REWIND-REMIND: INVESTIGATING HOW GAMIFICATION OF MEMORY TASKS CAN EVALUATE ASSOCIATIVE MEMORY PERFORMANCE IN HEALTHY, OLDER ADULTS

by

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"Ay hindi marunong lumingon so pinangalingan ay hindi makakarating sa paroroonan." / "He who does not know how to look back at where he came from will never get to his destination." – Jose Rizal

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Abstract

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Associative memory, the type of memory that allows us to relate information together (e.g., a person's face and name), is particularly susceptible to age-related deterioration. Older adults tend to engage in *retrieval shift*. This means they rely less on their memory, and more on visual search strategies, to remember information. *Rewind-Remind* is a proposed online cognitive training tool designed with memory research and human factors in mind. Users' memory was tested before and after playing *Rewind-Remind*. Results suggest that the current version of *Rewind-Remind* may be able to help screen people for instances of retrieval shift. Future research is aimed at enhancing *Rewind-Remind* as a research-backed, user-friendly cognitive training tool.

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Chapter 1

Introduction

Associative Memory Deficits in Older Adults

Memory complaints have been shown to increase with age, and episodic memory (particularly associative memory) seems to be especially impacted (CDC, 2011; US Preventive Services Task Force, 2014; Old & Naveh-Benjamin, 2008b). The Pew Research Center found that forgetting the names of familiar people is considered by the general population to be the most influential marker of old age, even more so than being retired or having grandchildren (Taylor, Morin, Parker, Cohn, & Wang, 2009). These so-called “subjective memory impairments” are indeed some of the most commonly reported issues that older adults experience. For instance, Holmen et al. (2013) found that forgetting the names of familiar people was one of the most frequently reported types memory issues, and an increase in severity in this deficit was seen in older participants. This difficulty of older adults to be able to link familiar faces with names is a hallmark of age-related associative memory deficits.

Factors that Influence Age-Related Associative Memory Deficits

Older adults experience many anatomical and functional brain changes due to normal and healthy aging. When these changes impact areas that are important for associative memory (e.g., prefrontal cortex; medial temporal lobe; default mode network), they can contribute to associative memory deficits. For example, frontal, striatal, and cerebellar gray matter reductions have been related to poorer associative memory performance, and frontal area dysfunction (e.g., unnecessary activity in the right inferior frontal gyrus; reduced activity in the dorsolateral prefrontal cortex), as well as frontal area susceptibility to memory interference, have been shown to obstruct associative memory processes (Bauer, Toepper, Gebhardt, Gallhofer, & Sammer, 2015; De Chastelaine, Matson, Wang, & Donley, 2015; Dulas & Duarte, 2016; Scimeca & Badre, 2012).

Impeded connectivity between medial temporal lobe areas (i.e., the hippocampus and the left anterior lobe) has also been related to associative memory retrieval deficits in older adults (Tsukiura et al., 2010). Additionally, changes in resting-state activity have been accompanied by worse associative memory. Ren, Li, Zheng, and Li (2015) found that older adults who did not have spontaneous activity in the right hippocampus and parahippocampus areas of the default mode network (DMN), while at rest, retrieved fewer associations than older adults who did have spontaneous activity in these areas while at rest. Additionally, Park et al. (2013) found that older adults who were unable to suppress DMN activity during associative memory tasks did worse than their similarly-aged counterparts who were able to suppress DMN function, as well as younger adults overall.

Anterior corpus callosum (ACC) white matter reductions also relate to poorer associative memory performance in older adults; it is thought that these reductions lead to the weakening of the ACC, which leads to improper utilization of cognitive resources needed for the formation of associative links between stimuli (De Chastelaine, Wang, Minton, Muftuler, & Rugg, 2011). Amyloid beta deposits are typically associated with Alzheimer's disease, but healthy older adults do accumulate such deposits throughout the brain in normal aging; the presence of these deposits, especially in areas important for associative memory processes, seem to hinder encoding and retrieval of associations (Rentz et al., 2011).

Older adults also experience deficits in other biological areas that may further influence associative memory performance. Sensory degradation, like vision and hearing loss, can negatively impact associative memory. Naveh-Benjamin and Kilb (2014) were able to simulate how vision and hearing loss can impact associative memory; presenting hard-to-read word pairs to younger adults resulted in memory performance similar to older adults. Differences in the type and pattern of sleep can influence general cognitive functioning and associative memory. Less slow-wave sleep and less consistent sleep have had negative impacts on associative memory (Backhaus, Born, Hoeckesfeld, Fokuhl, Hohagen, & Junghanns, 2007; Fernandes et al., 2015; Mary, Schreiner, & Peigneux, 2013; Mander et al., 2013; Sherman, Mumford, & Schnyer, 2015; Wilson et al., 2012).

Age-related cognitive declines also occur as a part of healthy aging. Disorganization of working memory processes may lead to improper or inefficient encoding, which may then affect associative memory (Chen & Naveh-Benjamin, 2012; Hara & Naveh-Benjamin, 2015; Oedekoven, Jansen, Keidel, Kircher, & Leube, 2015). Repeating information, giving individuals unlimited time to learn information, and organizing information in thematic or semantic categories, have mixed effects on associative memory in older adults (Brubaker & Naveh-Benjamin, 2014; Buchler, Faunce, Light, Gottfredson, & Reder, 2012; Kersten, Earles, Curtayne, & Lane, 2008; Kilb & Naveh-Benjamin, 2011; Light, Patterson, Chung, & Healy, 2004; Overman & Becker, 2009; Rhodes, Castel, & Jacoby, 2008; Zheng, Li, Xiao, & Jiang, 2015).

Furthermore, older adults may be more likely to use familiarity memory processes rather than recollection, suggesting that older adults may rely on a subjective feeling of having encountered information before, rather than remembering that information with enough objective, contextual details (Healy, Light, & Chung, 2005). Additionally, the complexity of the information being encoded may play a role in how well older adults can create associative links of that information. Meaningful relationships between stimuli may: be easier to link and, therefore, easier to recollect (Bastin & Van der Linden, 2006; Pitarque, Sales, Melendez, & Algarabel, 2015); may be more susceptible to confusion with other similar stimuli; or may have no difference at all (Badham, Estes, & Maylor, 2012; Bender, Naveh-Benjamin, & Raz, 2010; Hertzog & Touron, 2011; Naveh-Benjamin, Craik, Guez, & Kreuger, 2005; Rhoades, Castel, & Jacoby, 2008).

In some cases, being distracted by other tasks had a negative impact on associative memory (Castel & Craik, 2003; Naveh-Benjamin, Guez, Kilb, & Reedy, 2004); in other cases, distractions did not lead to age differences (Anderson et al., 2000; Cooper & Odegard, 2011; Kinjo, 2011). Whether distraction influences associative memory may depend on the nature of the associations (e.g., whether cues were used or not), as well as the nature of the distraction (e.g., concurrent distractor tasks vs. sequential distractor tasks). The effect of emotion and arousal is still unclear with regard to associative memory; some research shows that emotional valence makes information more memorable (Murray & Kensinger, 2013), whereas other research shows no effect (Naveh-Benjamin, Maddox, Jones, Old, & Kilb, 2012; Nashiro & Mather, 2011).

Encoding and Retrieval Strategies

The aforementioned possible factors that may influence associative memory in older adults stem from processes or characteristics that are largely out of older adults' control. Anatomical and functional changes in the brain, sleep pattern changes, sensory degradation, and diminished working memory capacity and/or processing speed are typical, if not inevitable, occurrences that happen with healthy aging. Individuals do not have complete control over their intelligence, and it is difficult to predict and observe how cognizant people are of their own memory. When gathering information from the environment, individuals often cannot control the complexity, style, order, or timing of the presentation of that information. Furthermore, individuals may respond emotionally to or be aroused by stimuli, but these are reactionary processes that individuals cannot control.

However, there are some factors that can be controlled at the individual level, to some degree. Older adults can learn encoding and retrieval strategies to influence associative memory performance. Age-related differences in these encoding and retrieval strategies have informed two major hypotheses about the information processing factors that influence these associative memory deficits. First, there is the *Associative Deficit Hypothesis*, which is an encoding-focused hypothesis

(Naveh-Benjamin, 2000). From this perspective, older adults experience associative memory deficits because they are unable to form relationships between stimuli. This is supported by researchers who assessed older adults' ability to remember word pairs, picture pairs, and actor-action associations. Generally, when older adults were distracted, unsupported, or overloaded while trying to learn associative information, they performed worse than their counterparts on follow-up tests (Old & Naveh-Benjamin, 2008a, 2008b; Silver, Goodman, & Bilker, 2012).

The *Environmental Support Hypothesis* builds on the *Associative Deficit Hypothesis* by incorporating a focus on retrieval processes. The *Environmental Support Hypothesis* posits that age-related associative memory deficits stem from not just the lack of encoding environmental details, but also the inability to use environmental support related to those details during retrieval (Craik, 1983; Sauzeon, Rodrigues, Corsini, & N'Kaoua, 2013). Older adults may not be able to use environmental support, like memory cues, to prompt retrieval; this can lead to increased cognitive demand, and decreased memory accuracy (Morrow & Rogers, 2008). This is supported by researchers who have assessed retrieval demands and decisions. Older adults often correctly identify studied material. This means that during memory tests, they correctly recognize as many stimuli as their younger counterparts. However, older adults in particular engage in *retrieval shift*; they correctly label studied stimuli as "studied", but they also label new stimuli as "studied", which increases their false alarm rates (Hertzog, Fulton, Mandviwala, & Dunlosky, 2013). Thus, older adults are capable of correctly encoding information at the same rate as younger adults; the older adult memory deficit comes from the inability to discern whether new information was previously seen. Also, perhaps due to various age-related changes, or perhaps in anticipation of poor memory performance, older adults often change retrieval strategies in favor of other cognitive processes (e.g., using working memory or visual search strategies) when completing memory tests (Cohn, Emrich, & Moscovitch, 2008; Touron & Hertzog, 2009).

Treatment of Age-Related Associative Memory Deficits

Pharmacological Treatment

Many older individuals who experience such memory deficits are primarily treated with pharmacological therapy. Aricept, Exelon, Razadyne, and Memantine are prescription medications that have been prescribed for memory loss in those who may be at-risk or who are diagnosed with Alzheimer's disease (Alzheimer's Association, 2016). Pharmacological treatment is also available for generally healthy, non-cognitively impaired older adults who report mild memory loss.

Prevagen® has been used for patients diagnosed with Alzheimer's, as well as self-sufficient older adults who give accounts of mild memory loss via self-report (Quincy Bioscience, 2016). However, individuals who take these drugs are susceptible to several side effects. Alzheimer's patients prescribed the aforementioned medications may become confused, dizzy, or nauseated; they may also report vomiting, losing their appetites, having more bowel movements, experiencing more headaches, or having either constipation or diarrhea (Alzheimer's Association, 2016). Prevagen® has yet to be assessed by the Food and Drug Administration for safety (Quincy Bioscience, 2016). In some cases, the use of neuroleptics to treat memory loss can reduce cognitive functioning and quality-of-life (Ballard et al., 2001; McShane et al., 1997).

It is unclear if drugs provide any benefits for patients. Kueider, Bichay, and Rebok (2014) report that dementia drugs are costly, and they only slow the progression of memory loss or attempt to maintain the cognitive performance of individuals at the start of the drug regimen. Also, these treatments often do not target associative memory and, therefore, do not necessarily ameliorate these associative memory deficits. For instance, an internal clinical study of Prevagen® (Lerner, 2016) found possible benefits for older adults (compared to a placebo group) on a maze-learning task and a verbal-learning task. Significant benefits were claimed to be found for performance on a working memory task, but the placebo group also experienced an increase in working memory performance at post-test, which raises questions about the findings regarding the impact of Prevagen® on working memory performance.

Aside from noting that this study being internal within Quincy Bioscience, it is also important to note that all of these tests fail to assess item-item associations and, therefore, may not reflect the associative memory deficits that older adults report. Other studies of pharmacological treatment of memory deficits have also reported high placebo-response rates (Ballard & O'Brien, 1999). The healthcare expenses, possible risk, and possible lack of results suggest that pharmacological therapies for memory loss may not be the best solution for older adults who report associative memory deficits.

Cognitive Remediation and Memory Games

One alternative to pharmacological treatment is cognitive remediation through the use of technology in cognitive screening and testing. Such behavioral interventions are: lower cost; can be made widely available; and, most importantly, are not accompanied by the aforementioned negative side effects. Cognitive remediation has not been as widely studied, in part due to perceived barriers in using such technology to address age-related issues. For instance, previous research has shown that, in the past, older adults were less open to using technology in relation to their self-reported health concerns (Best, Souders, Charness, Mitzner, & Rogers, 2015).

Interestingly, recent research conducted by the Pew Research Center revealed that 86% of all adults in the US use the internet via desktop and mobile devices, and 59% of those adults are seniors who are aged 65 older (Zickuhr & Madden, 2012). This suggests that technology acceptance may be increasing in the older population. One factor that can help increase technology acceptance in older adults is the use of a user-centric viewpoint in the creation of such technology (Best, Souders, Charness, Mitzner, & Rogers, 2015). Examining cognitive remediation avenues is particularly interesting at this time because research shows a rising use of technology among older adults. If older adults are more open to learning and adopting new technology, and computer-based remediation tools have several financial and health-related benefits over traditional medication, then the creation, use, and study of memory games could be highly supported by the older adult population.

Existing research-based cognitive remediation tools and strategies are varied (see Gross et al., 2012). Kueider, Bichay, and Rebok (2014) define three traditional approaches: cognitive stimulation; cognitive rehabilitation; and cognitive training. Cognitive stimulation refers to the engagement in an activity that encourages additional cognitive processing through integrated social components. One example given by Kueider, Bichay, and Rebok (2014) is the enrollment of older adults in a volunteer program for children. This provides older adults the opportunity to learn new skills (e.g., teaching, communicating, mentoring) in a social environment that has the added benefit of accomplishing community goals. Cognitive rehabilitation refers to the use of cognitive aids that are integrated into daily life; one example may be the use of electronically-mediated reminders for appointments or medications. This is usually tailored to individuals' needs, which makes cognitive rehabilitation highly personalized.

Cognitive training refers to standardized exercises that are designed to test and strengthen cognitive functioning in a more precise manner. This type of training can be further categorized as either instant vs. extended strategy training; instant training involves learning a single type of memory strategy, whereas extended training involves learning several types of memory strategies (Rebok, Carlson, & Langbaum, 2007). One example of traditional cognitive training is the *Advanced Cognitive Training for Independent and Vital Elderly*, or *ACTIVE*, study (Jobe et al., 2001). Researchers trained and tested older adults on their processing speed, reasoning, and memory, and they examined performance based on standardized memory tests (e.g., Hopkins Verbal Learning Test, Related Word Lists), as well as everyday tasks, like answering questions about daily situations (e.g., preparation of food, use of medication, driving). With regard to memory specifically, individuals were trained how to organize information semantically through the use of mnemonic strategies (e.g., reading a list of errands to run, and visualizing those errands).

Researchers have found that, with regard to cognitive training, participants did experience better processing speed, reasoning, and memory, even after five years (Tennstedt & Unverzagt, 2013). Each type of training only provided benefits for tests that were similar to training; for instance, training on increasing processing speed did not influence performance on tests of reasoning or memory. All types of training also positively impacted measures of daily functioning (e.g., bathing, taking medication); participants who received training could accomplish these tasks with more ease than their counterparts in the control group could. Finally, processing speed and reasoning training led to better driving behaviors; participants in these groups had fewer driver-based car collisions, and were more likely to be driving after five or six years, at the time of follow-up study.

Competing Systems of Cognitive Training

Evidence is mixed regarding the success of cognitive training (Kueider, Parisi, Gross, & Rebok, 2012, Nyberg et al., 2003; Willis et al., 2006). Some brain training sites have claimed similar findings with their computerized training programs, which aim to support neural plasticity. Such sites are: Lumosity (lumosity.com), NeuroNation (neuronation.com), Fit Brains (fitbrains.com), Brain Metrix (brainmetrix.com), Brainturk (brainturk.com), and Memorado (memorando.com). However, these particular competing systems do not provide much supportive research.

There are some examples of widely-used cognitive training programs that have been validated by research. For instance, the company Posit Science has offered several brain training exercises that have been shown to result in stronger working and item memory performance from older adults, outside of practice effects (Mahncke et al., 2006; Smith et al., 2009; Zelinski et al., 2011). The training games focus heavily on attention, processing capability, and working memory through the use of tasks like auditory processing of syllables (“Memory Grid”) and visual processing of scene details (“Scene Crasher”). When coupled with physical exercise, Post Science’s games have increased cognitive performance in older adults who have been diagnosed with neurocognitive disorders; specifically, these older adults performed better on tests of verbal learning and executive functioning (Bamidis et al., 2015).

However, these competing systems do not address associative memory deficits in healthy, older adults directly in their games. Instead, they address many processing and executive functioning aspects. By strengthening processing speed and working memory, individuals may indeed experience indirect benefits to their associative memory (Chen & Naveh-Benjamin, 2012; Hara & Naveh-Benjamin, 2015). In fact, video game training without using any specific cognitive strategies has been shown to provide working memory and attentional capacities (Basak, Boot, Vass, & Kramer, 2008). Although these indirect benefits could exist, the little research done on these competing systems has not specifically used measurements of associative memory performance to examine those possible benefits. Most of the assessments that are used are focused on measuring performance on item memory, working memory, or processing speed. More research is needed to examine how to address the particular problem of associative memory deficits – and instances of retrieval shift – in healthy, older adults.

Challenges in Cognitive Training for Associative Memory Deficits

Memory detriments, particularly associative memory deficits in older adults, have been well-documented in the literature and are easily identified in research settings, but it is difficult to identify what these memory deficits look like in real-world situations. It is especially hard to isolate, measure, standardize and meaningfully treat the everyday associative memory deficits that older adults report (Salthouse, 2012). This lack of transfer of gains from traditional cognitive trainings to memory problems experienced in daily life is perhaps the largest area of concern for this field of research (Rebok, Carlson, & Langbaum, 2007).

The *ACTIVE* study found such evidence of memory training specificity; older adults did not seem to experience benefits in cognitive aspects of activities of daily life as a result of memory training (Tennstedt & Unverzagt, 2013). In the *Improvement in Memory with Plasticity-based Adaptive Cognitive Training* (*IMPACT*) study, older adults engaged in six computerized sessions of adaptive-training tasks (i.e., tasks that would change the difficulty setting based on user ability), with an accompanying reward-point-system, as well as auditory exercises (Smith et al., 2009). Contrastingly, researchers reported evidence of training transfer, but these memory benefits were transferred to other standardized tests rather than to measures of everyday memory processes, much less associative memory processes.

Another concern is the influence of practice effects. The cognitive training industry is now valued at $300 million, but this industry is also highly unregulated, and many companies that market cognitive games do not utilize proper experimental methods to validate their findings (Kueider, Bichay, & Rebok, 2014). When companies do report significant findings, it is often unclear as to whether those findings are a) true benefits of training, or b) practice effects, which are enhancements in game performance due to merely becoming familiarized with the game. Long-term neuropsychological testing of healthy adults has been shown to result in enhanced performance during periods of repetitive testing, contrasted with a plateau of performance during periods of sporadic testing (Bartels, Wegrzyn, Wiedl, Ackermann, & Ehrenreich, 2010).

An example of practice effects in the cognitive game industry would be an increase in a player's scores on a memory game simply because that person plays the game frequently; benefits are game-specific and are not accurate measures of cognitive functioning. For instance, Lumosity recently settled a $2 million lawsuit for claiming that its games prevented cognitive decline (Federal Trade Commission, 2016). Benefits that players may have experienced have not been shown to result from cognitive training and, therefore, may instead be due to these practice effects. In fact, one study showed that playing the video game Portal 2 produced higher scores on problem solving and spatial tasks than the targeted Lumosity games did (Shute, Ventura, & Ke, 2015).

To encourage training transference and to combat practice effects, creators of memory games can include more aspects of memory study designs to target specific cognitive areas. Additionally, researchers can use both standardized (e.g., associative memory tasks in cognitive neuroscience studies) and everyday measures of functioning (e.g., the ADL from the *ACTIVE* study by Jobe et al., 2001) that are not game-related to examine whether training results in memory enhancement. Targeting associative memory may shed light on how best to optimize memory games to address the deficits seen in older adults.

Rewind-Remind: A Proposed Memory Game

Based on the aforementioned cognitive neuroscientific research, computer science research, and cognitive training industry trends, the major concerns of the development of cognitive training to address cognitive deficits include the following:

- Many cognitive training games currently on the market lack proper evidence of benefits, and are susceptible to practice effects
- Many cognitive training games developed by researchers show training-specific benefits, but not general cognitive benefits or everyday applicability
- Little research on user feedback of cognitive training games, and mixed evidence regarding the kind and amount of cognitive training that leads to benefits for different populations

Rewind-Remind aims to bridge the documented lab-life divide (Salthouse, 2012), and was built with these criticisms in mind. The main goal of *Rewind-Remind* as a whole is to strengthen episodic memory in older adults. More specifically, Game 2 of *Rewind-Remind* was developed to help strengthen associative memory deficits that older adults uniquely face, in part due to the natural and healthy aging process. *Rewind-*

Remind addresses the previous criticisms by combining research and industry solutions. For instance, targeting encoding and retrieval strategies, and integrating memory research methods, helps users to make meaningful connections between objects. Additionally, the consideration of human factors allows for a user-centric approach; the rules of the game allow users the ability to make connections in a way that builds upon their personal experiences, which can make semantic associations more meaningful to each individual person. The design of the game itself also considers the needs of the growing older adult population. It is designed: to be easy to read and use; to require no previous skillset other than general familiarity with a computer; and to offer the chance for users to provide feedback about the structure of the game. This allows for a more integrative experience than that of a strictly traditional cognitive training.

Game Instructions

Rewind-Remind Game 2 is the Associative Memory game (please refer to Figure 2). Users start by learning noun pairs in one of two ways. In the <u>Directed Encoding</u> condition, individuals are instructed to type either the phrase “fits into” or “contains” to describe the physical relationship between the nouns. In the <u>Self-Generated Encoding</u> condition, individuals are instructed to create their own meaningful responses to describe the relationship between the nouns. Users then move on to the test-round, where noun pairs are presented, and individuals must identify whether the presented noun pairs were seen earlier in the game or not. As they take this test, users can utilize a noun-pair lookup table to check their answers if desired. After completing the entire *Rewind-Remind* run, users are also asked to answer questions in order to give feedback on the game (please refer to Figure 3 for the *Rewind-Remind* Feedback Survey).

Game Design

Rewind-Remind is available at http://rewindremind.herokuapp.com. It is a web-based game (RESTful API with HTTP communication protocol) hosted by Heroku servers. This was chosen to ensure that the game is secure, can simultaneously handle several users with multiple requests, and minimizes end-user hardware requirements. Data are temporarily stored in the MongoDB NoSQL database, and then moved to UT Arlington servers.

Support from Memory Research

Many factors that may lead to associative memory deficits in older age are out of individuals' control (e.g., sensory degradation, age-related brain changes), but the use of memory strategies can be facilitated. Giving users encoding strategies, and allowing users to play at their own speeds, enhances associative memory performance and reduces the possible trade-off between using directed encoding strategies and attentional costs (Naveh-Benjamin, Craik, Guez, & Kreuger, 2005; Patterson & Hertzog, 2010; Salthouse, 1995). Also, examining different encoding strategies allows researchers to identify whether associative memory deficits in older adults stem from an inability to make associations on their own, depending on a variety of conditions. Semantic encoding is meaningful encoding, provides stronger links between information, and is more helpful in memory processes (Dunlosky, Hertzog, & Powell-Moman, 2005), and this benefit is boosted by allowing participants to complete the tasks at their own pace (Dunlosky, Kubat-Silman, & Hertzog, 2003). *Rewind-Remind's* two game "modes" build on this by offering Directed Encoding (unitization of the two nouns in the pair based on relative size) vs. Self-Generated Encoding (more semantic elaboration of the relationship between the paired nouns) can help elucidate this.

Research has shown that participant involvement in the form of self-generation of associative links between pair items increases associative memory retrieval (Crespo-Garcia, Cantero, & Atienza, 2012; McGillivray & Castel, 2010; White, Abrams, & Byrd, 2009). Interestingly, Gross et al. (2012) found that memory benefits did not depend on the *type* of encoding strategy, but that categorization, increased rehearsal, and increased number of strategies trained (rather than association or face-name learning) were the strongest predictors of larger effect sizes of memory enhancements facilitated by training. However, it is important to note that categorization was operationally defined by Gross et al. (2012) as the recognition and classification of items based on *conceptual* relationships. Also, Li et al. (2016) found that cognitive training that specifically supported encoding and retrieval resulted in better memory performance and larger effect sizes than combined cognitive trainings did. Because the Self-Generated Encoding Group will have the freedom to make associations between items based on *semantic* links (e.g., if the two items share attributes), the Self-Generated Encoding Group may still experience stronger memory effects. Therefore, the use of targeted training that employs semantic associations is supported.

Another study task that has been used to test associative memory in older adults is the *Noun-Pair Lookup Task (NPLT)*. This task asks participants to learn noun pairs, and then tests participants on whether they are able to remember those pairs with or without the aid of a noun-pair table (Hertzog & Touron, 2011; Hines, Hertzog, & Touron, 2012; Touron & Hertzog, 2014). Incorporating a noun-pair lookup table in during the *Rewind-Remind* test rounds offers two novel metrics (i.e., frequency of table use, and total time spent using tables) that can mark instances of *retrieval shift,* or instances when users move from a retrieval strategy (no table) vs. a visual search strategy (use of table) to complete the *Rewind-Remind* memory tests at the end of each game session.

Aside from these game session memory tests, there is no implementation of a score board or rewards for high scores. Instead, users can be referred to standardized or experimental methods of measuring memory performance (e.g., batteries, experimental tasks). This acknowledges the need for testing outside of the game to combat practice effects. Additionally, although many cognitive remediation tools are self-contained programs that may require specific hardware or software to be employed, Internet-based interventions have been shown to help protect against age-related cognitive decline (Klimova, 2016). This suggests that hosting *Rewind-Remind* online is acceptable. For the experimental methods of *Rewind-Remind,* refer to Chapter 2.

Consideration of Everyday Application

First, *Rewind-Remind* will be made available online for free, which allows users to complete the training at their convenience. Learning the training in the laboratory, but also engaging in training outside of the laboratory, may encourage more generalization of training strategies (Reisberg, 2013). Furthermore, the aforementioned changes and benefits of encoding strategy may reflect better everyday application. Because the Self-Generated Encoding Group will have the freedom to draw upon their own experiences to create these semantic associations, they may have an increased ability to incorporate this strategy in their daily lives. Finally, *Rewind-Remind* performance can be compared to measures of memory that better resemble daily associative memory failures (please refer to Chapter 2 for more information).

Inclusion of Human Factors

Ensuring a user-centric approach is thought to increase technology acceptance and use in older adults (Best, Souders, Charness, Mitzner, & Rogers, 2015). Fonts are large, uncrowded, and sans-serif for legibility and optimal processing (Bernard, Liao, & Mills, 2001; Pelli & Tillman, 2008). Stimuli will be centrally placed on the screen to ensure good visibility. Finally, The *Rewind-Remind* Feedback Survey offers more measures to help identify which users would benefit most from this game, as well as what aspects of the game that the users did or did not like. Factors of interest are age, education level, and overall experience with technology (please see Figures 3 and 4).

Chapter 2

Methods

Specific Aims and Hypotheses

Rewind-Remind employs gamification of research-based methods (e.g., differences in association directions; the noun-pair lookup task) in order to facilitate associative memory processes. The aims of this study were to investigate the effects of playing *Rewind-Remind* on associative memory performance in older adults in a manner that: minimized practice/testing effects; introduced memory specificity; and provided the opportunity for everyday applicability.

By testing *Rewind-Remind* with a task created for experimental memory research (an associative memory test), *Rewind-Remind* was evaluated in a way that minimizes practice/testing effects. This also allowed for specificity. General training does not seem to provide any particular cognitive benefits, so more targeted training was hypothesized to allow users to specifically address associative memory deficits. Targeted training was hypothesized to allow users to apply the associative memory strategies from *Rewind-Remind* to other associative memory issues. Finally, allowing users to complete these tasks outside of the lab provided greater insight into how memory research can become more applicable to everyday life. Users' scores provided information on the efficacy of *Rewind-Remind*, and their responses on the *Rewind-Remind* Feedback Survey (please see Figures 2 and 3) provided information on what users preferred in their memory games.

Generally, it was hypothesized: that younger adults would perform better on associative memory tasks overall; that older adults who played *Rewind-Remind* would have better follow-up test scores than their counterparts in the control group; and that older adults in the Self-Generated Encoding Group would have the highest follow-up test scores, relying least on the noun-pair lookup table in the *Rewind-Remind* game. More specifically, the following were hypothesized:

1. Reaction times
    a. Younger adults would have faster reaction times than older adults on the associative memory baseline and follow-up tests, regardless of experimental group.
    b. Older adults who played *Rewind-Remind,* and wo were given a specific encoding task (Directed Encoding Group), would have faster reaction times on the associative memory follow-up test, followed by older adults who played *Rewind-Remind* and were not given a specific task (Self-Generated Encoding Group).

c. Older adults who did not play the game (control group) would have the slowest reaction times.

2. Memory performance (discriminability)

    a. Younger adults would perform better than older adults on the associative memory baseline and follow-up tests, regardless of experimental group.

    b. Older adults who played *Rewind-Remind* (experimental groups) would perform better on the associative memory follow-up test than older adults who did not play *Rewind-Remind* (control group). Specifically, older adults who played *Rewind-Remind,* and who were not given a specific encoding task (<u>Self-Generated Encoding Group</u>), would have the best memory performance on the associative memory follow-up test, followed by older adults who played *Rewind-Remind* and were given a specific task (<u>Directed Encoding Group</u>).

    c. Older adults who did not play the game (control group) would have the worst performance.

3. Noun-pair lookup table usage:

a. Younger adults who played *Rewind-Remind* would use the noun-pair table fewer times than older adults who played *Rewind-Remind*, regardless of encoding strategy.
b. Older adults who played *Rewind-Remind,* and who were not given a specific encoding task (Self-Generated Encoding Group), would use the noun-pair table fewer times than those who were given a specific task (Directed Encoding Group).
c. Younger adults who played *Rewind-Remind* would use the noun-pair table for less time than older adults who played *Rewind-Remind,* regardless of encoding strategy.
d. Older adults who played *Rewind-Remind,* and who were not given a specific encoding task (Self-Generated Encoding Group), would use the noun-pair table for a shorter amount of time than older adults who played *Rewind-Remind,* and who were given a specific task (Directed Encoding Group).

Sample Size Estimation

In order to compare two age groups, two encoding strategies plus one control condition, and using baseline and follow-up test scores, this study utilized a 2 x 3 x 2 design. Dunlosky, Kubat-Silman, and Hertzog

(2003) implemented a similar design with the particular advantage of using self-pacing during experimental procedures and tests. The authors reported an effect size of Cohen's *d* = .72 with regard to the associative memory experimental group, which calculates to a Cohen's *f* = .36 (Cohen, 1988). *A priori* power analyses were run using G*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007) in order to estimate sample size with these parameters. With α = .05 and power (1-β) = .80, the projected total sample size needed for a medium-large effect size (*f* = .36) was 78.

Participants

Two groups of participants were needed for this study. As noted above, it was determined that, ideally, 39 younger adults (aged 18 to 25) and 39 older adults (aged 45 and over), meaning 78 participants total were needed. In total, 92 participants were recruited for the study, and 80 participants (40 older adults and 40 younger adults) were used for these analyses.

Stratified sampling was used to separate the participants into groups. First, participants were split by age, and then randomly assigned into experimental subgroups. The control group consisted of 15 older adults and 13 younger adults, totaling 28 participants. The control group completed a simple word matching task that required them to: read a list of three words; identify which words were duplicates; and type that word into the text box within the game.

The first experimental group, the Directed Encoding Group, consisted of 12 older adults and 14 younger adults, totaling 26 participants. These participants received specific instructions on how to link the nouns in the pair (i.e., how do the nouns physically fit into one another). This group was told to type “contains” or “fits into” to describe the relationship between the nouns. This is a typical memory task that is used merely to facilitate an association between pair items (Park, Abellanoza, and Schaeffer, 2014).

The second experimental group, the Self-Generated Encoding Group, consisted of 13 older adults and 13 younger adults, totaling 26 participants. These participants did not receive specific instructions on how to link the nouns. Instead, they were simply told to link the nouns in some way (e.g., whether the nouns were the same color, whether the nouns were used for the same purpose, etc.). This group was given a space to type their answers. Examples of the game and the two encoding conditions can be seen in Figure 2, and a demonstration of *Rewind-Remind* can be found at the following link: https://youtu.be/HAAA2oSLyds.

Measures and Materials

Measures of primary interest were participant memory performance before and after the use of *Rewind-Remind.* Baseline and follow-up associative memory test performance was tested using a baseline test and follow-up test of associative memory that are both computer-based and similar in nature, except that the noun pairs were different. Both baseline and follow-up test used measures of proportions, *Pr,* and *d'* (d-prime) to measure associative memory. *Pr* and *d'* are memory discriminability measurements that arise from Signal Detection Theory, which measures performance discriminability using signal-to-noise ratios (Andersen, Morris, Amaral, Bliss, & O'Keefe, 2007; Feenan & Snodgrass, 1990; Stanislaw & Todorov, 1999). *Pr* is simply the proportion of hits, or stimuli that are correctly identified by participants as "studied" pairs, minus the proportion of false alarms, or stimuli that are actually new but wrongly identified by participants to have been previously "studied". *d'* is the *z*-transformed (standardized) *Pr* ratio.

Also, a more general measure of cognitive ability was taken using the Mini-Mental State Examination. The Mini-Mental State Examination (MMSE) was developed to examine orientation, memory, attention, ability to name items, ability to follow spoken and written directions, ability to write sentences, and ability to copy/draw shapes (Folsten, Folstein, &

McHugh, 1974). The MMSE is a popular instrument that has been used in a variety of settings to screen short- and long-term cognitive function (Ericsson, Gatz, Kareholt, Parker, & Fors, 2016; Mitchell, 2009; Molloy & Standish, 1997). Participants completed the MMSE before and after playing *Rewind-Remind* in order to provide information on the general cognitive function of participants. For an example of the MMSE, please see Figure 5.

A measure of memory that more closely resembles daily memory processes was used to measure associative memory performance and possible memory gains through *Rewind-Remind.* The Everyday Cognition Battery (Allaire & Marsiske, 1999) measures cognitive functioning on Inductive Reasoning, Declarative Memory, Working Memory, and Knowledge subscales that use tasks that most adults often engage in daily (e.g., taking medication, preparing food, creating a budget). Cronbach's α values showed adequate internal-consistency reliability for these subscales (.88, .81, .72, and .69, respectively). The Declarative Memory battery was used for this study. For an example question from the Everyday Cognition Battery, please see Figure 6.

Memory performance within *Rewind-Remind* was also assessed. Some variables included: amount of times the participants play *Rewind-Remind;* duration of all games played; memory performance for each time the participants play the game; response time for the games; and amount of times the participants used the lookup table. Finally, at the end of the study, participants filled out the *Rewind-Remind* Feedback Survey. The *Rewind-Remind* Feedback Survey (please see Figure 4) asked users to rate the game on different aspects, to share more demographic information (computer expertise, level of education, etc.), and to provide insights about the playability, enjoyment, and efficacy of the game from a user-centered standpoint.

Procedure

To make data collection more convenient for participants who were unfamiliar with the UTA campus, an IRB modification was filed and approved to allow researchers to meet with participants off-campus in public places. Data collection for these participants was conducted at various public places that allowed the researcher and participants to work one-on-one, thus recreating the conditions of the research space at UTA (e.g., public libraries). First, participants were given information about the study. Once informed consent was obtained, participants completed the associative memory baseline test.

The associative memory baseline test is computer-based and contains words from the Medical Research Council (MRC)

Psycholinguistic Database (Wilson, 1988). When choosing word stimuli, the researchers considered several linguistic norms (e.g., Kucera & Francis, 1967). Researchers wanted to control word frequency, word familiarity, word concreteness, and word meaningfulness. This was done to make sure that the participants were familiar enough with the words to be able to make links between them, but not so familiar with the words that the links would become confusing. Words used in the associative memory tests needed to be familiar (as indicated by a *familiarity* score), easy to imagine (as indicated by *concreteness* and *imageability* scores), and meaningful (as indicated by a *meaningfulness* score). Researchers used nouns that had a minimum of 3 letters, and had familiarity, concreteness, imageability, and meaningfulness scores of at least 300. This would allow participants to focus on making meaningful links between the words.

For the associative memory baseline test, participants were instructed to learn 30 randomized word pairs. They saw a fixation cross in the middle of the screen, for 0.5 seconds. Then, a noun pair was presented. One noun was above the other noun, and the pair was centrally positioned on the screen. Once the participants completed this task, they were tested on their memory of those pairs. During this test, there were 90 pairs. The pairs could be presented as: intact pairs (30 pairs seen before); rearranged pairs (30 pairs that consist of words seen before but newly shuffled pairings); or new pairs (30 new pairs). Participants identified intact, rearranged, or new pairs by pressing corresponding keys on the keyboard. For an example of the associative memory baseline test, please see Figure 7. As with the Dunlosky, Kubat-Silman, and Hertzog (2003) study, both learning and test phases were self-paced. Participants then completed the Everyday Cognition Battery (ECB, Figure 6) and the MMSE (Figure 5) to give an everyday measure of cognitive ability, and a general measure of cognitive ability, respectively.

Participants were then asked to play *Rewind-Remind* (examples of *Rewind-Remind* can be seen in Figure 2). Participants in the control group were then asked to play a version of *Rewind-Remind* that required them to identify matching words. They were shown how to access *Rewind-Remind* (http://rewindremind.herokuapp.com), and played a practice version of the game. These participants were instructed to play the games from home, three times a week, for three weeks. They were asked to return in three weeks to complete the follow-up test.

Participants assigned to either of the experimental groups were also given instructions for how to log onto the *Rewind-Remind* website and play their respective games. These games consisted of word pairs that were randomly generated using similar MRC Psycholinguistic

Database parameters. These pairs were not identical to any of the pairs on the associative baseline test or follow-up test.

Participants in the Directed Encoding Group were instructed to make associations between the nouns based on how the nouns physically fit into one another. For instance, if given the pair “BALL ___ HAT”, the participant had to think of whether a BALL physically fits into a HAT, or if a HAT physically fits into a BALL). In a text box between the words of the pair, participants had to type either “fits into” or “contains” to show their connection. For instance, if given the pair “BALL ___ HAT”, the participant may think of a baseball fitting into a baseball cap. This would mean that the participant could type “fits into” into the blank so that the line would read, “BALL __fits into__ HAT”. If given the pair “SHELF ___ PENCIL”, and the participant thought a pencil fits on a shelf, then the participant would type “contains” to get “SHELF __contains__ PENCIL”. Participants may have differed in their conceptualizations and links between nouns (for instance, one participant might think of a baseball for the first pair, while another participant might think of a medicine ball). However, this is a subjective process meant only to facilitate the pairing of the nouns; the only requirement for the study was that they created some type of link.

Participants in the Self-Generated Encoding Group were given the same type of game, but there were no restrictions placed on what they could enter into the blank text box. For instance, if given the pair "BALL ___ HAT", a participant could enter whatever words or phrase they desired to create the association (e.g., "BALL __is used in sports like__ HAT", or "BALL __is logo on__ HAT"). For all participants who played *Rewind-Remind,* the scores on the games, and the number of/duration of use of the lookup table, were recorded. Participants were asked to play *Rewind-Remind* at least three times a week for three weeks. These games were self-paced, and participants could choose when they wanted to play the games.

Finally, all participants returned for the associative memory follow-up test. The associative memory follow-up test was also computer-based and used words that fit the same parameters used in the associative memory baseline test. Participants engaged in the same steps as they did in the baseline test visit (revisit Figure 7), but the noun pairs were completely different. (Note: Associative memory baseline tests and follow-up tests were counterbalanced across participants.) They then completed the MMSE, the ECB, and the *Rewind-Remind* Feedback Survey. The ECB provided a measure of everyday cognitive ability, the MMSE provided general measures of cognitive ability, and the *Rewind-Remind* Feedback Survey gave more information about user characteristics and user attitudes about the game.

Chapter 3

Results

Participant Demographics

Figure 1 (see Appendix) displays the CONSORT (Consolidated Standards of Reporting Trials) flow diagrams of participants (Hopewell, Hirst, Collins, Mallett, Yu, & Altman, 2011). Table 1 below shows a breakdown of participant demographics.

Table 1. Participant Demographics

Age Group	**Average Age**	**Age Range**	**Gender (*n*)**	**Average Reported Computer Use (1-3)**	**Average Self-Reported Computer Expertise (1-4)**	**Average Completed Level of Education (1-5)**
Older adults	61.28	46-86	Male: 11 Female: 29	2.68: I often use the computer (3-5 times a week).	2.23: I am an adept computer user (familiar with computers, can do many things that I want to do without help.)	2.90: Bachelor’s degree
Younger adults	19.58	18-24	Male: 23 Female: 17	2.73: I often use the computer (3-5 times a week).	2.60: I am a highly-skilled computer user (can accomplish most if not all desired tasks, can learn new things easily.)	1.20: High school diploma or GED

In total, 92 participants were recruited and participated in the study. Participants who expressed that they took medication for diagnosed memory problems, who did not play any *Rewind-Remind* games, and/or who did not return for Session 2 were excluded from the analysis. This resulted in a total *N* of 80 participants.

Data Screening

Data were first split by age (older vs. younger adults) and group (control vs. Directed Encoding vs. Self-Generated Encoding). Data were then explored for missing, minimum, maximum, and outlier values. Data for all groups were determined to be 100% valid, meaning that there were no missing data. Violations of normality were observed (Hypotheses 1 and 2), but Glass et al (1972) reported that analyses of variance have been shown to be generally robust against these violations (as cited in Field, 2009).

To address severe skewness, kurtosis, and violations of normality in variables related to noun-pair lookup table usage (Hypothesis 3), logarithmic transformations were applied, and one outlier was excluded. For all analyses of variance (ANOVAs) and covariance (ANCOVAs), Bonferroni post-hocs were run to examine significant differences.

One-way ANOVAs were used to check that age groups were consistent across experimental groups; that is, young adults in the control group and both experimental groups (Directed Encoding, Self-Generated

Encoding) performed similarly on all baseline measures, and that older adults in all three groups also performed similarly on all baseline measures. For younger adults, associative baseline test proportions were found to violate the assumption of homogeneity of variance (Levene's test: $t(2,37) = 3.86$, $p < .03$). Based on this finding, measures of *Pr* and *d'* were used to assess memory performance. No other violations of this assumption were found (Levene's tests of $p > .30$). Furthermore, no significant differences were found on any baseline measures (*F* statistics of $p > .31$).

For older adults, the assumption of homogeneity of variance was not violated (Levene's tests of $p > .29$). Furthermore, no significant differences were found on baseline measures (*F* statistics of $p > .08$). This helped ensure that *Rewind-Remind* would be responsible for any changes in memory performance during the associative memory follow-up test.

Main Analyses

Hypothesis 1

Hypothesis 1 stated that: a) overall, younger adults would have faster reaction times (measured in milliseconds) than older adults on the associative memory baseline and follow-up tests; and b) older adults in the Directed Encoding Group would have faster reaction times (as compared to older adults in the Self-Generated Encoding Group), because they were given a specific unitization task.

To test Hypothesis 1, a 2 (age: younger adults, older adults) x 3 (group: control, Directed Encoding, Self-Generated Encoding) x 2 (test: baseline/follow-up) mixed model Analysis of Variance (ANOVA) was run on reaction times. Levene's tests were not significant (*p*s > .24), indicating that the assumption of homogeneity of variance was not violated. A significant main effect of Age was found, $F(1,74) = 44.45$, $p < .001$, $\eta_p^2 = .38$. Overall, older adults had longer reaction times (*M* = 3707.12, *SE* = 125.99) than younger adults did (*M* = 2521.41, *SE* = 125.53). No other significant differences were found based on group, and no significant interactions were found between age, group, and/or test (*p*s > .28). Additionally, a significant main effect of the repeated-measures variable of Test was found, $F(1,74) = 15.02$, $p < .001$, $\eta_p^2 = .17$. Bonferroni post-hocs showed that participants had faster reaction times overall during the associative memory follow-up test (*M* = 2902.80, *SE* = 94.88) than the baseline (*M* = 3325.73, *SE* = 113.00). (Note: Violations of normality were found, but ANOVAs are robust against these violations if sample sizes are equal, as they are for age and test.) Results are also summarized in Figure 8 in the Appendix.

Encoding times were also recorded and analyzed. A logarithmic transformation was applied to average encoding times for correctly identified intact pairs. Levene's test was not significant (*p*s > .11). A significant main effect of Age was found, $F(1,74) = 20.76$, $p < .001$, $\eta_p^2 = .22$. Bonferroni post-hocs showed that older adults spent more time encoding pairs (logarithmic transformation: $M = 2.06$, $SE = .02$) that were later identified as correct, than did the younger adults (logarithmic transformation: $M = 1.92$, $SE = .02$). Results are summarized in Figure 9.

Also, a significant main effect of the repeated-measures variable of Test was found, $F(1,74) = 28.79$, $p < .001$, $\eta_p^2 = .28$. Bonferroni post-hocs showed that participants spent more time encoding pairs that were identified as correct during the associative memory follow-up test (logarithmic transformation: $M = 2.06$, $SE = .03$) versus pairs that were later identified as correct during the baseline (logarithmic transformation: $M = 1.92$, $SE = .02$).

Hypothesis 2

Hypothesis 2 stated that: a) younger adults would perform better than older adults on the associative memory baseline and follow-up tests overall; and b) older adults in the <u>Self-Generated Encoding Group</u> would be better at the associative memory test than those in the <u>Directed</u>

Encoding Group, because those in the Self-Generated Encoding Group would have created more semantically meaningful connections between nouns. To test Hypothesis 2, a 2 (age: younger adults, older adults) x 3 (group: control, Directed Encoding, or Self-Generated Encoding) x 2 (test: baseline/follow-up) mixed model ANOVA was run using the *Pr* and *d'* measures of memory performance. Levene's tests were not significant (ps > .22). No significant differences or interactions were found between Age, Group, and Test (ps > .10). A possible trend toward significance was found after including Gender; females in the Directed Encoding Group had a higher mean score on the follow-up associative memory test, but this finding was not significant (ps > .07).

Given the wide age range in the older adult group, further analysis was done to examine if any memory benefits were seen within age groups, with specific attention to the older adult group. This was done to examine possible "sliding scale" effects based on age. First, linear regressions were run to examine if Age predicted baseline and follow-up measures of associative memory test performance as measured by *Pr* and *d'*. Age was not found to be a significant predictor of associative memory test performance (ps > .60). To examine this more closely, the older age group was split into two subgroups, based on the average of the group (61.28 years). This created three age groups: Younger Adults (aged 18-25), Older Adults Group 1 (aged 45-60), and Older Adults Group 2 (aged 61-86). A 3 (age: Younger Adults vs. Older Adults Group 1 vs. Older Adults Group 2) x 2 (Group: Directed Encoding vs. Self-Generated Encoding) x 2 (Test: baseline vs. follow-up) mixed model ANOVA was run. No significant differences were found with regard to associative memory performance (*p*s > .20).

Further analyses were done to examine if there was an effect of minimum training (rather than comparing no training vs. training). First, the appropriate minimum number of training sessions was calculated. Dunlosky, Kubat-Silman, & Hertzog (2003) used two training sessions. However, each session lasted two hours, which would not be comparable to *Rewind-Remind's* design. *Rewind-Remind* games were created to be about 10-15 minutes long, though no specific time limits were set for any users. Therefore, to calculate a possible minimum number of training sessions (i.e., minimum number of *Rewind-Remind* games played), participants who completed fewer than two standard deviations of the average amount of sessions were omitted. The average number of games that the participants completed was 8.39 games, with a standard deviation of 1.62 games; this means that the number of games that was two standard deviations below the average is 6.77 games. This was rounded to 7 total games for this analysis. The ANOVAs were re-run after excluding participants who played fewer than 7 total *Rewind-Remind* games (two younger adults and seven older adults). No significant differences were found for *Pr* or *d'* (*p*s > .58).

Total time of treatment was also examined. As stated earlier, Dunlosky, Kubat-Silman, & Hertzog (2003) used training sessions that lasted 2 hours each, meaning that training lasted a total of 4 hours. *Rewind-Remind* was designed to last about 10-15 minutes each game, but there were no official time restraints; thus, only one participant had a total training time of around 4 hours (271.02 minutes, or 4.52 hours). To calculate a possible minimum total training time that would have an effect, further analysis was done of participants who completed at least two standard deviations of the average amount of total training time. The average time that participants spent playing *Rewind-Remind* was 73.08 minutes, with a standard deviation of 52.07 minutes; this means that the total time that was two standard deviations below the average was 21.01 minutes. The ANOVAs were re-run after excluding participants who had a total training time less than 21.01 minutes (four younger adults and one older adult). No significant differences were found for *Pr* or *d'* (*p*s > .71).

Hypothesis 3

Hypothesis 3 centered around the use of the noun-pair lookup table functionality in *Rewind-Remind.* This functionality was integrated through the use of a "Hint" table. Specifically, it was hypothesized that:

a) younger adults would use the noun-pair lookup table fewer times than older adults overall;
b) older adults in the Self-Generated Encoding Group would use the noun-pair table fewer times than those in the Directed Encoding Group;
c) younger adults would use the noun-pair table for a shorter amount of time than older adults overall; and,
d) older adults in the Self-Generated Encoding Group would use the noun-pair table for a shorter amount of time than those in the Directed Encoding Group.

To test Hypothesis 3, a 2 (age: younger adults, older adults) x 2 (group: Directed Encoding, Self-Generated Encoding) chi-square test of independence was run on the overall amount of times that participants used the noun-pair lookup table during *Rewind-Remind* play. It was anticipated that overall, older adults would use the noun-pair lookup table more frequently than younger adults, and that older adults in the Directed Encoding Group would use the table more frequently than the older adults in the Self-Generated Encoding Group would. However, no significant difference was found, $\chi^2(24) = 24.84$, $p = .42$.

Additionally, a 2 (age: younger adults, older adults) x 2 (group: Directed Encoding, Self-Generated Encoding) between-subjects ANOVA was run on the duration of time of use of the noun-pair lookup tables. It was anticipated that younger adults would spend less time using the table than older adults, and that older adults in the Directed Encoding Group would use the noun-pair lookup tables for more time than the older adults in the Self-Generated Encoding Group. Levene's test was not significant, $F(3,23) = .85$, $p = .48$. A significant main effect of Age was found, $F(1,23) = 37.90$, $p < .001$, $\eta_p^2 = .62$. Bonferroni post-hocs showed that older adults used the noun-pair lookup table for a longer period of time (logarithmic transformed variable: $M = 1.27$, $SE = .14$) than the younger adults did (logarithmic transformed variable: $M = -.08$, $SE = .17$). However, no other main effects or interactions were significant (*p*s > .51). Results are summarized in Figure 10.

Exploratory Analyses

Several exploratory analyses were also conducted using the Mini-Mental Status Examination (MMSE), Everyday Cognition Battery (ECB), and *Rewind-Remind* Feedback Survey data. A 2 (age: young adults, older adults) x 3 (group: control, Directed Encoding, Self-Generated Encoding) x 2 (battery: 2 (test: baseline/follow-up) mixed model ANCOVA was run on associative memory test data to examine if there were any differences while controlling for general cognition as measured by the MMSE (covariate 1), and while controlling for the number of times (covariate 2) and the total amount of time (covariate 3) participants played *Rewind-Remind* by the end of the three-week period. No significant covariates were found (*p*s > .31) for *Pr* or *d'* scores.

A 2 (age: young adults, older adults) x 3 (group: control, Directed Encoding, Self-Generated Encoding) x 2 (test: baseline/follow-up) mixed model ANOVA was run on Everyday Cognition Battery scores to examine if there were any interactions with cognitive training. A significant main effect of Age was found, $F(1,74) = 5.24$, $p = .03$, $\eta_p^2 = .07$. Bonferroni post-hocs showed that older adults did worse on the ECB (*M* = .79, *SE* = .02) than did younger adults (*M* = .85, *SE* = .02). Results are summarized in Figure 11. Also, a significant main effect of Group was found, $F(2,74) = 5.68$, $p < .005$, $\eta_p^2 = .13$. Bonferroni post-hocs showed that those in the Self-Generated Encoding Group did worse on the ECB (*M* = .76, *SE* = .02) than those the control group did (*M* = .86, *SE* = .02). There was no significant interaction of age and group ($p = .73$).

To follow this up, a linear regression was run (similar to the one used for associative memory test performance in Hypothesis 2) to see if Age was a significant predictor of Everyday Cognition Battery performance. Age was a significant predictor at baseline testing only, F1,79) = 6.81, p = .01, explaining 8% of the variance. Age was not a significant predictor of ECB performance during follow-up testing (p = 24). To examine this more closely, the older age group was split into two subgroups, based on the average of the group (61.28 years). This created three age groups: Younger Adults (aged 18-25), Older Adults Group 1 (aged 45-60), and Older Adults Group 2 (aged 61-86). A 3 (age: Younger Adults vs. Older Adults Group 1 vs. Older Adults Group 2) x 2 (Group: Directed Encoding vs. Self-Generated Encoding) x 2 (Test: baseline vs. follow-up) mixed model ANOVA was run. The only additional significant finding from this analysis was a main effect of Age, $F(2,71)$ = 3.39, p = .04, $\eta_p^2 = .09$. Bonferroni post-hocs showed no significant differences between younger adults and older adults in the 45- to 60-year-old age range (p = .67), or the two older adult groups (p = .58). However, a significant difference (p = .04) between the younger adults and the older adults in the 61- to 86-year-old age range was found, such that the younger adults performed better on the Everyday Cognition Battery test overall (*M* = .85, *SE* = .02) than the older adults in the higher age range (*M* = .76, *SE* = .03).

Some differences regarding gender were found. Overall, males and females performed about the same ($p = .63$). However, there was a significant interaction between Test and Gender, $F(1,67) = 4.53$, $p = .04$, $\eta_p^2 = .06$. Bonferroni post-hocs showed that males did better on the follow-up test (*M* = .83, *SE* = .02) than the baseline test (*M* = .77, *SE* = .02). Further, there was a significant interaction between Test, Group, and Gender, $F(1,67) = 4.89$, $p = .01$, $\eta_p^2 = .13$. Specifically, females in the control group did better on the ECB follow-up test (*M* = .87, *SE* = .03) than females in the <u>Self-Generated Encoding Group</u> (*M* = .73, *SE* = .03).

User Analyses

Analyses were also run on responses to the *Rewind-Remind* Feedback Survey. Figures 2 and 3 display the overall attitudes about the game. Also, Figures 11-14 in the Appendix contain further information on survey responses.

Descriptive statistics for Questions 1-4 of the *Rewind-Remind* Feedback Survey were examined to assess users' attitudes about the game. Question 1 of the survey asked users to indicate what they generally thought of *Rewind-Remind.* Responses were formatted in star ratings:

- 1 star = “I hated it”
- 2 stars = “I disliked it”
- 3 stars = “I thought it was OK”
- 4 stars = “I liked it”
- 5 stars = “I loved it”
- Average rating for *Rewind/Remind* was a 3.95 (*SD* = .78) out of a possible 5 stars.

Question 2 of the survey asked users to rate how easy or difficult it was to play *Rewind-Remind*. Star ratings were defined as follows:

- 1 star = “Extremely difficult to play”
- 2 stars = “Difficult to play”
- 3 stars = “Neither difficult nor easy to play”
- 4 stars = “Easy to play”
- 5 stars = “Extremely easy to play”
- Average rating was a 4.31 *(SD* = .80) out of a possible 5 stars.

Question 3 asked users to rate their memory after playing *Rewind-Remind.* Star ratings were defined as follows:

- 1 star = “I noticed no memory benefits in my daily life after playing *Rewind-Remind*”
- 2 stars = “I noticed some memory benefits in my daily life after playing *Rewind-Remind*”
- 3 stars = “I noticed strong memory benefits in my daily life after playing *Rewind-Remind*”
- Average rating was a 1.79 (*SD* = .67) out of a possible 3 stars.

Question 4 asked users to rate how likely they were to play *Rewind-Remind* in the future. Star ratings were defined as follows:

- 1 star = “Very unlikely to use in the future
- 2 stars = “Unlikely to use in the future”
- 3 stars = “Neither unlikely nor likely to use in the future”
- 4 stars = “Likely to use in the future”
- 5 stars = “Very likely to use in the future”
- Average rating was a 3.10 (*SD* = 1.33) out of a possible 5 stars.

Finally, a multiple regression was used to investigate whether reported frequency of computer use, reported computer expertise, and/or reported level of education predicted associative memory baseline and follow-up test performance. These variables were measured using questions 5, 6, and 9 on the survey. No significant predictors were revealed for associative memory tests.

Interestingly, reported frequency of computer use predicted Everyday Cognition Battery baseline and follow-up test performances for older adults. For baseline performance, reported frequency of computer use was marginally significant, $F(3,36) = 2.83$, $p = .052$, and explained 19.1% of the variance. For follow-up test performance, reported frequency of computer use explained 22.8% of the variance, $F(3,36) = 3.54$, $p = .024$. However, the direction of causality in this relationship is unclear (see Discussion, section entitled, “Participant Demographics that Predicted Memory Performance”).

Chapter 4

Discussion

Main Analyses

Hypothesis 1

Hypothesis 1 was partially supported. First, it was hypothesized that younger adults would be faster than older adults overall on the associative memory baseline and follow-up tests. A significant main effect of age supported this hypothesis. This suggests that age-related associative memory deficits may not solely be reflected by memory discriminability but also time spent retrieving information. Specifically, these results support the notion that older adults may require more time to retrieve associative information (Hultsch, MacDonald, & Dixon, 2002).

It was also hypothesized that, because older adults experience associative memory deficits, giving older adults a specific way to associate information (i.e., older adults in the Directed Encoding Group) would result in faster reaction times than not giving older adults a specific encoding strategy (i.e., older adults in the Self-Generated Encoding Group). This hypothesis was not supported by the data. Although focusing participants' attention to use an encoding strategy may reduce attentional costs, there may be an additional attentional burden on participants to learn an unfamiliar encoding strategy (Naveh-Benjamin, Craik, Guez, & Kreuger, 2005; Patterson & Hertzog, 2010; Salthouse, 1995). This is also reflected qualitatively in some participant responses to the *Rewind-Remind* Feedback Survey. One participant in the younger adult group stated, "I noticed in the game that using "contains" or "fits into" helped me better remember the pairs than just starting at the pair and trying to memorize it." A participant in the older adult group stated, "[Enjoyed] the experience, although I did not do particularly well. Somewhat distracted by the first comparison words. Should have ignored them and gone on answering the real question." This suggests that, while users followed game instructions, they may generally find the <u>Directed Encoding</u> strategy too difficult or confusing to implement, and age-related differences can arise in these attitudes. This will be reviewed more in-depth later in the Discussion section.

One possible explanation of this could be related to age-based changes in default mode network (DMN) activity. Reaction time has been related to default mode network activity: generally, the longer a person can actively try to remember stimuli, the better they can suppress DMN activity to remember those stimuli (Gimbel & Brewer, 2011). For younger adults, deactivation of DMN is not crucial to the formation and retrieval of associations (Park, Polk, Hebrank, & Jenkins, 2009). Contrastingly, not only do older adults need to deactivate the DMN in order to make memory associations (Park, Polk, Hebrank, & Jenkins, 2009), but they also have a harder time suppressing DMN activity in general (Park et al., 2013; Ren, Li, Zheng, & Li, 2015). The two encoding strategies presented in this study may not have been enough to help older adults override DMN activity, thus explaining the nonsignificant results within the older adult group. Moreover, Weissman, Roberts, Visscher, and Woldorff (2006) found that attentional lapses may also have decreased deactivation of the DMN. If older adults experience attention costs in learning the encoding strategies, they may have an even harder time suppressing DMN activity.

However, reaction time does not necessarily reflect memory accuracy or discriminability. If changes in reaction time do not relate to memory performance, then reaction time may not be improved by strategies designed to enhance memory performance. For instance, Simposon, Camfield, Pipingas, Macpherson, and Stough (2012) found that cognitive training on reaction time tasks (e.g., responding to a stimulus as quickly as possible based on certain rules) did lead to significantly faster reaction times as compared to a control task. However, faster reaction times did not lead to significant improvement in memory performance on working memory or item memory tests. Additionally, participants had significantly faster reaction times overall on the associative memory follow-up test than the baseline. This could be because all participants were familiar with the instructions for the task by then, meaning that they felt more comfortable moving at a faster pace.

Hypothesis 2

Hypothesis 2 was not supported. First, it was hypothesized that younger adults would perform better on the associative memory tests overall. It was also hypothesized that older adults in the Self-Generated Encoding Group would do better on the associative memory tests than their counterparts in the Directed Encoding Group, as the Self-Generated Encoding Group would be creating more semantically meaningful connections between the words in the given pairs. Results were nonsignificant even when comparing calculated minimum number of trainings (seven *Rewind-Remind* games) and minimum total training time (approximately 21 minutes).

The nonsignificant results may be explained by the self-pacing of the task. Although Dunlosky, Kubat-Silman, and Hertzog (2003) used self-paced tasks in their study, and found significant age differences in associative memory performance, there is research that suggests that self-pacing can alleviate age-related associative memory deficits as well (Kilb & Naveh-Benjamin, 2011; Light, Patterson, Chung, & Healy, 2004; Overman & Becker, 2009; Rhodes, Castel, & Jacoby, 2008; Salthouse, 1995). For example, Rhodes, Castel, and Jacoby (2008) found that self-pacing modestly impacted associative memory in older adults, leading to more comparable memory performance to their younger counterparts. This may have to do with increased encoding time of stimuli. Kilb & Naveh-Benjamin (2011) found that even though older adults did worse than younger adults on associative memory tests, simply showing older adults a face-scene pair for five seconds resulted in better memory performance than showing older adults a face-scene pair for three seconds. The present study could provide some support for this research with the finding that for correct intact responses, older adults spent more time encoding information that was correctly identified later during test, thus leading to more comparable memory performance to the younger adults. Also, an effect of age was seen on the Everyday Cognition Battery, a timed test that better reflects daily associative memory functions; the timed aspect may have forced older adults to make more errors (a more in-depth examination of these results is located in the Exploratory Analyses section).

Further analyses centered around other factors that may have impacted associative memory performance. A possible trend toward significance was found for females in the Directed Encoding Group. Females in this group had a higher (but nonsignificant) mean score on the follow-up associative memory test. Also, no differences were found when examining "sliding scale" effects of age; no significant differences in associative memory performance were found after splitting the older adult group into two subgroups (ages 45-60 vs. 61-86).

Finally, a qualitative review of participant responses within the game suggested that participants in both the Directed Encoding and Self-Generated Encoding Groups followed their respective instructions. However, because the aims of the study were to examine whether *Rewind-Remind* cognitive training could extend to everyday life, associative memory performance was tested implicitly. Participants may not have used the encoding strategies during the associative memory follow-up test, which may help explain the nonsignificant results, especially for the older adults.

Hypothesis 3

Hypothesis 3 was partially supported. It was hypothesized that:

a) younger adults would use the noun-pair lookup table fewer times than older adults overall;

b) older adults in the Self-Generated Encoding Group would use the noun-pair table fewer times than those in the Directed Encoding Group;

c) younger adults, overall, would use the noun-pair table for a shorter amount of time than older adults overall; and,

d) older adults in the Self-Generated Encoding Group would use the noun-pair table for a shorter amount of time than those in the Directed Encoding Group.

When playing *Rewind-Remind,* older and younger adults did not differ in their frequency of use of the noun-pair lookup table, nor did older adults in either of the experimental groups differ in their frequency of use of the table. However, older adults did use the noun-pair lookup table for a longer total duration than their younger counterparts did (though the experimental groups within the older adult category did not differ in their total duration of use of the table). This provides encouraging evidence that the *Rewind-Remind* game can serve as a new and unique screening tool to help identify instances of retrieval shift in healthy, older adults.

The *Rewind-Remind* noun-pair lookup table is based on the noun-pair lookup task. Kyllonen (1990) developed the noun-pair lookup task for the Cognitive Abilities Measurement (CAM) Battery. The CAM measures success on the following learning tasks: processing speed, working memory, declarative knowledge, declarative learning, procedural knowledge, and procedural learning (Kyllonen, 1994). The noun-pair lookup task specifically examines how individuals memorize a set of pairs, and whether those individuals later use a direct retrieval strategy or a visual search strategy. Ackerman and Woltz (1994) first examined how this noun-pair lookup task measures how word-pair memory could influence noun-pair lookup task performance. They found that, with practice, individuals who used consistent mapping of the noun-pair table performed better on subsequent memory tests with increasing accuracy and speed, which reflected the use of retrieval rather than visual search strategies. Touron and Hertzog (2004) applied the task to older adults to investigate how these strategies may relate to age-related associative memory deficits. They and other researchers have found that older adults tend to switch to visual search strategies when completing associative memory tests that incorporate noun-pair lookup tasks or similar tasks (Cohn, Emrich, & Moscovitch, 2008; Hertzog & Touron, 2011; Hines, Hertzog, & Touron, 2012; Touron & Hertzog, 2009; Touron & Hertzog, 2014).

Older adults tend to switch to visual search strategies on these types of tests for several reasons. This switch may reflect lower confidence in the direct retrieval strategy, regardless of knowledge or accuracy (Beier, 2008; Hertzog & Robinson, 2005). It may also reflect older adults' prioritization of accuracy over speed, beliefs about how/what they will remember, and an erroneous mental model that the retrieval strategy will not be as efficient (Hertzog, 2008). Receiving feedback about reaction times can facilitate how often older adults use the noun-pair lookup table (Hertzog, Touron, & Hines, 2007). Even extraneous variables, like financial incentives, have been shown to influence older adults' use of visual search vs. retrieval strategies (Touron, Swaim, & Hertzog, 2007). In these studies, visual search strategy use has been measured by comparing reaction times and eye movements. As discussed, reaction times may have various inconsistencies regarding measurement of memory performance. Furthermore, eye movement studies may not clearly reflect the use of visual search strategies. For instance, Touron, Hertzog, and Frank (2011) found that older adults still looked at the noun-pair lookup even when the table was filled with unrelated placeholders, suggesting that the participants were merely attending to the table rather than using it to gather relevant memory information.

Rewind-Remind may be able to address these aspects by providing a screening tool that may capture more deliberate uses of the noun-pair lookup table. Users must click on the "HINT" button during memory testing to access the noun-pair lookup table. Also, users must click an "X" at the top right-hand side of the noun-pair lookup table to return to the memory test. These actions help to ensure that users are actively choosing to use the noun-pair lookup table, thereby switching to a visual search strategy. This may result in more accurate measurements of retrieval shift. Additionally, reaction times are displayed on the screen during memory testing. Providing users feedback on their performance times has been shown to help older adults use retrieval strategies instead.

Exploratory Analyses

The exploratory analyses revealed that Mini-Mental Status Examination (MMSE) scores, the number of *Rewind-Remind* games played, and the total amount of time participants played *Rewind-Remind* did not serve as significant covariates. This suggests that general cognition and frequency/duration of *Rewind-Remind* gameplay did not covary with associative memory test performance. The MMSE is a general state cognitive assessment meant to screen individuals for things like orientation, short-term memory, and the ability to follow simple instructions (Folsten, Folstein, & McHugh, 1974). Overall, participants performed consistently well on this assessment (baseline: M = .97, SE = .004; follow-up test: M = .99, SE = .002), which may explain the nonsignificant results.

However, Everyday Cognition Battery scores did differ based on age. Older adults performed worse than younger adults in general. This may be because of the restricted study time. For the ECB, participants are given 1 minute to study a page of associative information that they may encounter during daily life, like prescription, budget, and nutritional information; for instance, participants may be shown a fake patient's prescription, and may later be asked which doctor prescribed that medication to the fake patient. Having a more complex bank of associative information to memorize in a limited time may have showcased age-related associative memory deficits.

Furthermore, splitting the older adult age group into two groups (ages 45 to 60 vs. ages 61 to 86) showed age differences on Everyday Cognition Battery scores such that the older adults in the higher age range performed significantly worse than their younger adult counterparts, but that both sub-groups of older adults performed similarly. This could be due to the wide range of ages used to define the older adult group; though memory deficits start to appear around age 45 (Park, Kennedy, Rodrigue, Hebrank, & Park, 2013), they may not have been severe enough to elicit any differences in the associative memory tests, or to gain any benefit from cognitive training.

It was also found that males did better on the follow-up ECB than on the baseline ECB. This effect was not seen in females. Males had a numerically lower mean at baseline (M = .77) than females did (M = .82).

Gender differences regarding visuospatial aspects of *Rewind-Remind* and the ECB could have contributed to the males' ability to make up this deficit for follow-up testing. Wang and Carr (2014) found that males tend to benefit from visuospatial short-term and working memory techniques. Also, Terlecki, Newcombe, and Little (2008) found that males who had undergone video game training had better initial scores on spatial tasks, though females' scores eventually increased over time.

Rewind-Remind encouraged participants to visualize word pairs in order to make associations between the words, which may have prompted visuospatial memory processing. Furthermore, the ECB contained information in grids and boxes, which could have given participants more environmental support during memory retrieval. Given this inclination to use more visuospatial processing techniques, male participants could have benefited from using mental imagery during the *Rewind-Remind* games. This could have related to the Directed Encoding Group in particular; participants in this group used a memory strategy that involved making a size judgment about how the two nouns would physically fit together. However, there were no significant ECB follow-up test differences based on experimental Group within males.

This suggests that any benefits from visuospatial processing would not have been facilitated by *Rewind-Remind* but rather just simply playing a computer game. Males could have gained an initial advantage after using the computer to play *Rewind-Remind* by using mental imagery to process placement of words on the screen. However, as Terlecki, Newcombe, and Little (2008) found, females might have eventually seen a benefit after continued play. Male participants could also just have used more visuospatial processing on the ECB follow-up test. They might have used mental imagery of the ECB (e.g., which box or grid the information was contained in) to help them visualize where certain information was located on the page. This, in turn, could have helped them remember the details of that information.

User Analyses

Opinions of *Rewind-Remind*

Generally, users liked *Rewind-Remind*. Below are some positive feedback regarding user attitudes of the game:

- "I had a lot of fun playing the game. Bridging two words with a phrase led to lots of interesting mental images, and plenty of little opportunities to sharpen my wit. Overall, I am happy that I participated in this study."

- "It was interesting to observe my memory strategies in the associative memory test. Generally i feel like I have a bad memory, and yet I was very successful at this task."

Users who gave lower star ratings also provided feedback about what they did not like about the game. Much of this feedback centered around the game being too repetitive:

- "Didn't like playing the same game for three weeks"
- "Change how each week's game goes."
- "It was really long and mundane."
- "To make it more gamelike- I like puzzles,spider solitaire, pogo word whomp- so a little more exciting. It was very challenging-got that- now just better marketing."

This feedback is helpful in re-tooling *Rewind-Remind* for future study. For instance, making games more engaging, and perhaps including more context (this point will be discussed in more detail in the Limitations section).

Playability of *Rewind-Remind*

Users also generally found it easy to play *Rewind-Remind.* However, users gave much needed feedback on how to make the game navigation and overall design more user-friendly. In its current iteration, *Rewind-Remind* requires users to click the text box before entering their responses (the matched words for the control group, “contains/fits into” for the Directed Encoding Group, and subjective encoding phrases for the Self-Generated Encoding Group). This was done to minimize accidental clicks or submissions. However, users may prefer a more automatic experience:

- “I think for the online game, they should make it where the participant can [press] enter to go to the next set of words instead of clicking the next button as it consumes time specially if you're using a laptop.”

One user also pointed out that this may have inflated reaction time unfairly, as there may be increased variance in the speed and accuracy of users clicking “Next” to progress through the games. Although this inflation was initially anticipated to be minimal, future iterations of *Rewind-Remind* can take this into account.

Memory Benefits from and Future Interest in *Rewind-Remind*

Some users reported noticing memory benefits in daily life (e.g., “I feel I will use word association in the future to help me remember names etc.”, “it [has] strong memory benefits”). However, most users reported minimal to no daily memory benefits after playing *Rewind-Remind:*

- “Maybe this game does not help for [future memory]. It just [helps] you to remember [right now]. Even then I am not sure if it helps much at all. Maybe if there are tips on how to remember certain words, that could help.”

This is supported by the nonsignificant results on associative memory performance. Additionally, although some users reported an interest in playing *Rewind-Remind* again (e.g., “This game is very useful in testing my memory. Hope we could play again.”), users generally felt that they were neither likely nor unlikely to play the current iteration of *Rewind-Remind* in the future. Future iterations of *Rewind-Remind* should examine how to promote and extend memory benefits, as well as behaviorally incentivize repeated play over time.

Participant Demographics that Predicted Memory Performance

It was found that reported frequency of computer use predicted Everyday Cognition Battery scores in older adults. Research has suggested that computer use and cognition may be related, especially in older age. Tun and Lachman (2010) found that frequent computer use predicted better executive functioning in older adults, even after controlling for education level. Better executive function may have provided additional associative memory support in a time-constrained memory task like the ECB. Also, Silbert et al. (2016) found that less daily computer use (defined by mouse and pixel movement data) is linked to smaller hippocampal volume. Research has shown that decreased hippocampal volume may contribute to associative memory deficits in older adults (Ward et al., 2014). Thus, it is possible that participants who endorsed less frequent computer use may have comparatively smaller hippocampal volumes, which may indicate potential additional associative memory deficits for those users.

The causality of this relationship is unclear. It is unknown if increasing computer use would necessarily cause an increase in hippocampal volume. Additionally, those who had high scores on the ECB may have been more likely to use computers, or may have had stronger confidence in their computer use. More research is needed in order to clarify this relationship.

Limitations

Study Limitations

Because the focus of this study was to examine user behavior and memory performance implicitly, lack of environmental control for *Rewind-Remind* was a limitation of the study. There was no control over the gameplay environment, frequency, or quality (as compared to the highly-controlled environment of associative memory test during Sessions 1 and 2). Furthermore, there was no control for other cognitive training that the participants may have engaged in before or during participation in *Rewind-Remind*. Additional cognitive training may have influenced associative memory performance measures.

Another study limitation that may have contributed to the nonsignificant associative memory results could be the lack of retrieval context during the *Rewind-Remind* games. The games focused on providing a forum to facilitate the subjective creation of, or give specific strategies for supporting encoding processes. This addresses the *Associative Deficit Hypothesis*, which primarily focuses on ensuring that proper encoding processes lead to successful memory formation. However, the games did not provide any retrieval cues or other context. This does not address the *Environmental Support Hypothesis,* which states that strong encoding *and* rich context during retrieval can help support memory processes. The nonsignificant results regarding associative memory in this study may indicate support for the *Environmental Support Hypothesis*.

Other limitations of the study include the associative memory tests themselves. Although the associative memory test paradigm used in this study was based on signal detection theory and is a hallmark of associative memory studies in general, it was used in basic experimental tasks that have clearer links to brain imaging (e.g., fMRI, EEG) or brain activity (e.g., transcranial direct current stimulation). Therefore, while the paradigm does provide information on memory discriminability, it may not be the best test to use in a behavioral study with the aim of measuring everyday associative memory. The Everyday Cognition Battery was used to address this point. There was a significant three-way interaction between Test, Group, and Gender in that during follow-up testing, females in the control group performed better than females in the Self-Generated Encoding Group. However, it was also found that those randomly selected for the Self-Generated Encoding Group did worse than their counterparts in the control group, overall. Though this impacts the results minimally (as no significant differences were found for ECB performance based on Group overall), results on the ECB should still be interpreted cautiously.

Rewind-Remind Limitations

Some game limitations exist in this study. First, Herokuapp servers went down temporarily at the start of data collection. The servers were fixed quickly, which led to minimal impact on the study. However, users who though the game was permanently inaccessible may not have returned for follow-up testing. Users could have played fewer games than they would have had they not experienced that initial server error. Additionally, users reported several points for consideration regarding the *Rewind-Remind* gameplay, like having to click in the text box each time, possible inflated reaction times, and monotony of game play (as discussed in the User Analyses section).

Future Directions

Several changes can be made to *Rewind-Remind* to enhance its efficacy. First, providing retrieval support within the game may provide additional environmental support (e.g., memory cues) that can help with associative memory. The *Environmental Support Hypothesis* states that providing rich contextual details at retrieval can help older adults remember associations. One such change could be to prompt users to repeat the semantic linkage phrases that the used when learning the word pairs. *Rewind-Remind* currently records the phrases entered by participants. One function that could be added could be displaying those phrases or showing parts of those phrases during test, showing the word pair and asking participants to make recognition judgments (like in the current iteration), or requesting the participants to recall the word pair (cued recall). This may be a better way to encourage implicit learning of the memory strategy.

Further, *Rewind-Remind* could incorporate memory mnemonics that incorporate the stimuli to help facilitate associative learning and reintroducing those mnemonics as retrieval cues. Li et al. (2016) incorporated this strategy when assessing encoding and retrieval of face-name pairs. Participants were shown pictures of individuals and were instructed to identify prominent facial features; then, participants learned the names of these individuals, and were instructed to associate the name to the prominent facial feature.

Also, *Rewind-Remind* could provide additional visuospatial structures, like with the Method of Loci/Memory Palace (Legge, Madan, Ng, & Caplan, 2012; Li et al., 2016). This process requires imagining a familiar place (e.g., the living room in one's house, a garden in one's backyard, the path one takes to work) and placing to-be-remembered stimuli in that place. As participants mentally navigate those places, they remember the stimuli. This process has been adapted for virtual environments, and *Rewind-Remind* can capitalize on this technology.

These additions may not only lead to enhance associative memory, but may be more engaging for the participants. Adding visuospatial aspects could encourage participants to be more active in the task and could provide richer context for memory encoding and retrieval. Finally, using everyday stimuli (faces and names, familiar places) may help extend memory benefits to participants' daily lives.

Conclusions

Associative memory test results generally aligned with previous research on associative memory deficits in healthy, older adults. Age differences were found in overall associative memory test reaction times such that younger adults were faster than older adults. Additionally, age differences were found in encoding times for correct intact responses, such that older adults spent more time encoding than did younger adults for later correctly identified noun pairs. Everyday Cognition Battery scores also resulted in significant age differences, possibly due to the timed nature of the tests. However, no significant differences were found on associative memory discriminability. This supports research that shows that older adults' associative memory deficits may be partially alleviated when older adults have enough time to study information.

The present results also align with research on retrieval shift seen in older adults. They used the *Rewind-Remind* noun-pair lookup tables for significantly longer amounts of time than their younger counterparts. This supports research that suggests that older adults switch to visual search strategies when completing associative memory tests in order to: compensate for associative memory deficits; ensure accuracy; counteract their low confidence in their memory processes, and; align with possibly incorrect mental models about their associative memory retrieval abilities.

This first iteration of *Rewind-Remind* did not provide measurable memory enhancements for associative memory deficits that may arise in older age. However, instead of being used as a therapeutic tool, this iteration of *Rewind-Remind* could be more useful as a screening tool specifically for retrieval shift. This is supported by the finding that *Rewind-Remind* gameplay analysis uncovered a significant age difference in the duration of the participants' use of the *Rewind-Remind* noun-pair lookup table. If incorporated into other cognitive remediation tools, the *Rewind-Remind* noun-pair lookup table can serve as a novel, non-intrusive way to measure instances of retrieval shift. This is particularly relevant to healthy, older adults, as they increasingly engage in retrieval shift strategies to compensate for associative memory deficits (Hertzog & Touron, 2011).

Finally, user analyses revealed valuable feedback regarding attitudes about, playability of, efficacy of, and future interest in *Rewind-Remind.* Namely, protection from server issues and quality control should be addressed. Also, future iterations of *Rewind-Remind* should make navigation through the games more user-friendly by automating the input submission process (without sacrificing input or response accuracy). Future studies can address user feedback to make *Rewind-Remind* more user-friendly, accurate, and engaging. Specifically, researchers can incorporate richer retrieval contexts to the gameplay, which aligns with the *Environmental Support Hypothesis*. This would mean helping users during retrieval by providing memory cues, or prompting the users to Making these changes can help provide a useful cognitive remediation tool that can address associative memory deficits in healthy, older adults.

Appendix

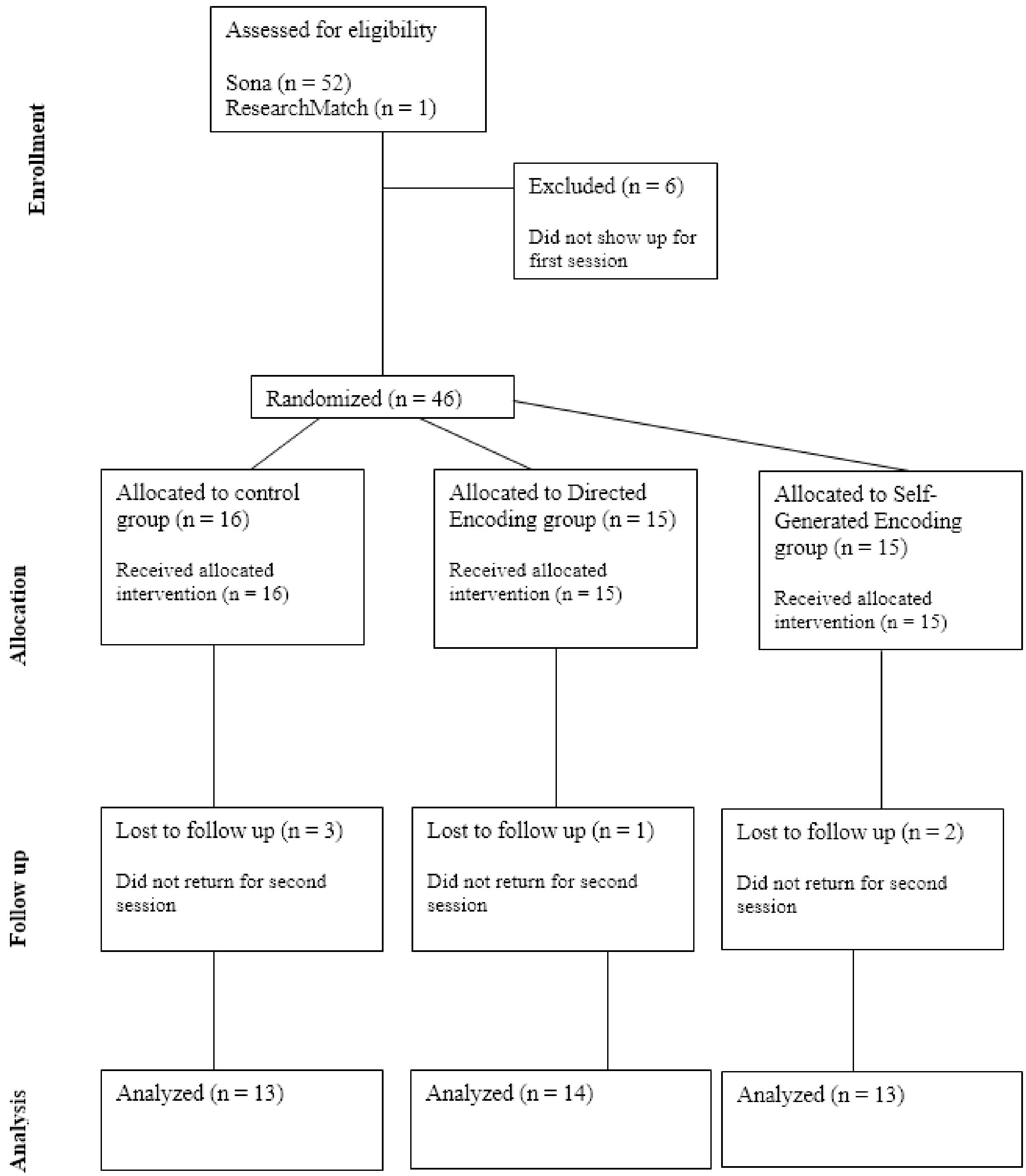

Figure 1A. CONSORT Flow Diagram (Younger Adult age group).

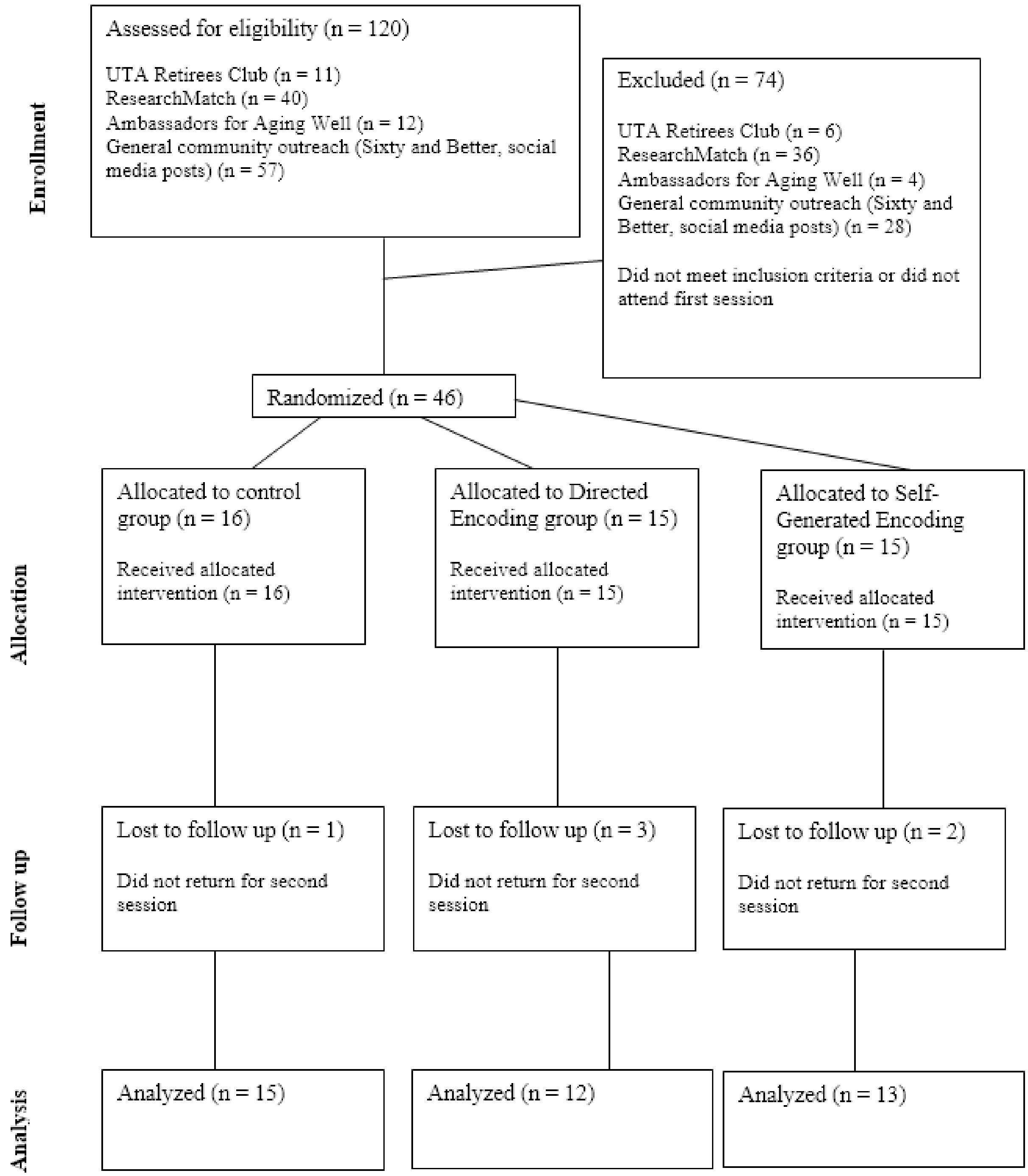

Figure 1B. CONSORT Flow Diagram (Older Adult age group).

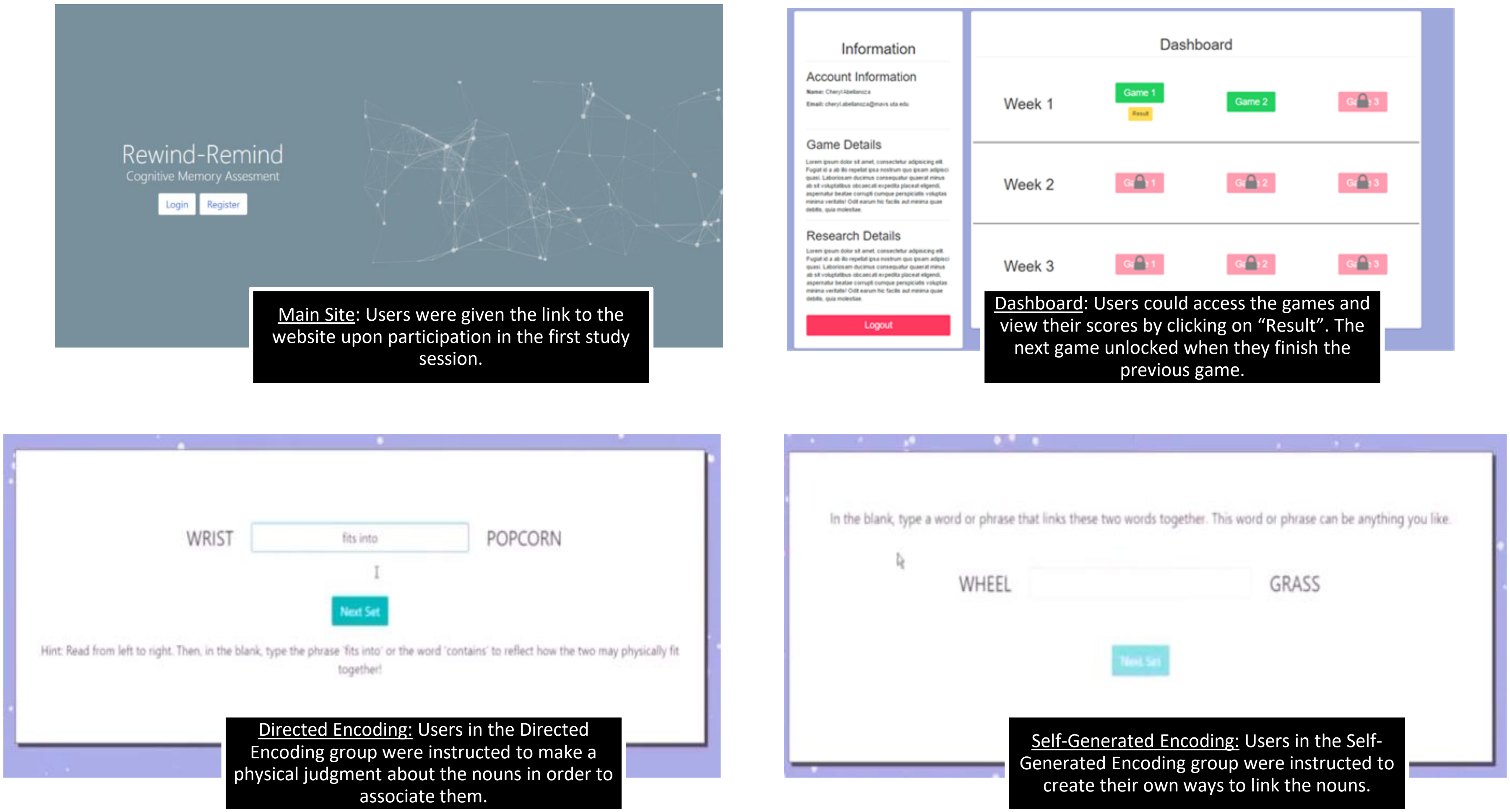

Figure 2. Rewind-Remind Example. The game can be accessed at http://rewindremind.herokuapp.com. A demonstration of the game can be found at https://youtu.be/HAAA2oSLyds.

Rewind/Remind

Thank you for your participation in the Rewind/Remind study! Please answer the questions below reflecting your thoughts about Rewind/Remind. We value honest feedback that will help us make the Rewind/Remind games better! If you have any questions, please let us know.

1. Please indicate your overall opinion of Rewind/Remind.

I hated it.	I disliked it.	I thought it was OK.	I liked it.	I loved it.
☆	☆	☆	☆	☆

2. Please rate the playability of Rewind/Remind.

Extremely Difficult to Play	Difficult to Play	Neither Difficult nor Easy to Play	Easy to Play	Extremely Easy to Play
☆	☆	☆	☆	☆

3. Please rate the efficacy of Rewind/Remind.

I noticed no memory benefits in my daily life after playing Rewind/Remind.	I noticed some memory benefits in my daily life after playing Rewind/Remind.	I noticed strong memory benefits in my daily life after playing Rewind/Remind.
☆	☆	☆

4. Please rate your possible future use of Rewind/Remind.

Very unlikely to use in the future	Unlikely to use in the future	Neither unlikely or likely to use in the future	Likely to use in the future	Very likely to use in the future
☆	☆	☆	☆	☆

Figure 3. Rewind-Remind Feedback Survey, part 1. The survey can be accessed at https://www.surveymonkey.com/r/WHXP8XT.

Please answer the following demographic questions. If you have any questions, please let us know!

5. How often do you use the computer?

- ◯ I rarely use the computer (0-3 times a week).
- ◯ I often use the computer (3-5 times a week).
- ◯ I frequently use the computer (at least once every day).

6. What is your computer expertise?

- ◯ I am a computer novice (new to computers).
- ◯ I am an adept computer user (familiar with computers, can do many things that I want to do without help).
- ◯ I am a highly-skilled computer user (can accomplish most if not all desired tasks, can learn new things easily).
- ◯ I am a computer expert (worked with computers often, can fix computers, have an understanding of coding, etc.).

7. What is your age?

8. What is your level of education?

- ◯ High school diploma or GED
- ◯ Associate's degree
- ◯ Bachelor's degree
- ◯ Master's degree
- ◯ Doctoral degree

Figure 4. Rewind-Remind Feedback Survey, part 2. The survey can be accessed at https://www.surveymonkey.com/r/WHXP8XT.

Mini-Mental State Examination (MMSE)

Patient's Name: ______________________________ Date: ______________

Instructions: Score one point for each correct response within each question or activity.

Maximum Score	**Patient's Score**	**Questions**
5		"What is the year? Season? Date? Day? Month?"
5		"Where are we now? State? County? Town/city? Hospital? Floor?"
3		The examiner names three unrelated objects clearly and slowly, then the instructor asks the patient to name all three of them. The patient's response is used for scoring. The examiner repeats them until patient learns all of them, if possible.
5		"I would like you to count backward from 100 by sevens." (93, 86, 79, 72, 65, …) Alternative: "Spell WORLD backwards." (D-L-R-O-W)
3		"Earlier I told you the names of three things. Can you tell me what those were?"
2		Show the patient two simple objects, such as a wristwatch and a pencil, and ask the patient to name them.
1		"Repeat the phrase: 'No ifs, ands, or buts.'"
3		"Take the paper in your right hand, fold it in half, and put it on the floor." (The examiner gives the patient a piece of blank paper.)
1		"Please read this and do what it says." (Written instruction is "Close your eyes.")
1		"Make up and write a sentence about anything." (This sentence must contain a noun and a verb.)
1		"Please copy this picture." (The examiner gives the patient a blank piece of paper and asks him/her to draw the symbol below. All 10 angles must be present and two must intersect.) 
30		TOTAL

Figure 5. Mini-Mental State Examination.

You will have 1 minute to study the medication labels below. Please study them very carefully. Do not turn the page until you are told. 2
BEGIN STUDYING NOW.

DATE OF PRESCRIPTION: 07-31-97
DR: Deems, J. M. **RX:** 081221
Melissa Hardin **REFILLS** 1
EXPIRES: 09-23-97
TAKE 1 CAPSULE ON TUESDAY AND THURSDAY, AT BREAKFAST
LANOXIN - 0.125 mg 60 CAPSULES

DATE OF PRESCRIPTION: 07-31-97
DR: Cooper, M. W. **RX:** 081222
Melissa Hardin **REFILLS** 1
EXPIRES: 09-30-97
TAKE DAILY WITH MEALS AND AT DINNER
VASOTEC - 10 mg 60 CAPSULES

DATE OF PRESCRIPTION: 07-31-97
DR: Deems, J. M. **RX:** 081223
Melissa Hardin **REFILLS** 1
EXPIRES: 09-17-97
TAKE DAILY, EVERY MORNING AND BEFORE BED
PRINIVIL - 5 mg 60 CAPSULES

Answer the following questions with out looking back on the previous page.
Do not look back on previous page.

1) On which days is Mrs. Hardin suppose to take her Lanoxin?
   a. Tuesday and Thursday
   b. Monday and Sunday
   c. Tuesday and Wednesday
   d. whenever she wants

2) In which month do all three of her medications expire?
   a. January
   b. September
   c. May
   d. August

3) Which one of these medications was Mrs. Hardin **not** prescribed?
   a. Lanoxin
   b. Vasotec
   c. Prinivil
   d. Furosemide

4) Who are the two doctors that prescribed these drugs medications for Mrs. Hardin?
   a. Dr. Deems and Dr. Hong
   b. Dr. Cooper and Dr. Deems
   c. Dr. Cooper and Dr. Stevens
   d. Dr. Hill and Dr. Buck

Figure 6. Example of Everyday Cognition Battery. Explicit permission for the use of this scale was obtained from the creators (adapted from Allaire & Marsiske, 1999).

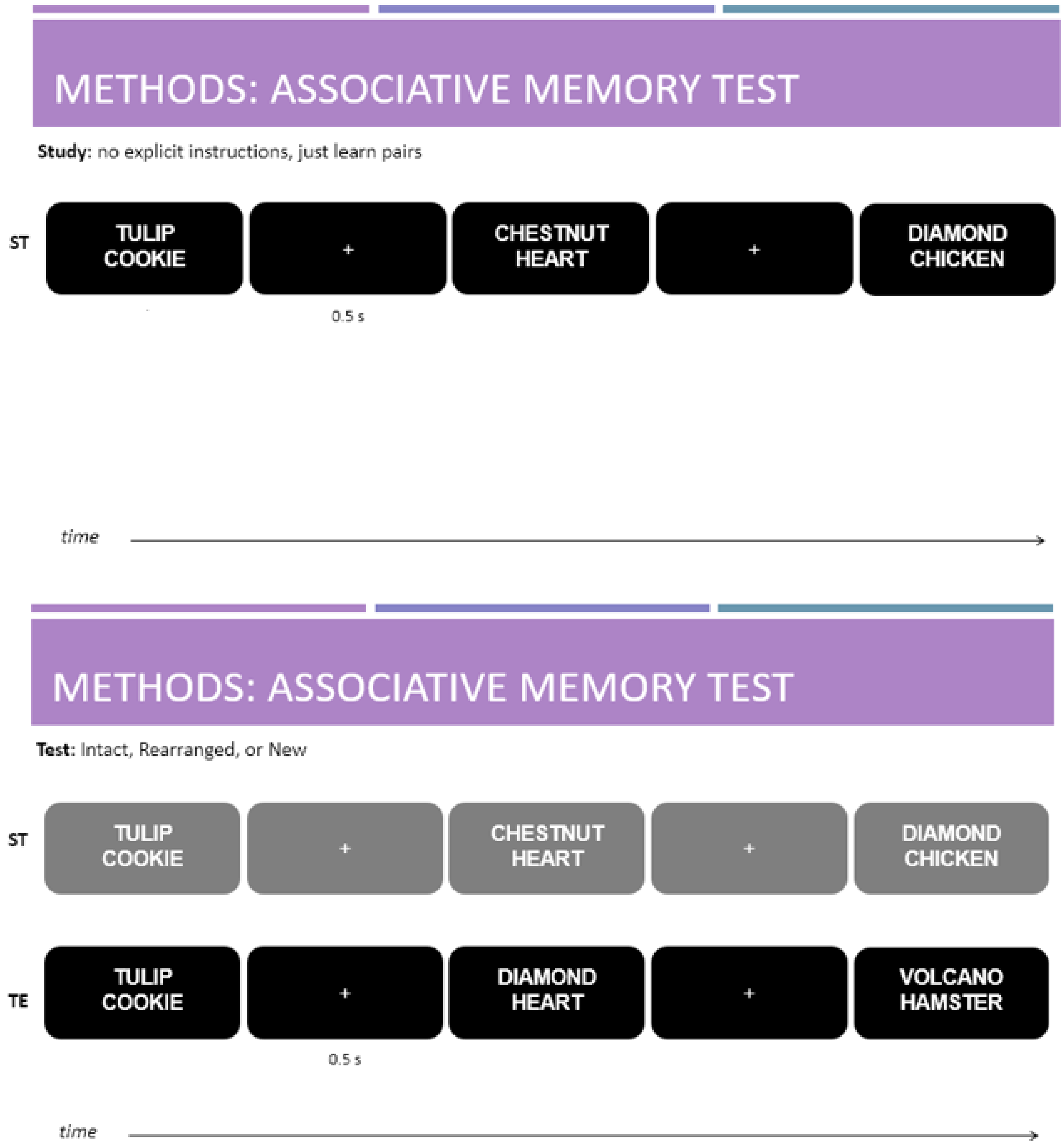

Figure 7. Associative Memory Test.

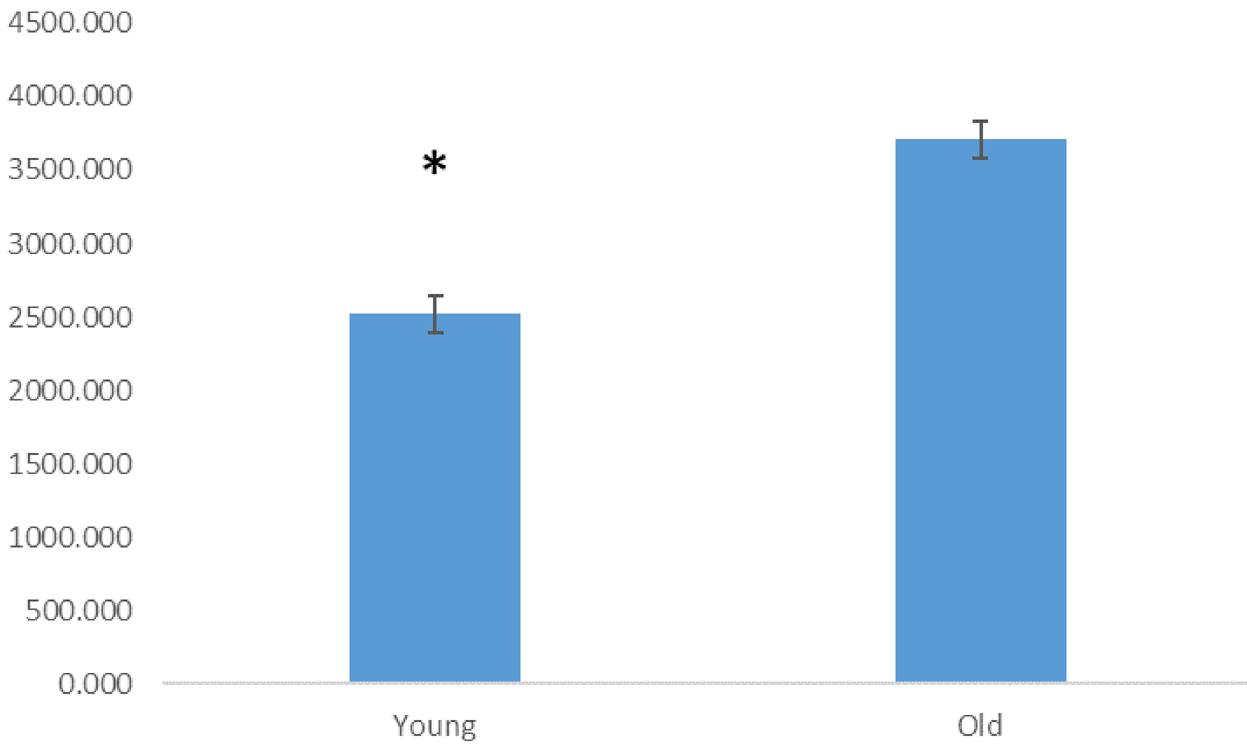

Figure 8. Associative Memory Reaction Times (ms)

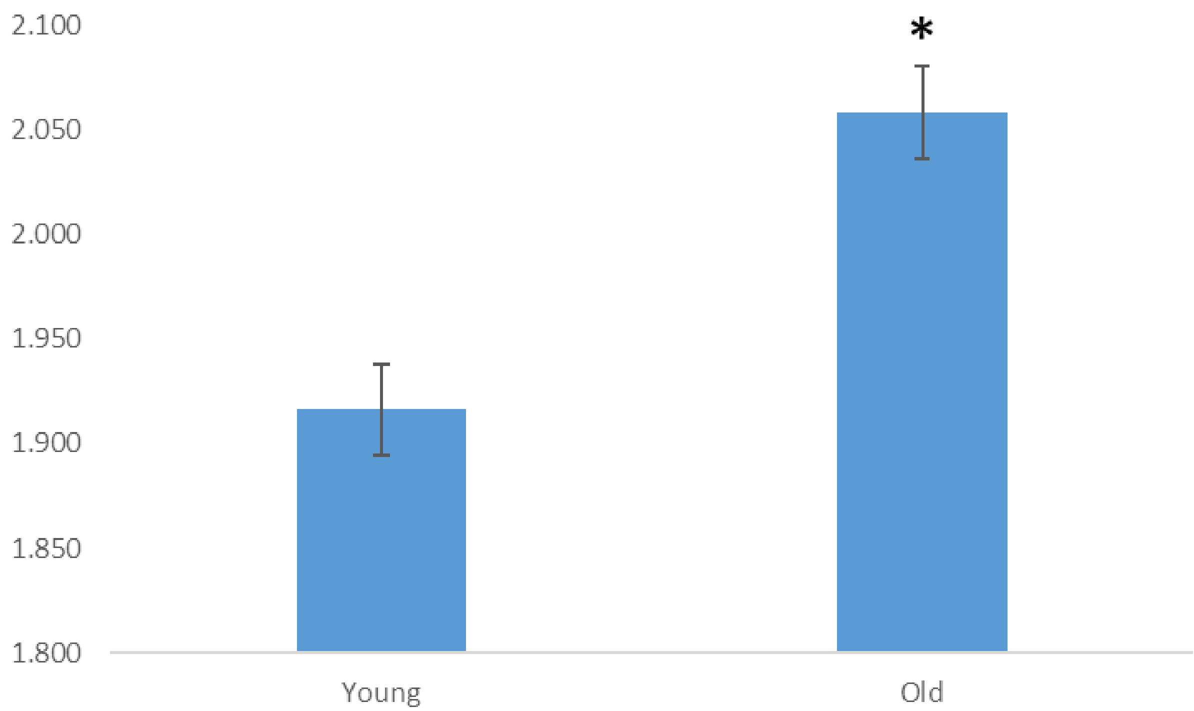

Figure 9. Associative Memory Encoding Times (ms with logarithmic transformation)

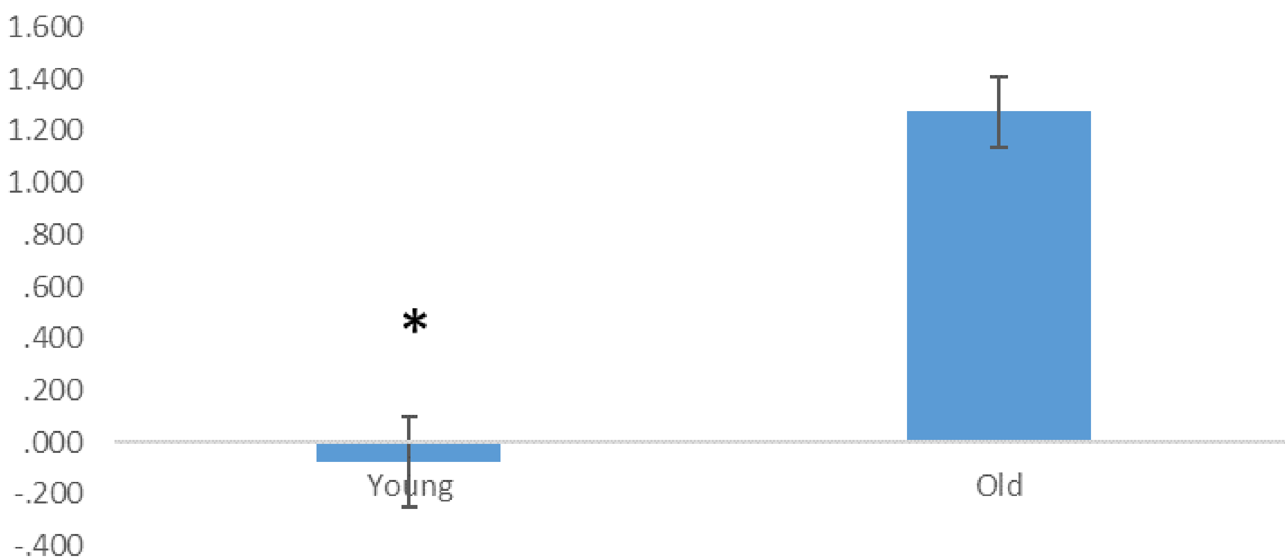

Figure 9. Duration of Noun-Pair Lookup Table Use (s with logarithmic transformation)

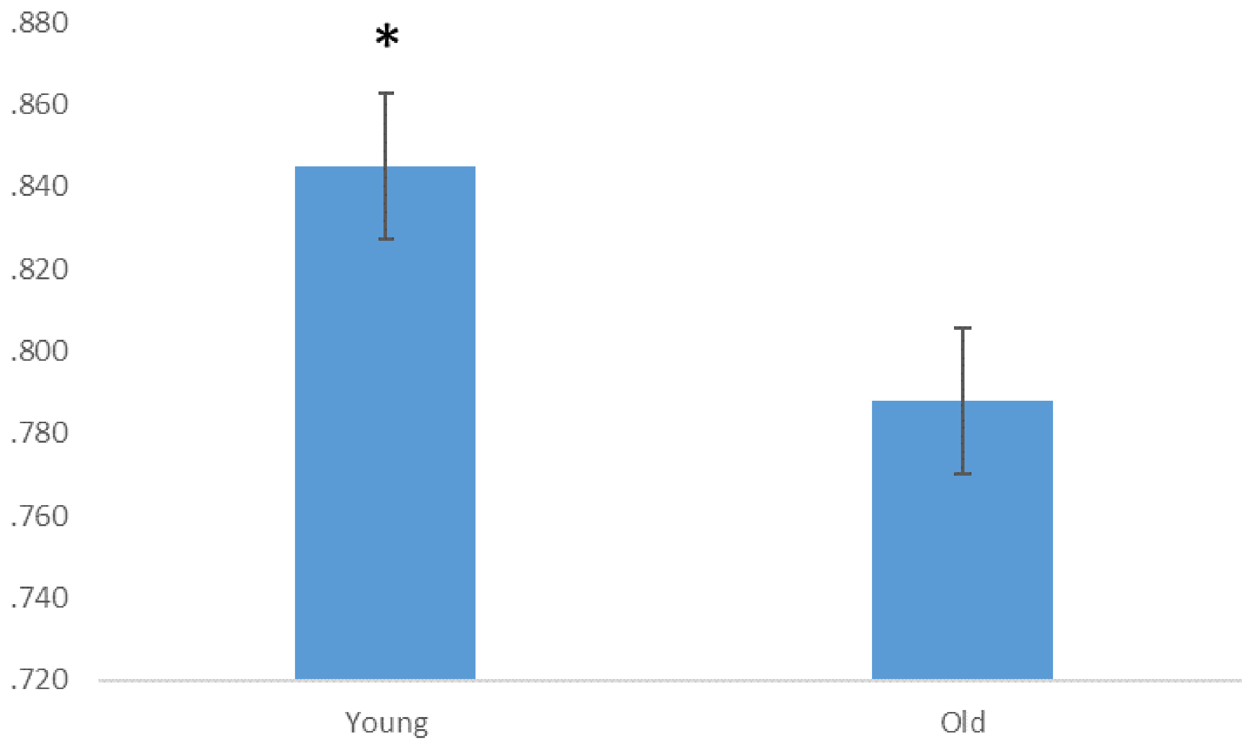

Figure 11. Everyday Cognition Battery Scores (proportion of correct answers)

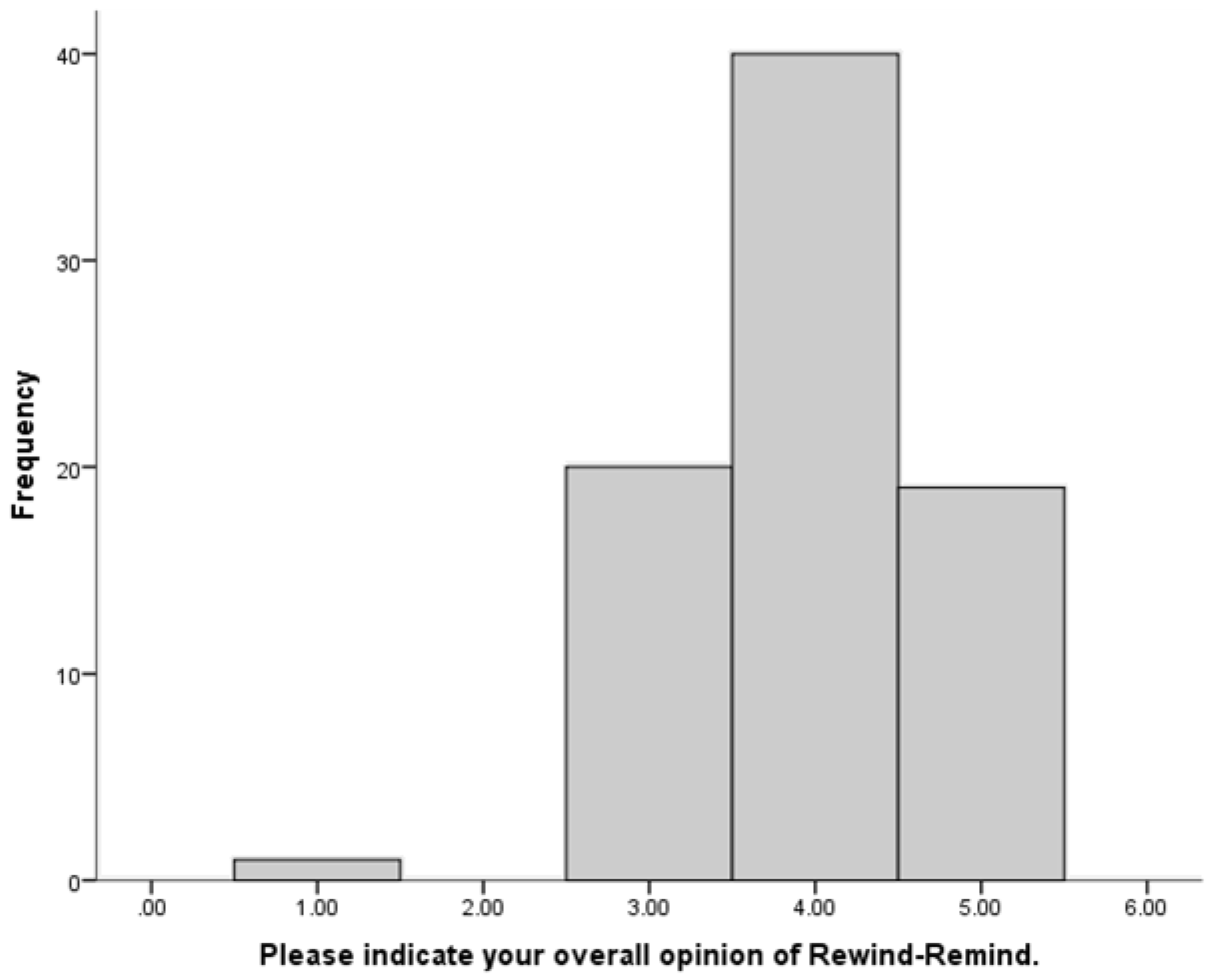

Figure 12. Rewind-Remind Feedback Survey Responses: Question 1

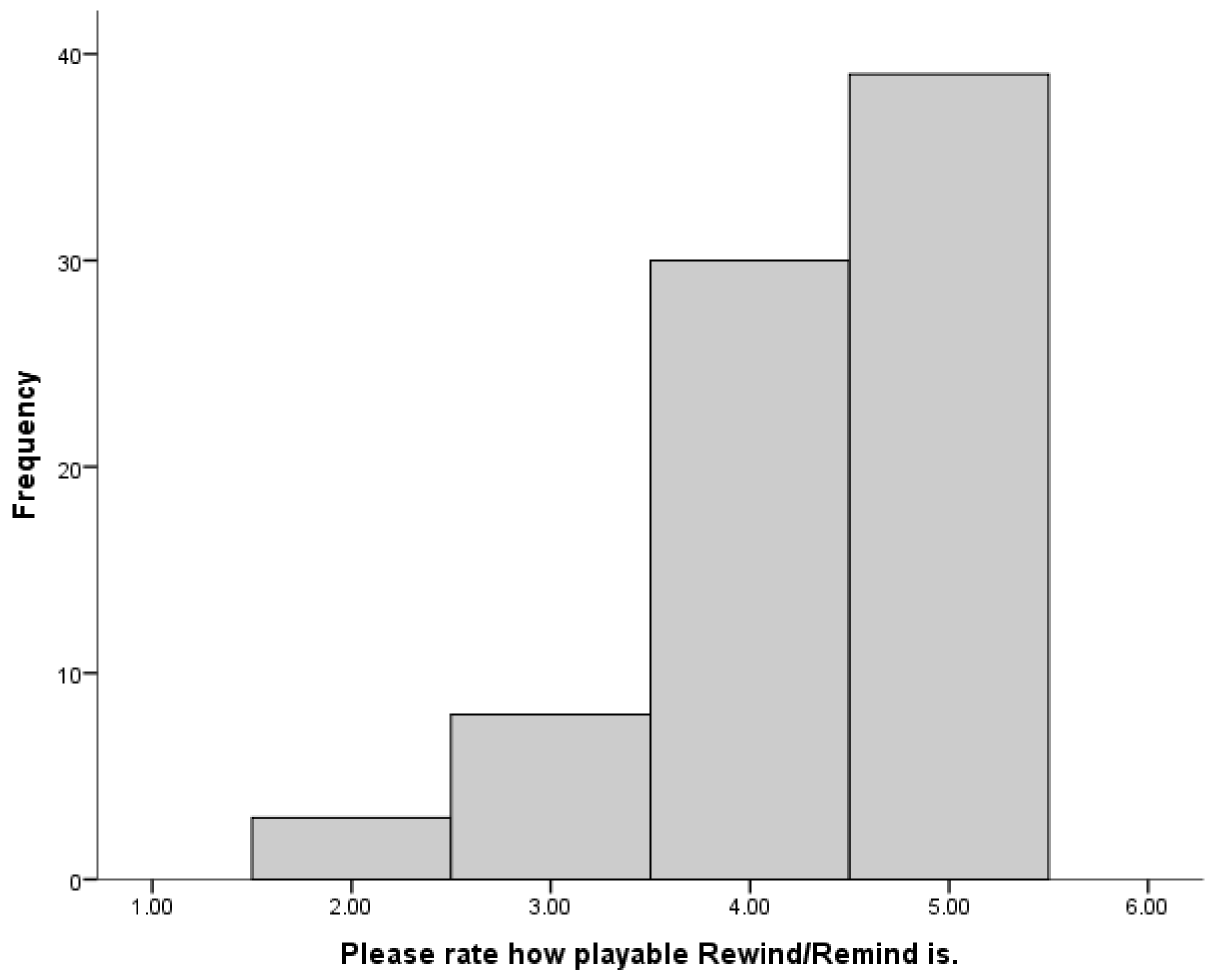

Figure 13. Rewind-Remind Feedback Survey Responses: Question 2

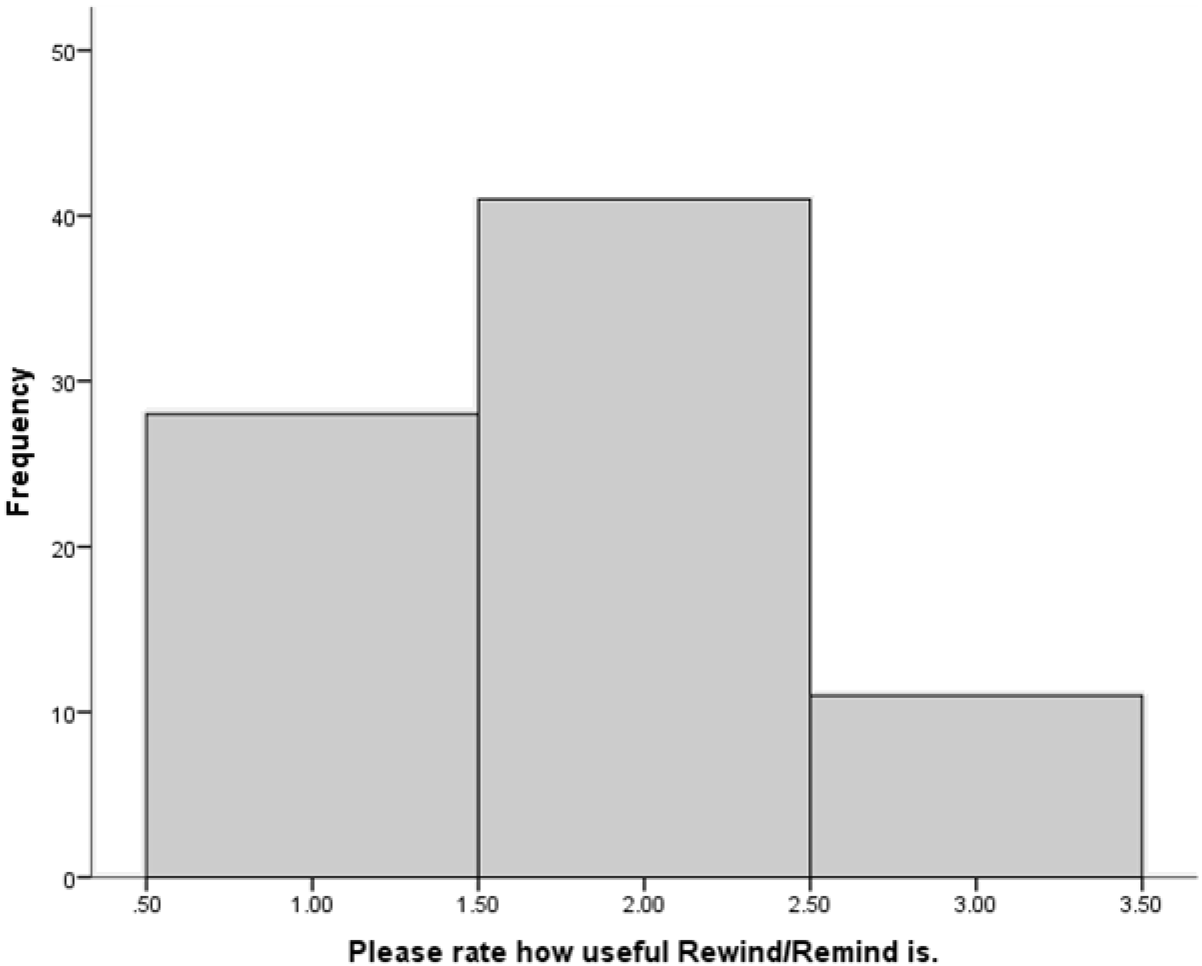

Figure 14. Rewind-Remind Feedback Survey Responses: Question 3

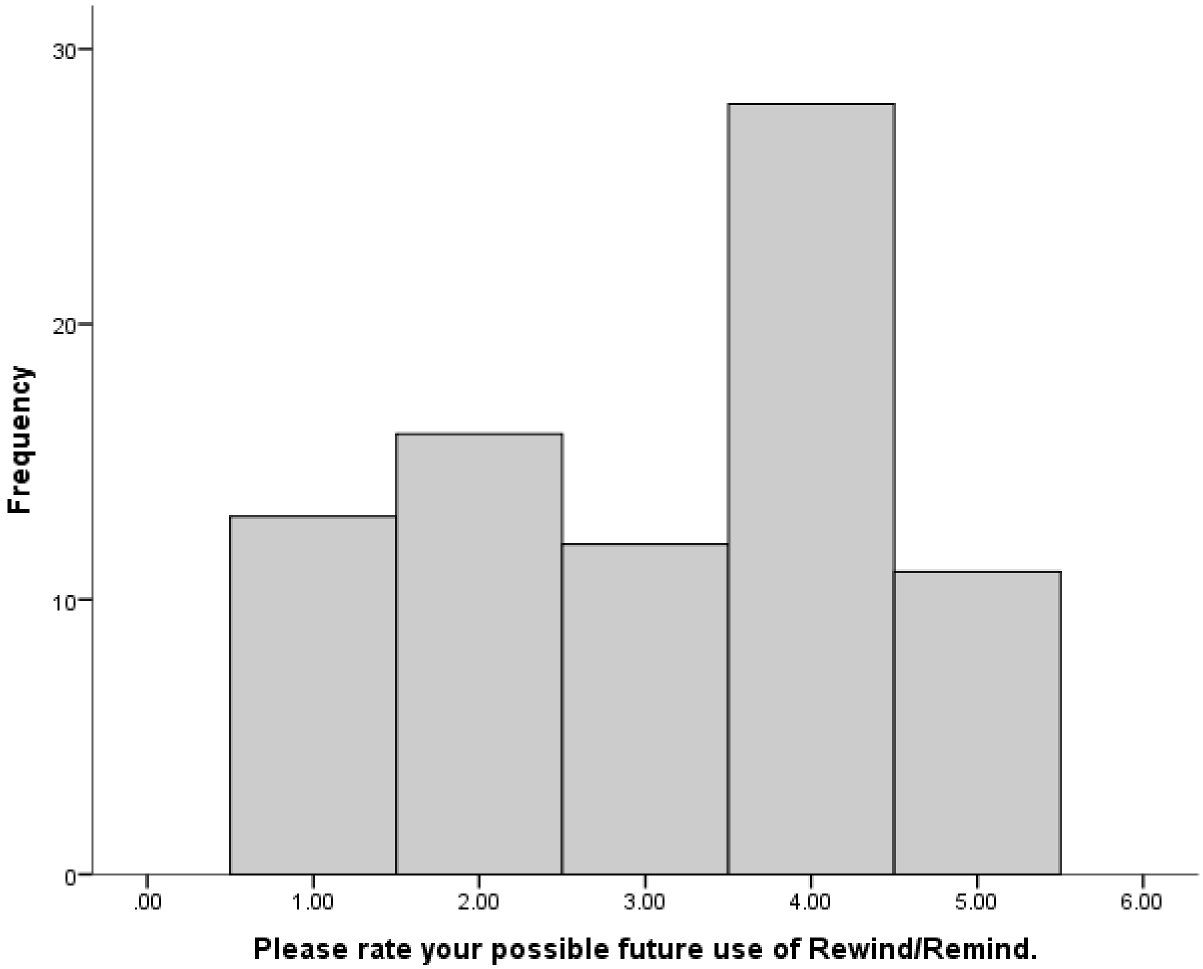

Figure 15. Rewind-Remind Feedback Survey Responses: Question 4

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