Title

CREATING A SHORT-TERM ASSOCIATIVE MEMORY VERSION OF OUR LONG-TERM ASSOCIATIVE MEMORY TASK

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CREATING A SHORT-TERM ASSOCIATIVE MEMORY VERSION OF OUR LONG-TERM ASSOCIATIVE MEMORY TASK

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A capstone project submitted for Graduation with University Honors

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ABSTRACT

Associative memory refers to a form of memory in which separate pieces of information are linked together into a cohesive memory through binding processes. The long-term memory version of our QuadMax associative task demonstrated that memory performance decreased as the number of items to-be-remembered together increased from two to three to four words, as would be expected if demand on binding processes also increased with associative load. However, an alternative interpretation is that memory worsens at higher associative loads due to increased demands on short-term associative memory processes which may exceed the amount of information that can be held in mind at once (short-term memory capacity), as there is more information to hold in mind when encoding and retrieving sets of four versus two words. The current study aimed to disentangle these processes by developing a short-term associative memory variation of the QuadMax task. Thirty-five young adults studied pairs, triplets, and quadruplets of words and were immediately tested on novel, repeated, or recombined word sets. Results revealed that there was no statistically significant effect of set size on accurate memory for repeated sets (hits) relative to inaccurate memory for novel (recognition memory score) or recombined (associative memory score) sets. The lack of statistical significance supports the notion that short-term associative memory does not contribute to memory deficits found in long-term associative memory tasks, even at increased associative loads that may exceed short-term memory capacity.

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TABLE OF CONTENTS

INTRODUCTION

Associative memory has been extensively researched, as it is a profoundly prevalent form of memory used in day-to-day life. Associative memory is a form of memory in which separate pieces of information are linked together (Mayes, Montaldi & Migo, 2007). For instance, we recognize our friends by seeing their face and recalling their identity, we remember a café we might frequent and our regular order, or we remember information read in an article when a keyword from said article is mentioned. The associations we make dictate how we perceive and interact with each other and the world. By binding separate unrelated pieces of information as a cohesive memory trace, we are able to create and maintain memories of respective events and items that occurred together. We can accurately discriminate between individual moments and items that are a part of their own separate, respective memories, such as being able to discriminate what we had for lunch yesterday versus the day before yesterday, and remembering one part of a memory can remind us of other parts of the same memory. We can also store detailed memories with many different items or events, all encoded into one cohesive associative memory trace. (Mayes, Montaldi, & Migo, 2007). All of this is motivated by the process of associative binding, wherein stimuli are linked into a cohesive memory (Bender et al., 2010). Much of our current understanding of associative memory and its components revolve around long-term associative memory, however, less is known about short-term associative memory (Menzel and Sugawa, 1986), the latter of which is the focus of this current study.

Researchers have developed tasks to examine long-term associative memory. Many long-term associative memory tasks introduce item-pairs to participants during a study phase, and then ask participants to recognize which items (item recognition test) or pairs (associative recognition test) they did (“yes”) or did not (“no”) see at the study phase during a test phase. These paired-associative memory tasks require participants to bind two separate units of information together in a memory. The item recognition test contains items from pairs that the participant had previously been exposed to during the study phase (repeated item) and items the participant had not seen prior (novel item). An item memory measure is calculated as hit rate (accurate “yes” responses to repeated items divided by the total number of repeated items) minus novel false alarm rate (incorrect “yes” responses to novel items divided by the total number of novel items). The associative recognition test contains pairs that the participant had previously been exposed to during the study phase (repeated pair) and pairs in which an item from two different pairs are presented together in the study phase, making it an unfamiliar word pair (recombined pair). An associative memory measure is calculated as hit rate (accurate “yes” responses to repeated pairs divided by the total number of repeated pairs) minus the recombined false alarm rate (incorrect “yes” responses to recombined pairs divided by the total number of recombined pairs). This tests the participant’s ability to successfully bind the individual items presented in a study pair together into a cohesive memory and discriminate between repeated pairs and recombined pairs (Mayes, Montaldi, & Migo, 2007). Prior literature has shown that young adults perform significantly better on the item than associative memory test (Guez et al., 2016).

Some research on long-term associative memory has examined age-related deficits. It has been experimentally found that older adults perform significantly worse than younger adults, as seen by an age-related deficit for associative memory, with no age group difference for item memory (Bender et al., 2010). These findings have been attributed to binding deficits in older adults (Bender et al., 2010, Castel et al., 2003). A prominent theory explaining this age-related decline in associative memory is the associative deficit hypothesis (ADH). The ADH postulates that associative memory performance decreases with age due to an age-related deficit in associative binding processes, wherein older adults are able to remember individual pieces of information accurately but they struggle to bind the multiple pieces of information into a cohesive memory (Naveh-Benjamin et al., 2000; Naveh-Benjamin et al., 2004).

While many associative memory tasks that examine binding processes utilize singletons (items) and pairs, far fewer studies examine higher order associations of memory using higher associative loads, such as triplets or quadruplets. One study that examined associations for pairs and triplets in young adults found that increasing the number of stimuli to be remembered together significantly decreased associative memory performance for the recombined word groups (Torres-Trejo and Cansino, 2016). Repeated word groups were not affected by the increase in set size from pairs to triplets, showing it was more challenging for participants to accurately remember associations between more items at a higher associative load, compared to fewer items. Our group extended this work by using a novel associative memory recognition task for pairs, triplets, and quadruplet word sets in younger and older adults, allowing us to manipulate associative load and assess for age-related effects (Franco et al., 2021). Participants studied word sets of each set size during the study phase before proceeding to the test phase in which they saw repeated, recombined, and novel sets of each size. We found that, as set size increased, from pairs to triplets to quadruplets, associative memory scores (hits – recombined false alarms) decreased for both younger and older adults, and older adults displayed significantly poorer performance in the associative memory metric with each set size increase through triplets and quadruplets, when compared to younger adults. This age-related deficit in performance for the QuadMax task was attributed to a deficit in binding word sets at higher associative loads, which supports the associative deficit hypothesis. (Franco et al., 2022)

While the QuadMax task investigated long-term associative memory at increased associative loads, that is, memory for studied sets that occurred >30 seconds prior to the test sets, this task also required participants to utilize short-term associative memory functions, in that participants held the words within the sets in mind while imagining them doing something together during the study phase, before being consolidated into a longer-term associative memory form (Baddely, 2010). This type of short term associative memory is one component of working memory, which includes the maintenance and manipulation of information held for a short period of time (Baddely, 2010; Aben et al., 2012). Thus, if the amount of information within a given word set exceeds the capacity of the participant's short-term memory store, such as when holding a quadruplet in mind during the study phase, it may affect their performance on QuadMax associative memory task. This brings up the question of whether the deficit in associative memory performance as set size increased in adults of all ages seen in the Franco et al. (2022) paper can be better explained by short-term associative memory failing to properly hold the increase of information during the study phase, instead of, or in addition to, binding deficits in long-term associative memory at higher associative loads, as postulated.

The current study investigated short-term associative memory with the goal of informing us of the extent to which the previously observed deficits in long-term associative memory at higher associative loads with the QuadMax task is due to short-term memory capacity limits or binding deficits. To test this, we developed a short-term associative memory variation of the QuadMax task and tested young (18-25 years) adult participants on their short-term memory for repeated, recombined, and novel pairs, triplets, and quadruplet word sets. If short-term memory capacity is not exceeded at higher associative loads, then we would predict that young adults' short-term associative memory performance would yield no significant difference across set sizes, and this may indicate that the previously observed worse performance at these higher associative loads in the long-term QuadMax task may instead reflect an associative binding deficit with long-term associative memory functions. On the contrary, if there were a statistically significant difference in short-term associative memory performance as associative load increased, then triplets and/or quadruplets may exceed participants' short-term associative memory capacity and may have contributed to the long-term associative memory deficits previously seen in the QuadMax task.

METHODS

Participants

Forty-eight college students were initially recruited for our study. They were all enrolled at the University of California, Riverside (UCR) in the Introductory Psychology (PSYC001) course. As a course component, all students are required to participate in psychological research for course credit using the Psychology Research Participation System (SONA System). Students have the option to select a study they are interested in participating in from a list of available studies. All students in this study opted in by choice, completed informed consent, and received subsequent academic credit upon successful completion of the study.

Participants were excluded if they had not successfully answered all the questions before exiting the study (n=4); scored below 50% accuracy (n=3); failed to respond to more than 20% of the trials (n=5); or re-enrolled and completed the task more than once, thus providing a second set of results (n=1). The exclusion criteria were applied to the participant data pool sequentially, in the order shown above. Our final cohort consisted of 35 participants who successfully completed this task.

The education level of the college students enrolled in the study spanned across all four years, from having completed high school (12 years) to completing a bachelor's degree (16 years). The majority of the participants were freshmen (40%), and thus had a completed education level of high school senior, with a high school diploma or equivalent. The demographics are shown below in Table 1.

Table 1

Demographic/Informational Table

Sample Characteristics	N	%	M	σ
Gender				
Male	15	42.9		
Female	19	54.3		
Non-binary	1	2.9		
Years of Education			13.7	1.2
HS Senior (12)	5	14.3		
BA Freshman (13)	14	40.0		
BA Sophomore (14)	8	22.9		
BA Junior (15)	6	17.1		
BA Senior (16)	2	5.7		
Age			19.2	1.2

Note. Demographic information displayed above, including gender identity (N = number of individuals), years of education (12-16 years), and age (M = mean, σ = standard deviation)

General procedure

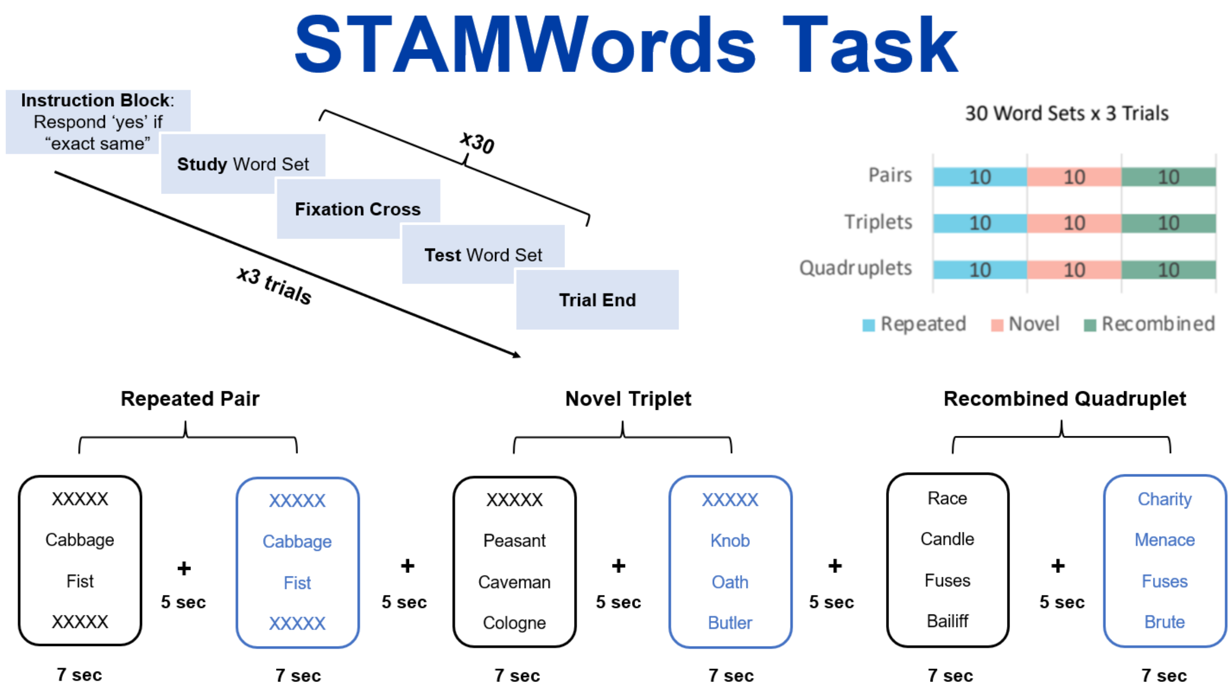
The novel task developed and used in this study was the Short-term Associative Memory for Words (STAMWords). The task was hosted using Inquisit6 software on (https://www.millisecond.com/). When students selected this study for participation, the participants first completed an online informed consent document before starting the STAMWords task. Participants completed this task independently on their own device at a time and location of their choosing.

Short-term associative memory for words task

Participants completed three separate sessions each containing 30 trials (10 per set size). Each trial involved presentation of a study word set, immediately followed by a test word set. For the study set, participants viewed a pair (2 words), triplet (3 words), or quadruplet (4 words) set of words. They were instructed to imagine the words "doing something together" and indicate if they were able to successfully imagine the words together by pressing 'q' (yes) or 'p' (no) on their keyboards. For the test set, participants again viewed a set of words that were the same size as the study set (pair, triplet, or quadruplet) that were either identical to the study set (repeated; 10 sets; 3-4 per set size), contained entirely new words that had not yet been presented in the study set (novel; 10 sets; 3-4 per set size), or had a combination of studied, repeated and non-studied, novel words (recombined; 10 sets; 3-4 per set size). For example, a recombined triplet may present 'knob, onion, supper' at study and then 'knob, tabloid, iceberg' at test. Across the three sessions, there were 10 repeated, novel, and recombined test sets per set size (pairs, triplets, quadruplets). Participants were instructed to indicate whether the test set word was exactly the same as the study set words by selecting 'q' (same) or 'p' (different) on their keyboards. Descriptives are shown in Figure 1.

Figure 1

Visual Description of the STAMWords Task



Note. This figure shows a visual description of the STAMWords Task, including its overall progression (top left), its composition (top right), and visual examples of the repeated, novel, and recombined set sizes (center bottom)

Different font colors were used to differentiate the study (black) and test (blue) sets within each trial, with a white background. For each set, a single word appeared on each of four rows in the center of the computer screen, with five x's in the top and/or bottom row for pairs and triplets to visually match quadruplets. Each word set was presented for 7s, with a 5s delay between the study and test set in each trial and a 5s inter-trial-interval (ITI). Words sets of each size were randomly presented within each session. After each session, participants received a break and pushed the spacebar when they were ready to continue.

Memory Measures

For each set size, we calculated the proportion of correct “same” responses to repeated (hits), incorrect “same” responses to novel (novel false alarms, FA), and incorrect “same” responses to recombined (recombined FA) test sets. A composite short-term associative memory score was calculated using hit rate minus recombined FA rate and the short-term recognition score (which measures set recognition memory) was calculated as hit rate minus novel FA rate. We calculated each metric for each set size and participant.

RESULTS

Separate repeated-measures ANOVAs were conducted using statistical software JASP ver. 0.18.1.0 to assess effects of Set Size (pairs, triplets, quadruplets) for each memory measure (associative memory, recognition, hits, novel FA, recombined FA). Significance level was set as p =.05.

For associative memory, there was no significant main effect of Set Size, $F(2) = .880$, $p = .419$, revealing no statistically significance difference in performance for pairs (*M* ± *SD:* .814 ± .142), triplets (.814 ± .168), and quadruplets (.849 ± .167). Results are shown in Figure 2a.

For recognition, there was no significant main effect of Set Size, $F(2) = 1.449$, $p = .231$, revealing no statistically significance difference in performance for pairs (.909 ± .098), triplets (.863 ± .155), and quadruplets (.880 ± .141). Results are shown in Figure 2b.

For hits, there was no significant main effect of Set Size, $F(2) = 1.262$, $p = .290$, revealing no statistically significant difference in performance for pairs (.917 ± .89), and triplets (.880 ± .135), and quadruplets (.889 ± .137). Results are shown in Figure 2c.

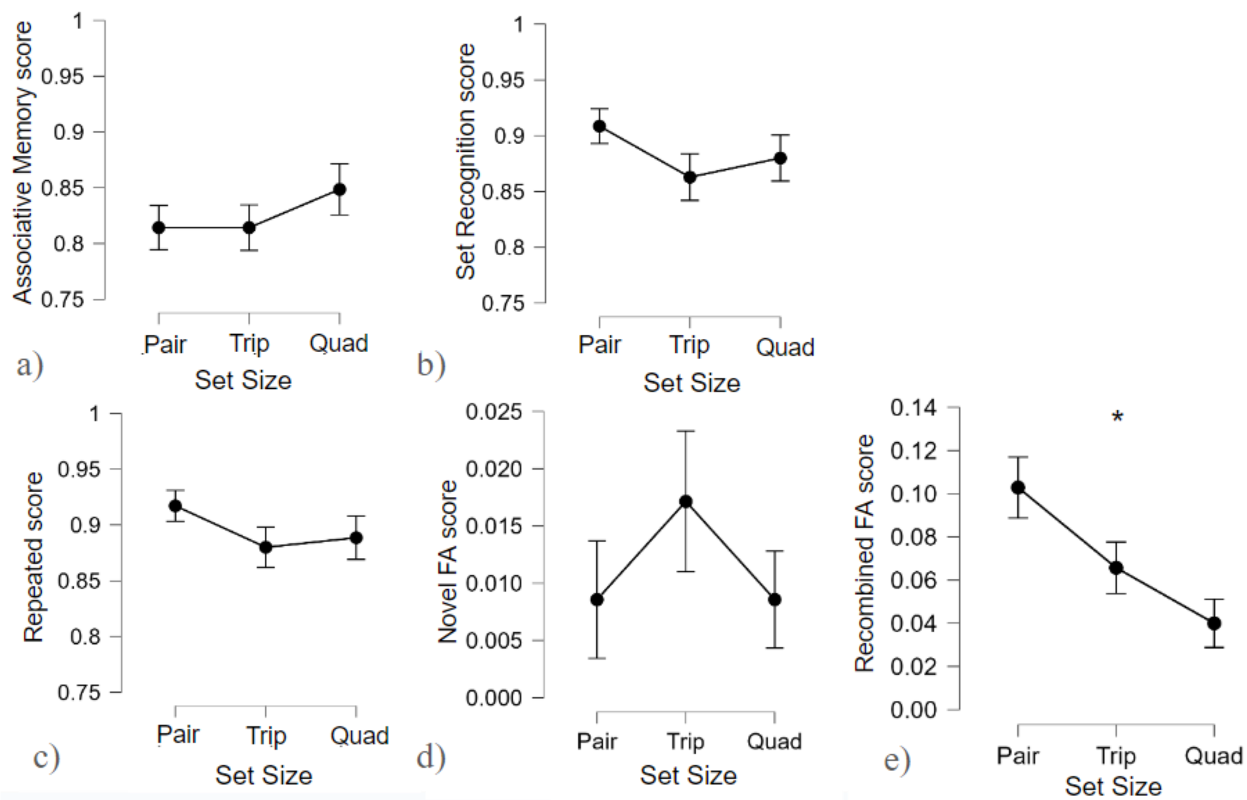
For novel FA, there was no significant main effect of Set Size, $F(2) = .897$, $p = .412$, revealing no statistically significant difference in performance for pairs (.009 ± .037), triplets (.017 ± .045), and quadruplets (.009 ± .28). Results are shown in Figure 2d.

For recombined FA, there was a significant main effect of Set Size, $F(2) = 6.422$, $p = .003$. Post Hoc Holm comparisons revealed significantly worse performance to quadruplets (.040 ± .074) than pairs (.103 ± .098) ($p = .002$), but no significant difference in performance between pairs and triplets (.066 ± .108) ($p = .078$) or quadruplets and triplets ($p = .149$).

Additional 2 Gender (M, F, gender 3 excluded) x 3 Set Size mixed factorial ANOVAs were also run for each memory metric to assess sex effects. There were no significant effects of sex, so the results are not reported.

Figure 2

Line Graphs displaying Memory Metric Across Set Size



Note. Repeated-Measure ANOVA line graph showing Associative Memory score (a); Set Recognition score (b); Repeated score (c); Novel FA score (d); Recombined FA score (e); across pairs (pair), triplets (trip), and quadruplets (quad) word sets. Error bars are standard error of the mean (SEM). * = statistical significance ($p < .05$)

DISCUSSION

This study examined the effects of higher associative load in short-term associative memory in an effort to understand whether short-term associative memory capacity at an increased associative load of four words can explain the binding deficit found in the long-term QuadMax task. To parse these effects, we developed a short-term associative memory task (STAMWords), that removed the long delay between the study and test phases present in the original QuadMax task by assessing performance to similar study and test sets, separated by 5 seconds, for pairs, triplets, and quadruplets of words. The current results revealed no significant effect of set size for the associative memory metric. There were additionally non-significant effects of set size for the short-term set recognition measures, hits, and novel FA metrics, which supports the notion that short-term associative memory does not explain the deficit in associative memory performance at higher associative loads. However, there was a significant effect of set size for the recombined FA metric, with a post-hoc analysis paradoxically revealing significantly worse performance in pairs compared to quadruplets. Each of these findings is described in detail below.

Young adults had no statistically significant difference in short-term associative memory performance as associative load (set size) increased. This contradicts with our prior work (Franco et al., 2022) which used the long-term associative QuadMax task and found a decrease in associative memory performance in younger adults for increased set size, from quadruplets, to triplets, to pairs. In that paper, we speculated that the decrease in long-term associative memory performance at higher associative loads was due to a binding deficit. However, we could not rule out the alternative interpretation that it may have also been due to the increase of set size exceeding the short-term associative memory capacity needed to keep four words in mind. The results of the current study, specifically finding that associative memory performance for quadruplets, triplets, and pairs were all considerably similar, indicates that the increase of set size did not exceed participants' short-term associative memory capacity. Therefore, we have more confidence that the performance decrease with increased associative load found in the long-term QuadMax task can be attributed to an associative binding deficit, as opposed to exceeding short-term memory capacity.

The current results also showed that young adults unexpectedly performed worse on pairs than quadruplets for the recombined FA metric. This result is the opposite of what was found in Franco's (2022) usage of the QuadMax task in which participants did significantly worse to quadruplets than pairs. This is possibly due to the nature of how the recombined sets are constructed in this short-term task, wherein one word of the test set is repeated from the immediately preceding study set and the one (pairs), two (triplets), or three (quadruplets) remaining words were from other study sets that they had previously seen or will eventually see. Thus, for recombined pairs, 50% of the words are more familiar (from the immediately preceding study set) and 50% are less familiar (seen more than one trial ago or not yet seen), leading to a higher probability of incorrectly indicating that the test set was "exactly the same" as the study set. In contrast, for recombined quadruplets, only 25% of the words are more familiar and the remaining 75% are less familiar, making it less likely for the participant to incorrectly indicate that the test set was "exactly the same" as the study set, as the participant would be more likely to correctly recognize at least one unfamiliar word. A related issue with the nature of the recombined sets is that not all of the less familiar words in the recombined sets were from sets the participant had previously seen during a study trial. In some cases, those less familiar words were selected from sets that the participant will see in future trials, making them, essentially, novel words. This differs from long-term associative memory tasks in which recombined sets are comprised solely of previously seen words. Additional research is needed to verify whether these differences in the construction of recombined sets explain why participants did significantly worse identifying recombined pairs when compared to recombined quadruplets.

To corroborate the associative memory score results, we also found that the calculated set recognition metric, hits, and novel FA yielded no statistically significant difference in performance as an effect of Set Size. These results differ from what was found in our prior work (Franco et al., 2022) in which there was a significant decrease in set recognition, hits, and novel FA performance as an effect of increased set size. If the alternative interpretation of short-term associative memory capacity being exceeded at higher set sizes held up, we would expect the results of our STAMWords task to coincide with the QuadMax task. Subsequently, the lack of significant performance difference with these metrics attained through our STAMWords task imply that the recognition, not just associative memory, performance deficit originally found by Franco et al. (2022) is not due to short-term associative memory capacity.

This study only examined short-term associative memory capacity in young adult populations, whereas long-term associative memory studies often also investigated older adult populations (Franco et al. 2022, Bender et al., 2010; Castel et al., 2003; De Brigard et al., 2020, Naveh-Benjamin et al., 2000; Naveh-Benjamin et al., 2004). It is widely recognized that as older individuals age, they become more vulnerable to non-pathological memory and cognitive decline (Khan et al., 2014), especially with regards to associative memory functions which are more vulnerable to breaking down with age (Naveh-Benjamin et al., 2004). Franco et al. (2022), through its use of the QuadMax task, sought to better understand these deficits by comparing younger and older adults' associative memory performance through the frame of the ADH, in which older adults' associative memory performance are thought to worsen with age due to poorer binding capabilities. Because we did not include older adults in the current study, we cannot fully assert that short-term associative memory capacity does not play a role in age-related memory deficits found in prior associative memory tasks. It is possible that while short-term memory capacity may not be exceeded at four words for younger adults, older adults may have a more limited short-term memory capacity. However, a prior study from Bartsch et al. (2018) had a similar aim, using word set size paradigms to discern if the age-related deficit in associative episodic memory is due to binding deficits (similar to what the ADH postulates) or due to encoding deficits in working memory. While their paradigm and method of comparison for long- and short-term forms of memory were different than ours (e.g., using a forced-choice procedure to test participant's ability to accurately identify previously-encoded word-pairs out of a presented three options consisted of an accurate pair, a recombined pair, and a pair with one entirely novel word), the researchers determined that their manipulations of working memory capacity had no significant effect on subsequent episodic memory performance in young and old adults, meaning that working memory performance is not the root cause of the observed age-related associative episodic memory deficits. Testing older adults would further strengthen the results of this study, and further investigate short term associative memory function with regards to the ADH and age-related memory deficits.

In summary, the aim of this paper was to develop a short-term associative memory task (STAMWords task), based on our novel QuadMax task, to discern whether deficits in long-term associative memory performance at higher word set sizes found in the QuadMax task were due to binding deficits, or a possible short-term memory capacity at higher associative loads. What we found was no statistically significant difference in associative memory performance across set sizes, meaning that associative load did not affect short-term associative memory performance to any significant degree. These results are also backed by our set recognition, hits, and repeated FA metrics, again yielding no significant effects. Our recombined FA metrics yielded significant results, in which participants performed worse to pairs than quadruplets, though these results are the opposite of what would be expected from the Franco et al. (2022) paper, in which participants did worse to quadruplets. These results may be due to the way in which the recombined sets are constructed in this STAMWords task. Our findings allow us to reject the alternative interpretation from the Franco et al. (2022) paper, in which the decreased long-term associative memory performance found with higher associative loads are due to the increased set size exceeding a short-term associative memory capacity. As a result, the original conclusion of the Franco et al. (2022) paper remains the strongest possibility, wherein the performance deficit found at higher loads are due to a binding deficit present in long-term associative memory functions.

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