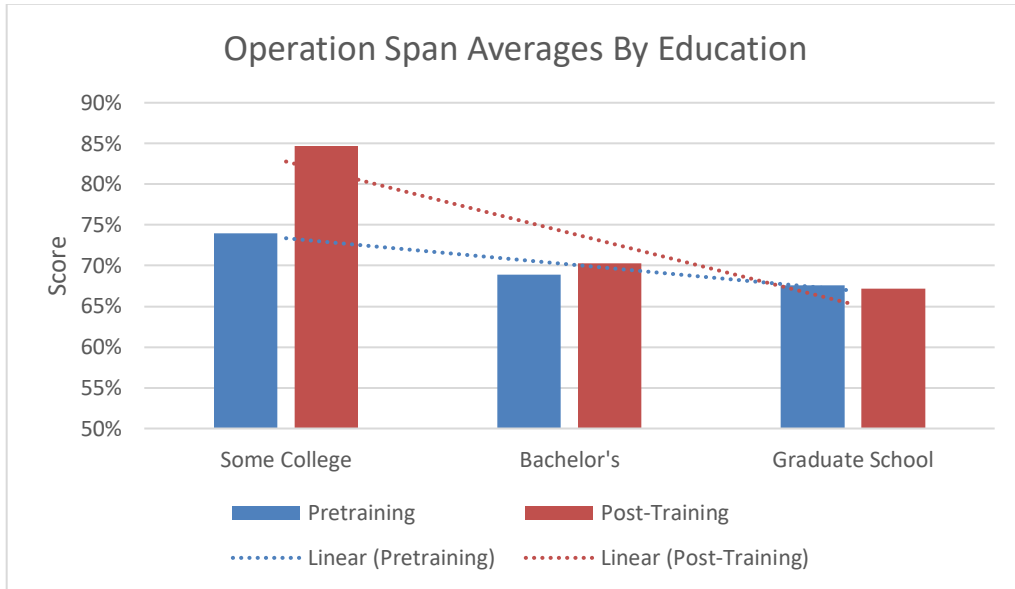
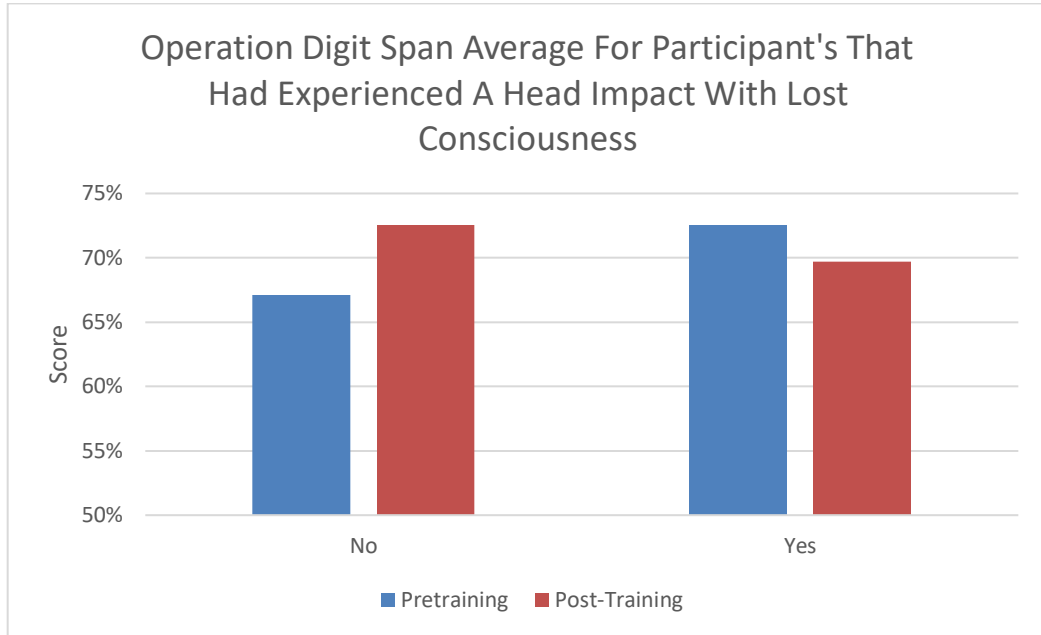


Figure 13. The average scores for the Operation Span task by education.

Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task on Mobile Application: Results 33



*Figure 14.* The average Operation Digit Span task scores for study participant's that had experienced a head impact with lost consciousness.

## Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task 34 on Mobile Application: Conclusion

### Chapter 7: Conclusion

This application-based experiment disproved the hypothesis that participants ages 65 to 75 can improve their working memory in three weeks, while training on their own using the reverse digit span task and the order digit span task. There was no statistical significance between the experimental and control groups for either of the three before and after test tasks. There are several reasons why this three-week app-based training did not measurably improve the participants' scores.

The first rationale is that the task may have been too simple, and the test subjects were not sufficiently challenged. Additionally, the participants may have needed to train for a longer time per day and for more than three weeks to realize results. Previous studies that saw positive results used complex tasks including Zinke et al. (2014) which employed the subtract-2-span task and several non-verbal working memory tasks. Similarly, Payne and Stine-Morrow (2017) used a combination of category span, lexical decision span, and sentence span tasks. Additionally, these studies required participants to train for thirty minutes per day versus ten. That is, they spent ten minutes each day on three different tasks versus ten minutes per day on two ordering or sequential tasks. However, despite the positive Payne and Stine-Morrow (2017) study results I would not recommend asking users to train with the reverse and order span task app for an increased time. As in the Payne and Stine-Morrow (2017) study several participants stated the tasks were increasingly tedious towards the end of the three weeks. Based on test subject comments like this older adult users would be more likely to drop the training. The motivation for older adults is more nuanced and requires more positive reinforcement to keep them going with the training. Based on this three-week reverse and order span task app experiment and the research studies noted, training tasks for older adults need to be of daily use over a long time period and produce results in the long run as longer sessions are not sustainably. This could explain why past studies chose to only train for three weeks because participants lost interest.



## Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task 35 on Mobile Application: Conclusion

Many factors can influence working memory, ranging from lack of sleep to brain injury, as shown by Blasiman and Was (2018), causing improvement of working memory to be an elusive goal. Many researchers cannot control factors such as emotions and stress/anxiety, while others would require a near-impossible amount of effort to regulate, including dieting and brain simulation. As a result, it is challenging to record overall improvements in working memory when something as simple as a bad night's sleep can significantly impact a participants' memory task scores. This is shown in this researcher's reverse and order span task app study results, where 1/3 of control participants saw an increase of over 10% in the operation span task from pretraining to post-training trials. And another three participants in the control group saw an increase of over three points in the reverse digit span task. However, one experimental group participant saw a 14% decrease in the operation span task. As a result, in future research it would be essential to control for or take into account mental conditions, bilingualism, and drug use so as to reduce the number of factors influencing the results. One method to help adjust for these factors would be to track the study participant's daily training sessions, providing the researcher with more data to examine past dips in scores or other test score anomalies.

Another component that could have impacted study results was completing the testing online. While the online aspect did allow participants, who would not usually participate in the study to take part, it also meant the researcher could not control the study environment. During testing, the researcher could frequently hear loud noises in the test subject's environment including other people talking, children crying, or the sound of a radio or television. Several times family members would interrupt the participant's testing between tasks, thus breaking the subject's attention and causing the participant to use more energy to refocus. The technology itself also impacted several participants as many of the older adult test subjects had not used Zoom before. Additionally, some study participants were performing the before and after tests on devices they themselves had selected but had not used frequently and were therefore less comfortable with. These technology challenges led to mild frustration and/or confusion at the beginning of the

## Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task on Mobile Application: Conclusion 36

Zoom meetings and occasionally during the testing itself. The internet connection could have impacted test results as well. A bad internet connection can cause a grainy or bitmapped image, poor audio quality and dropped connections. Participants that experienced these environmental challenges likely had fragmented attention causing them to work harder than other test subjects and likely resulting in faster mental fatigue.

The last factor that likely affected this study outcome is the probability of participants not sticking to the study's prescribed training regimen. A tool to support user compliance such as a reminder or a checklist to show that they have completed the day's training would be helpful. Even with a checklist tool relying on older adult users to remember to complete a daily training task may be problematic. Remembering to perform this daily testing forces participants to use their prospective memory. Prospective memory is described as the ability of a person to remember to perform an act later, such as when they take medication (Aberle et al., 2010). In 2012, Zogg et al. found that prospective memory is important for medication adherence and as older adults prospective memory declined Shruthi et al. (2016) saw participants' medication compliance level decline. Participants between the ages of 60 and 70 only showed medication compliance 55.36% of the time, while participants ages 71 to 80 were 25.80%. However, there are likely other unrecognized variables involved with remembering to do daily training or take medication as a meta-analytic review in 2004 showed older adults had a better prospective memory than younger adults (Henry et al., 2004). Still, in order to achieve the most reliable test outcomes with future research it is best not to depend solely on the participants' personal abilities to adhere to a prescribed training schedule.

The results of this study provide further support that scores have a negative trend with age. In the experimental group, all improvements in tasks decreased with age as shown in previous studies such as Zinke et al. (2014), Teixeira-Santos et al. (2019), and Borella et al. (2017). Interestingly participants that started with a lower baseline showed the most improvement in all three tasks, which disagrees with the referenced studies.

## Increasing Verbal Working Memory in Young-Old Adult by a Subtract-2 Span Task on Mobile Application: Conclusion 37

That said, there was a sharp increase in scores for those with some college compared to participants with a bachelor's or master's degree. The data implies these participants understood the task better the second time due to their exposure to the website or their experience from the initial testing session. This finding could mean the previously recorded high improvement for those participants with an initial lower baseline is from their lack of understanding of the task the first time they are exposed to it. This task understanding or lack thereof is worth further exploration as previous working memory studies do not record or score the participant's initial understanding of the requested task.

An additional study finding suggests that a "warm-up" task can increase the working memory scores of participants. The data shows that study participants working memory score were 1.28 points higher on average on the order digit span task than on the reverse digit span task in pretraining. The same result was found in post-training with an increase of 0.78 points. It stands to reason that this "warm-up" affected the operation span task as well. In future studies, it is recommended to include a short warm-up task to allow participants to reach similar levels of "alertness." In this study some participants reported that they had just woken from a nap while others said they had just returned home from work, thus providing evidence of very different mental states of alertness and focus.

This study provides further support that working memory by its very nature is exceptionally volatile, indicating that studies such as this need to be longer-term to reduce the impact of disparate variables. In the end, this experiment did not succeed in finding a way to improve working memory at home, but its design guidelines can be used in future iterations of working memory training.

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