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# Examining the dynamics of strategic search from long-term memory

Nash Unsworth

*Department of Psychology, University of Oregon, Eugene, OR 97403, United States*

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ABSTRACT

In two experiments the dynamic nature of strategic search from long-term memory was examined. Participants retrieved exemplars from various categories over several minutes. Periodically during retrieval participants were presented with a probe asking what strategies, if any, they were currently using to retrieve the desired information. This novel thought probe technique allowed for insights into the nature of in-the-moment retrieval strategies. Across both experiments it was found that participants reported using a variety of strategies, but depending on the task certain strategies were used more often than others. In particular, some strategies were used more frequently in one task than another, whereas other strategies seemed to cut across tasks. Furthermore, examining the time course of strategies suggested that participants often started off using one strategy, but then switched to using other strategies during the retrieval period. Finally, individual differences in general retrieval abilities were shown to be due to unique and joint contributions of search strategies and working memory capacity. These results provide evidence for the notion that when retrieving information from long-term memory, participants use various search strategies that are tailored to the task at hand and these strategies dynamically change throughout the retrieval period.



## Introduction

Throughout the day we are constantly being asked to retrieve facts, events from our life, names of acquaintances, and other important information. The ability to retrieve this information, generally in the absence of potent external cues, is vital for the success of many everyday tasks. As such, strategic retrieval processes are critical aspects of the overall cognitive system. In the current study we examined retrieval processes in a variety of tasks to better examine the dynamics of strategic search from long-term memory (LTM).

### *Strategic search processes*

A number of models of LTM retrieval assume that a search process is used to find and select information from LTM (e.g., Howard & Kahana, 2002; Polyn, Norman, & Kahana, 2009; Raaijmakers & Shiffrin, 1980; Shiffrin, 1970; Williams & Hollan, 1981; Wixted & Rohrer, 1994). In these models, retrieval relies on a cyclical search process in which the generated information is used as an additional cue to refine the search (e.g., Davelaar & Raaijmakers, 2012; Raaijmakers & Shiffrin, 1980; Williams & Hollan, 1981). In particular, the search process begins with an overarching general cue and then proceeds by utilizing information generated by this cue to further cue the memory system (Graesser & Mandler, 1978; Gruenewald & Lockhead, 1980; Herrmann & Pearle, 1981; Hills, Jones, & Todd, 2012; Hills, Todd, & Jones, 2015;

*E-mail address:* nashu@uoregon.edu

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Reiser, Black, & Abelson, 1985; Whitten & Leonard, 1981; Williams & Hollan, 1981; Wixted & Rohrer, 1994). An important aspect of search frameworks is the notion that there are both directed and random components to the overall search process (Shiffrin, 1970; Shiffrin & Atkinson, 1969). The directed component refers to strategic processes that are under direct control of the individual. These directed control processes include setting up a retrieval plan, selecting and generating appropriate cues to search memory with, as well as various monitoring strategies and decisions to continue searching or not. The random component refers to the probabilistic nature of the search process in which a subset of information is activated by the cues and representations are subsequently sampled and recovered from this subset (Raaijmakers & Shiffrin, 1980; Shiffrin, 1970). Thus, directed control processes are critically important for successful retrieval from LTM (Atkinson & Shiffrin, 1968; Benjamin, 2008; Hintzman, 2011; Nelson & Narens, 1990).

To examine strategic search processes, researchers have relied on a number of different techniques including using think-aloud protocols, manipulating strategy use by instructing participants to use specific retrieval strategies, or directly asking what strategies participants used after the retrieval task. Each of these methods has provided important information on which strategies are likely to be used and the overall effectiveness of particular strategies. For example, Williams and Hollan (1981) had participants name individuals they went to high school with while utilizing a think aloud procedure in which participants were instructed to say everything that came to mind during recall. Williams and Hollan (1981) found that participant's utilized a number of different strategies to generate names including thinking of different activities individuals participated in, thinking of different locations individuals were associated with, thinking of names that began with each letter of the alphabet, generating and mentally scanning pictures from yearbooks, as well as starting with a given individual and thinking of people associated with that individual. Thus, rather than merely automatically retrieving information from LTM, search strategies allowed individuals to dynamically search LTM via multiple different routes. Importantly, Williams and Hollan also noted that participants typically adopted strategies for some time and then shifted to other strategies when the current strategy was no longer generating usable information. In a similar vein, Whitten and Leonard (1981) had participants name their teachers while thinking aloud and found that participants used a variety of different strategies (including a visual location strategy). Similarly, Walker and Kintsch (1985) found that participants used a number of different strategies (again including a visual location strategy) when retrieving a variety of different items from LTM (including retrieving types of automobiles, types of soups, and types of detergent). Importantly, these studies demonstrate that when asked to retrieve information from LTM in a prolonged retrieval task, participants spontaneously use a variety of different strategies, many of which are tailored to the specific task, and some that seem to cut across tasks (such as a visual location strategy).

In addition to using think-aloud procedures to determine in-the-moment strategies, a number of studies have instructed participants to use various retrieval strategies as a means of determining the effectiveness of different strategies. For example, Whitten and Leonard (1981) had participants name their teachers either in a backward order, a forward order, or in a random order. Whitten and Leonard found that a backward search resulted in better retrieval than the other orders. Similarly, Gronlund and Shiffrin (1986) had participants retrieve information from LTM via different instructed strategies. For example, participants had to retrieve animal names using no strategy (free recall), in alphabetic order, or in order based on size. Gronlund and Shiffrin found that that the free recall condition resulted in much better performance than the alphabetic or size strategy conditions suggesting that some retrieval strategies can lead to poor retrieval. Following up on this research we (Unsworth, Brewer, & Spillers, 2014) had participants retrieve animal names using an alphabetic strategy, a semantic strategy (retrieve animals based on shared semantic characteristics), a size strategy, a visual location strategy (retrieve animals by visualizing different locations where you may find animals), or no strategy. Similar to Gronlund and Shiffrin (1986) we found that the free retrieval condition was better than the alphabetic or size conditions. Interestingly we found that the free and visualization conditions resulted in identical performance and the semantic condition was not quite as good (perhaps due to the ambiguous nature of this condition whereby participants could have interpreted it differently). In an additional experiment we had participants name their friends with a variety of different strategy instructions and found that free retrieval and various visualization conditions resulted in the same levels of performance, which was much better than various ordered strategies (e.g., alphabetic, forward chronological, backward chronological). Thus, across various retrieval tasks some strategies (visualization) seem to produce better performance than other strategies (ordered search).

Finally, examining retrospective strategy reports suggests that participants use a variety of different strategies and some strategies correlate with overall retrieval levels better than others. For example, Schelble, Therriault, and Miller (2012) had participants name animals and then fill out a questionnaire regarding the various search strategies they used to perform the retrieval task. Schelble et al. found that participants reported a number of different strategies with the most common being environments, locations, classification, animals that live with humans, and personally relevant animals. Similarly, Unsworth et al. (2014) had participants name animals and fill out a retrospective questionnaire on various strategies. We found that the most common strategies were visualization of various locations, semantic strategies (similar to Schelble et al.'s classification), and no strategy (i.e., items passively came to mind). In a subsequent experiment naming friends, we similarly found that participant reported using visualization strategies, personal relevance, and again a high proportion indicated using no strategy during some aspects of the retrieval. Similar to the results from think-aloud procedures and from strategy instructions, the results from retrospective strategy reports suggest that participants rely on a number of different strategies during retrieval, with some strategies being specific to the particular retrieval task and other strategies cutting across various tasks.

### Individual differences in strategic search

Clearly, strategic search processes are an important component of overall retrieval. Not only has prior research suggested that various strategies are important for retrieval, but prior research has also suggested that individual differences in strategic search processes are a major reason for individual differences in retrieval (e.g., Schelble et al., 2012; Unsworth, Brewer, & Spillers, 2013; Unsworth & Engle, 2007). In particular, a number of studies have found that retrieval from various fluency tasks correlate and load on the same factor (Barnett, Newman, Richardson, Thompson, & Upton, 2000; Silvia, Beaty, & Nusbaum, 2013; Unsworth, Spillers, & Brewer, 2011) in line with Carroll's (1993) notion of a broad retrieval factor. Examining individual differences in retrospective strategy reports has suggested that some of the individual differences variation in retrieval is due to strategic factors.

For example, Schelble et al. (2012) found that the classification and environment strategies tended to correlate with overall retrieval levels as did a measure of working memory capacity (WMC). Recent work in our laboratory has provided consistent evidence (Unsworth et al., 2013). Specifically, we found that high WMC individuals retrieved more animal names than low WMC individuals. Both high and low WMC groups reported using a number of different strategies (visual and semantic based strategies), but high WMC individuals reported using a knowledge based strategy more often than low WMC individuals and low WMC individuals more often reported using no strategy where participants specifically noted that the words just randomly popped into their heads compared to high WMC individuals. Thus, these results suggest that working memory control processes, and individual differences in working memory control processes, are of vital importance when one is attempting to strategically search LTM. In particular, WMC is needed to self-generate retrieval cues and to use those cues to guide the overall search process.

These findings are consistent with recent work by Hills and colleagues (Hills, Mata, Wilke, & Samanez-Larkin, 2013; Hills & Pachur, 2012) suggesting that WMC is needed to maintain cues in an active state to further dictate the search of LTM. In particular, it is assumed that the prior cue is actively maintained in working memory and used to guide subsequent retrievals from LTM. High WMC individuals are better able to maintain these cues than low WMC individuals resulting in more efficient searches and better overall memory performance (see also Unsworth & Engle, 2007). In support of these ideas Hills and Pachur (2012) and Hills et al. (2013) found that WMC was related to better overall recall and this was partially due to individual differences in the ability to transition between global and local cues (see also Unsworth, Spillers, & Brewer, 2012). Based on these results Hills et al. (2013) suggested that search through LTM is based on a dynamic process whereby individuals switch between global and local retrieval cues and WMC is needed to maintain retrieval cues in an active state to ensure an efficient search of LTM.

### The present study

Utilizing a variety of techniques, prior research has demonstrated the importance of various retrieval strategies when one is strategically searching LTM. Despite prior work suggesting these basic notions, additional work is needed to better examine the dynamic nature of strategic search from LTM. In particular, there are a number of important questions that still need to be addressed. For example, do people dynamically shift strategies during recall as suggested by Williams and Hollan (1981)? While it seems intuitively obvious that participants will dynamically shift strategies during an extended recall period, there are remarkably little data on this. Thus, examining how and when participants shift their strategies will be an important component to understanding how individuals search their LTM. Furthermore, as suggested by Nickerson (1981), do participants start off with a passive search and then switch to a more directed search? Again, while this seems plausible, there is little evidence for this dual-mode retrieval idea. Likewise, it was previously suggested that individuals will tailor their search strategies to particular tasks. For example, while recalling animals one might rely on their knowledge of biological phyla, whereas while recalling the names of one's friends one might rely on their knowledge of their friends personality characteristics. Clearly, these strategies are fairly task specific. How is it that participants dynamically change strategies not only within a given task, but also across tasks to increase their performance and better access information from LTM? Furthermore, do various strategies cut across the different tasks? Previously it was noted that a location strategy seems to be used when recalling from semantic and autobiographical memory. Is a location strategy (where one visualizing different contexts) actually used in these different tasks and does it actually benefit recall? Are there other search strategies that are similarity utilized in various tasks? While most of the prior work has specifically focused on aspects of recall such as clustering and temporal dynamics, far less work has directly examined search strategies. An important endeavor, then, is to better examine how individuals utilize search strategies to access information from their LTM.

To test these ideas we developed a new probe technique to better get at the different strategies participants use when retrieving information from LTM. In this technique participants are instructed to retrieve specific information from LTM (e.g., animal names) for an extended period of time. Periodically throughout the task participants were probed to determine what strategies, if any, they were just using. This technique is borrowed from the mind wandering literature where participants are required to perform a task and periodically throughout the task participants are probed to see if they were just mind wandering or not (e.g., McVay & Kane, 2012; Smallwood & Schooler, 2006). With the current thought probe technique we should be better able to examine the different types of strategies participants use, when they are most likely to use different strategies, and to examine how participants dynamically switch to different strategies to determine if certain strategy transitions are more likely than others. Likewise, by examining various retrieval tasks we should be able to examine similarities and differences in retrieval strategies across various tasks. Like task appropriate encoding strategies (McDaniel & Kearney, 1984) we should see that participants dynamically switch strategies not only within a given task, but also across tasks. A final goal of the present study was to examine possible individual differences in strategies and WMC as reasons for variability in retrieval. To examine these issues we conducted two experiments in which participants retrieved information from various categories and thought probes were presented.

## Experiment 1

To examine strategic search processes and to test the thought probe method, participants performed an animal fluency task in which they were instructed to retrieve as many exemplars from the category of animals as possible in 5 min. In one condition participants performed the animal fluency task under normal conditions. In the other condition, participants performed the same animal fluency task, with the exception that periodically they were presented with a thought-probe asking what strategy they were currently using to retrieve items from LTM. The reason for including a condition where participants were not presented with thought probes was to examine possible reactivity effects whereby answering the probes could lead to changes in performance to more standard versions of the animal fluency task. If there are little to no differences between the two conditions, we can assume that the thought probes provide a window into normally ongoing processes.

### *Method*

Participants were 285 undergraduate students recruited from the subject pool at the University of Oregon. All participants were native English speakers. Participants were randomly assigned to one of the two conditions. Three participants in the control condition and six participants in the probe condition were excluded due to failing to complete the fluency task leaving 143 participants in the control condition and 133 in the probe condition. Participants were between the ages of 18 and 35 and received course credit for their participation. Participants first performed the three working memory capacity tasks followed by the animal fluency task. All participants performed the same computerized version of the animal fluency task with the exception that participants in the thought-probe condition were periodically presented with thought probes.

#### *Working memory capacity measures*

*Operation span.* Participants solved a series of math operations while trying to remember a set of unrelated letters that were presented for 1 s each. Immediately after the letter was presented the next operation was presented. Three trials of each list-length (3–7) were presented, with the order of list-length varying randomly. At recall, letters from the current set were recalled in the correct order by clicking on the appropriate letters. For all of the span measures, the score was the proportion of correct items in the correct position (see Unsworth, Heitz, Schrock, & Engle, 2005 for more task details).

*Symmetry span.* Participants were required to recall sequences of red squares within a matrix while performing a symmetry-judgment task. In the symmetry-judgment task participants were shown an $8 \times 8$ matrix with some squares filled in black. Participants decided whether the design was symmetrical about its vertical axis. The pattern was symmetrical half of the time. Immediately after determining whether the pattern was symmetrical, participants were presented with a $4 \times 4$ matrix with one of the cells filled in red for 650 ms. At recall, participants recalled the sequence of red-square locations in the preceding displays, in the order they appeared by clicking on the cells of an empty matrix. There were three trials of each list-length with list-length ranging from 2 to 5.

*Reading span.* Participants were required to read sentences while trying to remember the same set of unrelated letters as Ospan. For this task, participants read a sentence and determined whether the sentence made sense or not. Half of the sentences made sense while the other half did not. Nonsense sentences were made by simply changing one word from an otherwise normal sentence. After participants indicated whether the sentence made sense or not, they were presented with a letter for 1 s. At recall, letters from the current set were recalled in the correct order by clicking on the appropriate letters. There were three trials of each list-length with list-length ranging from 3 to 7.

#### *Composite score*

To ensure that any relations with WMC were not due to idiosyncratic task effects and to ensure we were measuring the broad domain-general WMC construct we computed a composite score from the three complex span tasks. That is, single tasks represent a combination of construct variance along with task-specific method variance (Wittmann, 1988). Thus, in order to ensure true abilities are being measured, one should use several tasks designed to tap the ability of interest. For the composite score, scores for the three complex span tasks were $z$-transformed for each participant. These $z$-scores were then averaged together.

#### *Animal fluency*

Participants were instructed that they would be retrieving as many exemplars from the category of animals as possible in 5 min. Participants were informed that they could retrieve the names of animals in any order they wished. Participants were required to type in each animal name and then press ENTER to record the response. Note, only responses that included an actual animal name were counted. If a participant pressed ENTER without typing an animal name it was not counted. Repetitions of the exact same response were not counted (i.e., typing dog twice, but if a participant typed dog and then typed husky, both were counted). Participants were instructed that they needed to keep trying to retrieve animal names throughout the entire 5 min retrieval period.

*Thought probes*

During the fluency task in the thought probe condition, participants were periodically presented with thought probes asking them to indicate which strategy, if any, they had just been using. The thought probes asked participants to press one of eight keys to indicate what strategy they were using just prior to the appearance of the probe. Specifically, participants saw:

What type of strategy were you just using to come up with animal names?

1. VISUALIZATION strategy (i.e., you imagined yourself walking around looking at animals)
2. SEMANTIC strategy (i.e., you listed animals based on common characteristics)
3. RHYME strategy (i.e., you listed animals based on whether they rhymed)
4. LITERATURE strategy (i.e., you listed animals based on whether appeared together in books.)
5. ALPHABET strategy (i.e., you listed animals in alphabetic order)?
6. SIZE strategy (i.e., you listed animals based on their size)?
7. NO strategy, results were based on random responding (i.e., words just popped into your head)?
8. OTHER

Type in the number that best corresponds to what strategy you were just using and then press ENTER.

These thought probes were based on prior retrospective strategy reports and strategy instruction studies (e.g., Gronlund & Shiffrin, 1986; Schelble et al., 2012; Unsworth et al., 2013, 2014). During the instructions participants were given instructions regarding the different categories. Probes appeared after 5, 14, 20, 29, 38, 49, 61, 74, 82, 93, and 102 responses. Probes appeared after a number of responses rather than after a certain amount of time because we wanted to make sure that participants had actually just retrieved an item rather than probing during a time interval when it was possible that nothing was being retrieved.

*Search strategy questionnaire*

Following the fluency task participants also completed a brief questionnaire regarding any search strategies that they used during the animal fluency task (e.g., Schelble et al., 2012; Unsworth et al., 2013). Participants answered closed-ended questions regarding their strategies. Participants indicated (in order) whether they had used a visualization strategy, a semantic strategy, a rhyme strategy, a literature strategy, a strategy based on overall knowledge of animals, or no strategy was used and the results were based on random responding. The participants could indicate that they used more than one strategy during the course of retrieval.

*Results*

Overall levels of performance were similar for the control ($M$ = 51.75, $SD$ = 11.29) and thought probe ($M$ = 48.55, $SD$ = 11.49) conditions, although the control condition retrieved slightly more animals than the thought probe condition, $t(274) = 2.33$, $p = .02$, $d = .28$. This makes sense given that answering the thought probes takes time, and thus in a timed task there is less time for retrieval. Importantly, being exposed to the different strategies in the probes did not seem to increase performance in the probe condition.

*Thought probe responses*

Given that there were minimal reactivity effects the thought probe responses were examined in more detail. Overall, participants reported using 2.68 ($SD$ = .96) strategies. Of these, 10.5% of participants reported using only one strategy, 33.1% reported using two strategies, and 56.4% reported using more than two strategies.

Examining overall strategy reports across the entire duration of the retrieval period suggested differences among the different types of strategies used, $F(7,924) = 57.46$, $MSE = .04$, $p < .001$, partial $\eta^2 = .30$. Specifically, as shown in Fig. 1a, participants tended to use visualization, semantic, and no strategies most frequently and rarely relied on several of the other strategies. Follow-up $t$-tests suggested that the semantic strategy was used slightly more frequently than the visualization strategy, $t(132) = 2.03$, $p = .045$, $d = .18$, but there were no differences between semantic and no strategies, $t(132) = 1.02$, $p = .31$, $d = .09$, or between visualization and no strategies, $t(132) = 1.10$, $p = .28$, $d = .09$. Additionally, all three of these strategies were used significantly more often than the other strategies, all $t$'s > 5.89, all $p$'s < .001, all $d$'s > .54.

Next, the time course of the usage of different strategies was examined by examining the proportion of strategies reported for each of the first five thought probes. Note, the first five thought probes were examined because nearly all participants responded to at least five thought probes. Similar results were obtained when examining the first ten thought probes. Additionally, note that for these analyses rhyme responses were not examined given that they constituted less than 1% of all responses. Similar to the analysis of all thought probe responses, there was a main effect of strategy type, $F(6,792) = 48.79$, $MSE = .21$, $p < .001$, partial $\eta^2 = .27$. Importantly, there was also a strategy type by probe response interaction, $F(24,3168) = 5.31$, $MSE = .09$, $p < .001$, partial $\eta^2 = .04$, suggesting that the use of different strategies changed during the course of the retrieval period (see Fig. 1b). Because the visualization, semantic, and no strategy options were used most frequently these were examined in more detail. Participants reported using no strategy more frequently than semantic or visualization strategies at the first probe both $t$'s > 2.08, both $p$'s < .04, both $d$'s > .17, but by the second probe participants reported using a semantic strategy more frequently, both $t$'s > 2.88, both $p$'s < .01, both $d$'s > .25. Over the course of the retrieval period, no strategy reports decreased, $F(4,528) = 10.18$, $MSE = .15$, $p < .001$, partial $\eta^2 = .07$, whereas semantic strategy reports initially

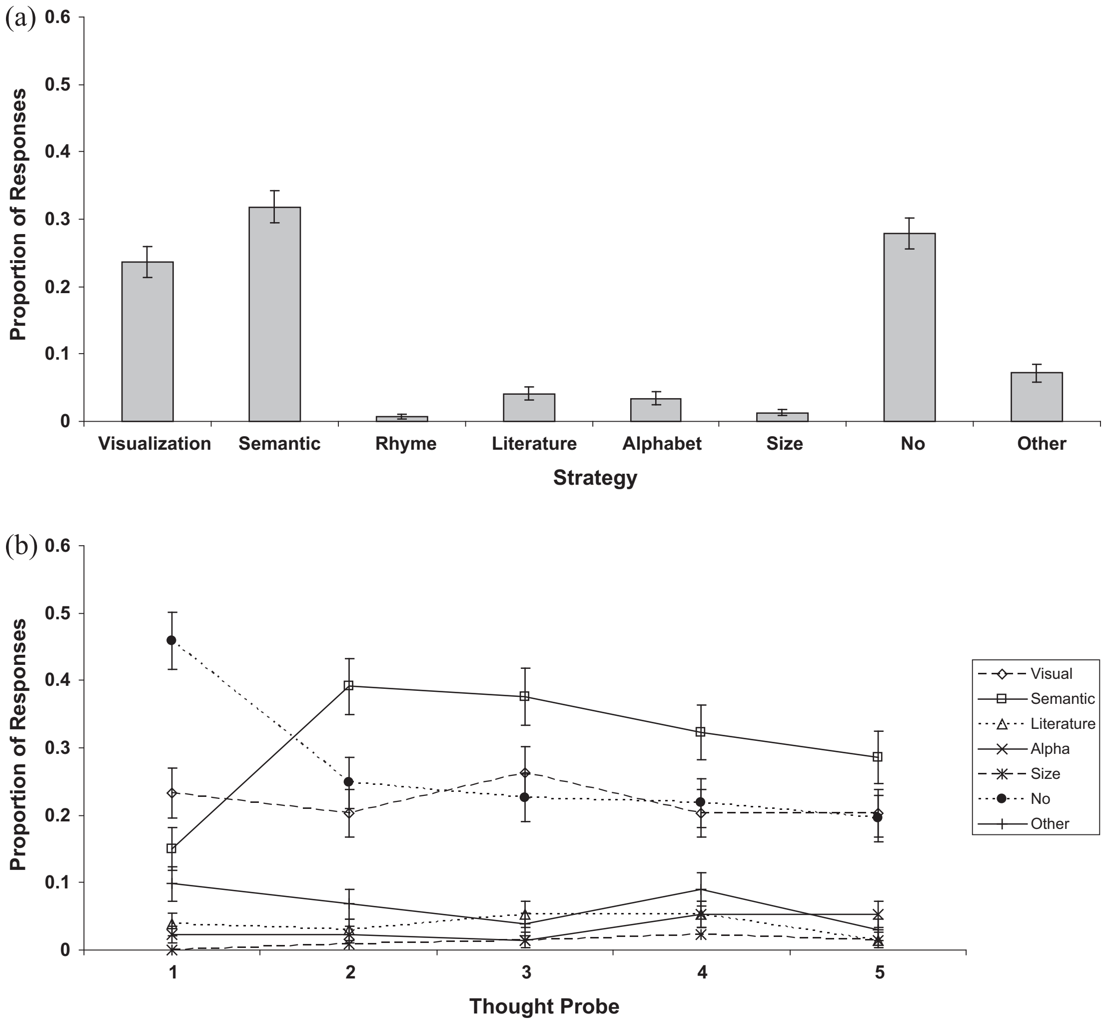


**Fig. 1.** (a) Proportions of reported strategy by strategy. (b) Time course of reported strategy use for the first five thought probes. Error bars reflect one standard error of the mean.

increased and subsequently decreased, $F(4,528) = 7.61$, $MSE = .16$, $p < .001$, partial $\eta^2 = .05$. Use of a visualization strategy tended to remain fairly constant during the retrieval period, $F(4,528) = .76$, $MSE = .13$, $p = .55$, partial $\eta^2 = .01$. These results suggest that not only do participants rely on various strategies to retrieve information from LTM, but participants also dynamically change their strategy use during the course of retrieval.

To examine whether and how participants switch between strategies, transition probabilities between the different strategies were examined. Specifically, transition probabilities were computed for each possible transition for visualization, semantic, rhyme, literature, alphabetic, size, no, and other strategy reports individually. These transition probabilities were calculated separately for each strategy type. Shown in Table 1 are the transition probabilities. Note probabilities in a row sum to 1.0. As can be seen, when participants were using one type of strategy they tended to report using that same strategy on the next probe much of the time. For example, when reporting using a visualization strategy, participants reported continuing to use that same strategy on the next probe 50% of the time. However, in some cases transitions to another strategy were equally likely as continuing to use the same strategy. For example, when using no strategy participants were equally likely to report continuing to use that same strategy or to switch to a semantic strategy, $t(132) = 1.45$, $p > .15$. This is consistent with the time course analysis suggesting that early on participants relied on no strategy, but then switched to a semantic strategy at the second probe.

*Individual differences*

Correlations between each type of strategy reported in the probe condition with overall fluency scores and WMC were examined. Consistent with prior research, overall fluency scores and WMC were correlated, $r = .30$, $p < .001$. Shown in Table 2 are the correlations with the strategies. As can be seen, frequency of using a semantic strategy was positively correlated with the total number of items

**Table 1**
Transition probabilities between different types of strategies.

| Strategy | Visual | Semantic | Rhyme | Lit | Alpha | Size | No | Other |
|---|---|---|---|---|---|---|---|---|
| Visual | .50 | .23 | .01 | .03 | .01 | .01 | .15 | .06 |
| Semantic | .17 | .55 | .00 | .03 | .03 | .01 | .15 | .05 |
| Rhyme | .25 | .25 | .00 | .25 | .00 | .25 | .00 | .00 |
| Lit | .09 | .43 | .04 | .26 | .04 | .04 | .09 | .00 |
| Alpha | .19 | .25 | .00 | .00 | .38 | .00 | .19 | .00 |
| Size | .00 | .33 | .00 | .00 | .00 | .17 | .50 | .00 |
| No | .13 | .31 | .01 | .03 | .03 | .01 | .44 | .04 |
| Other | .23 | .26 | .00 | .00 | .00 | .03 | .13 | .36 |

Note. Visual = visualization; lit = literature; alpha = alphabetic.

**Table 2**
Correlations between different types of strategies from the probes and overall fluency scores and working memory capacity in Experiment 1.

| | Visual | Semantic | Rhyme | Lit | Alpha | Size | No | Other |
|---|---|---|---|---|---|---|---|---|
| Fluency | −.06 | .37* | −.01 | −.13 | −.11 | −.04 | −.18* | −.06 |
| WMC | −.10 | .16 | −.03 | .05 | .05 | −.02 | −.13 | .05 |

Note. Visual = visualization; lit = literature; alpha = alphabetic; WMC = working memory capacity.
* $p < .05$.

retrieved, while frequency of using no strategy was negatively correlated with the total number of items retrieved. None of the correlations with WMC reached conventional levels of significance. Additionally, the total number of strategies used did not correlate with either the number of items retrieved, $r = .09$, $p > .32$, or with WMC, $r = .03$, $p > .74$. Given that WMC, frequency of using a semantic strategy, and frequency of using no strategy all correlated with the total number of items retrieved, all three of these variables were entered into a regression predicting the total number of items retrieved. Shown in Table 3 is the resulting regression analysis suggesting that both WMC and frequency of using a semantic strategy accounted for unique variance in the total number of items retrieved. Frequency of using no strategy no longer accounted for significant variance in the total number of items retrieved once WMC and semantic strategy use were taken into account.

The final set of analyses examined correlations among the different strategies reported in the self-report questionnaire with the total number of items retrieved and WMC in the full sample. Note, in the full sample the total number of items retrieved and WMC were correlated, $r = .37$, $p < .001$. Shown in Table 4 are the correlations. Consistent with prior research, reported strategy use correlated with the total number of items recalled with semantic and knowledge-based strategies correlating positivity and rhyme, size, and no strategies correlating negatively with the total number of items recalled (Schelble et al., 2012; Unsworth et al., 2013). Additionally, replicating prior work, WMC was positively correlated with semantic and knowledge-based strategies, but negatively correlated with no strategy usage (Schelble et al., 2012; Unsworth et al., 2013). Overall, these results are consistent with the probe results suggesting that the use of some strategies is associated with better performance, whereas the use of other strategies is associated with poorer performance.

### *Discussion*

The results from Experiment 1 demonstrated a number of findings. Examining the thought probe responses suggested that participants tended to rely on visualization, semantic, and random strategies the most. Furthermore, the use of these strategies changed during the course of retrieval such that participants tended to start out relying on no strategy in which items simply popped into their heads consistent with prior speculation by Nickerson (1981). However, participants then switched to relying more on a semantic strategy or a visualization strategy for the rest of the retrieval period. Furthermore, following this first switch in strategy use, participants seemed to rely on generally the same strategy. That is, if a participant reported using a semantic strategy on one probe, they were likely to report using the same strategy on the next probe. These results provide important information on the nature of strategic search from LTM, by suggesting that participants use a variety of different strategies during retrieval, but that some strategies and some transitions between strategies are more likely than others. Additionally, examining individual differences suggested that individuals who retrieve the most items tend to have higher WMC and to rely more on semantic strategies than individual who retrieve fewer items who tend to have lower WMC and rely more on no particular strategy.

## Experiment 2

Experiment 2 was conducted to better examine the nature of dynamic search processes. In Experiment 1 only one fluency task was used requiring participants to retrieve exemplars of animals. Although these initial results are informative, it is not known whether different strategies will cut across different retrieval tasks or whether there will be strategies that are more specific to each retrieval task. Thus, in Experiment 2 participants were asked to

**Table 3**
Simultaneous regression predicting total number of items retrieved in Experiment 1.

| Variable | *B* | *t* | $sr^2$ | $R^2$ | *F* |
|---|---|---|---|---|---|
| WMC | .25 | 3.07** | .07 | | |
| Semantic | .32 | 3.75** | .10 | | |
| No | −.04 | −.45 | .00 | .20 | 10.62** |

** $p < .01$.

**Table 4**
Correlations between different types of strategies from the questionnaire and overall fluency scores and working memory capacity.

| | Visual | Semantic | Rhyme | Lit | Alpha | Size | Know | No |
|---|---|---|---|---|---|---|---|---|
| Fluency | −.05 | .23* | −.13* | −.06 | −.07 | −.12* | .22* | −.26* |
| WMC | −.07 | .12* | −.15* | −.01 | −.05 | −.05 | .18* | −.23* |

Note. Visual = visualization; lit = literature; alpha = alphabetic; know = knowledge; WMC = working memory capacity.
* $p < .05$.

retrieve animals, super market items, friends, and teachers. Each of these tasks has been used previously to examine how participants retrieve both semantic and autobiographical information from LTM (e.g., Bahrick, Bahrick, & Wittlinger, 1975; Bond & Brockett, 1987; Hills & Pachur, 2012; Troyer & Moscovitch, 2006; Unsworth et al., 2012, 2014; Whitten & Leonard, 1981; Williams & Hollan, 1981). This should allow for an examination of tasks that are more semantic in nature (animals and super market items) and tasks that are more autobiographical in nature (friends and teachers), and examine similarities and differences across these two types of retrieval tasks. Additionally, in Experiment 1 participants reported using the semantic strategy most often and much of the individual differences variability was related to semantic strategy use. However, the semantic category is quite ambiguous including a number of potential strategies that could be associated with it. For example, sometimes when reporting using a semantic strategy it is possible that participants are in fact relying on categorical retrieval whereby participants are first generating a subcategory of animals (e.g., Pets) and then generating exemplars from this sub-category. Conversely it is possible that when sometimes when reporting using a semantic strategy participants are relying on associative retrieval whereby participants are using the last retrieved item to cue the next item based on associative strength. Hills et al. (2015) recently suggested that when retrieving animals participants primarily rely on associative retrieval, but there was some evidence for categorical retrieval as well. Thus, when reporting use of a semantic strategy it is not clear what participants are always doing. Furthermore, Unsworth et al. (2013) found that in an animal fluency task participants reported using both a general-to-specific strategy (similar to Hills et al., 2015 categorical retrieval) and a link-to-previous strategy (similar to Hills et al., 2015 associative retrieval). Therefore, in Experiment 2 we included a broader array of potential strategies some of which were included for both semantic and autobiographical tasks and some that were specific to only one type of task. By examining a more diverse set of retrieval tasks and additional strategies, the current experiment should provide important information on the dynamic nature of strategic search processes.

*Method*

Participants were 172 undergraduate students recruited from the subject pool at the University of Oregon. All participants were native English speakers. Fifteen participants were excluded due to failing to complete one or more of the fluency tasks leaving 157 participants. Participants were between the ages of 18 and 35 and received course credit for their participation. Participants first performed the three working memory capacity tasks followed by animal fluency, friend fluency, super market fluency, and teacher fluency.

*Working memory capacity measures*

Same as Experiment 1.

*Fluency measures*

Participants were instructed that they would be retrieving as many exemplars from a given category (animals, super market items, friends, or teachers) as possible in 5 min. Supermarket items were counted as correct based on prior work (e.g., Troyer, 2000; Troyer & Moscovitch, 2006; Unsworth et al., 2011) in which items are counted if they can be found in supermarkets (such as apples, deodorant, charcoal, etc.). Prior work with this task suggests that nearly all items generated are common items found in supermarkets. Participants were informed that they could retrieve exemplars from the category in any order they wished. Participants were required to type in each exemplar and then press ENTER to record the response. Participants were instructed that they needed to keep trying to retrieve exemplars throughout the entire 5 min retrieval period.

*Thought probes*

Similar to Experiment 1, during the fluency tasks participants were periodically presented with thought probes. One set probes was used for the semantic fluency tasks and another set was used for the autobiographical fluency tasks. Additionally, it should be noted the number of thought probes was not adjusted in Experiment 2 because it was not clear how many items would be generated in the other fluency tasks used. That is, Experiment 1 only pro-

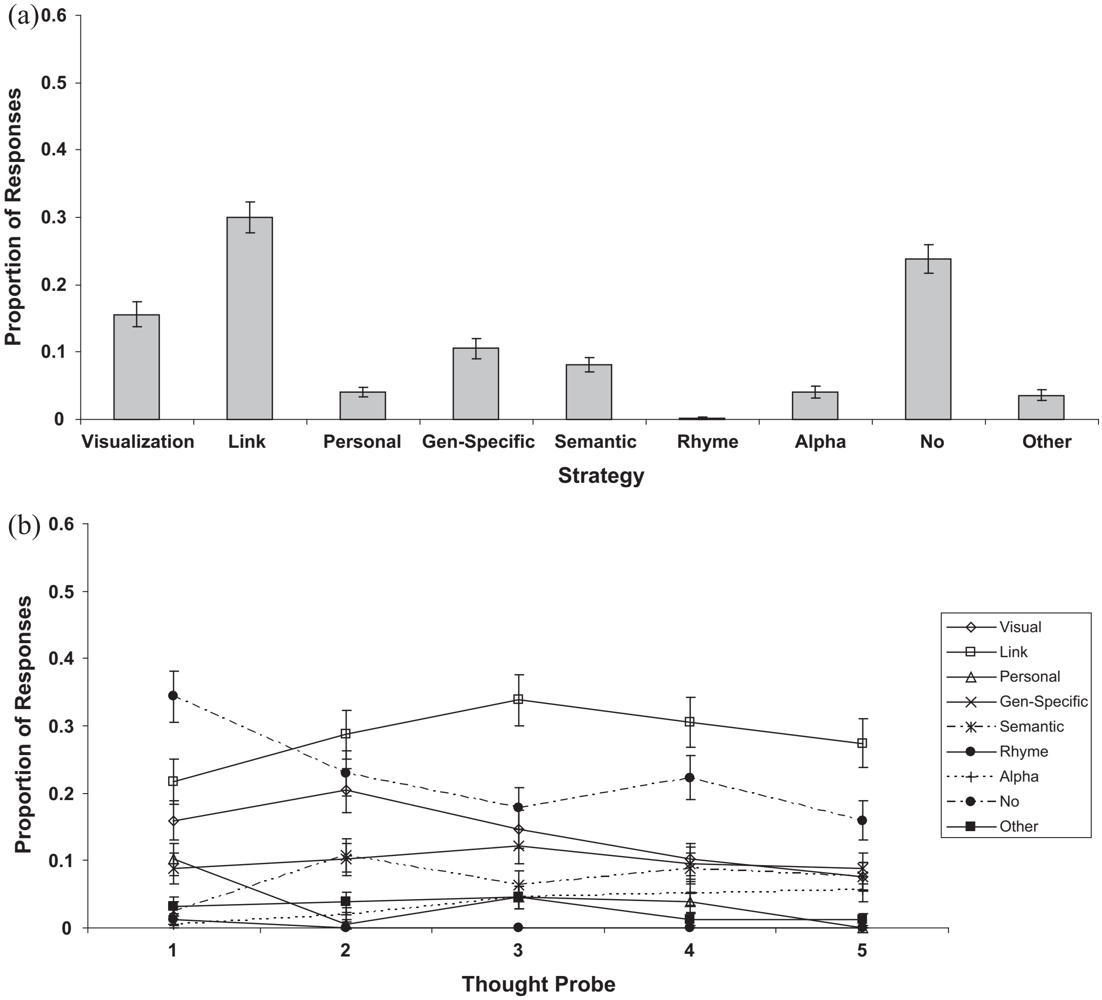


**Fig. 2.** (a) Proportions of reported strategy by strategy in the animal fluency task in Experiment 2. (b) Time course of reported strategy use for the first five thought probes in the animal fluency task in Experiment 2. Error bars reflect one standard error of the mean.

vided information on potentially adjusting the number of thought probes in the animal fluency task. Therefore, in order to ensure consistency across tasks (which is important for individual differences studies), the same number and ordering of probes was used for all tasks in Experiment 2.

For the semantic fluency tasks participants saw:
What type of strategy were you just using?

1. VISUALIZATION strategy (i.e., you imagined yourself walking around looking at animals)
2. LINK TO PREVIOUS (i.e., you specifically used the last item generated to think of new items)
3. PERSONAL IMPORTANCE (i.e., you generated items based on how important they are to you)
4. GENERAL TO SPECIFIC (i.e., you generated general categories and then specific items from those categories)
5. SEMANTIC strategy (i.e., you listed items based on common characteristics)
6. RHYME strategy (i.e., you listed items based on whether they rhymed)
7. ALPHABET strategy (i.e., you listed items in alphabetic order)
8. NO strategy, results were based on random responding (i.e., words just popped into your head)?
9. OTHER

Type in the number that best corresponds to what strategy you were just using and then press ENTER.

For the autobiographical fluency tasks participants saw:
What type of strategy were you just using?

1. VISUALIZATION LOCATION strategy (i.e., you imagined various LOCATIONS that you see your friends at)
2. VISUALIZATION ACTIVITY strategy (i.e., you imagined various ACTIVITIES that you see your friends at)

3. FORWARD CHRONOLOGICAL (i.e., you named friends based on chronological order starting with your oldest friends)
4. BACKWARD CHRONOLOGICAL (i.e., you named friends based on chronological order starting with your newest friends)
5. LINK TO PREVIOUS (i.e., you specifically used the last item generated to think of new items)
6. PERSONAL IMPORTANCE (i.e., you generated items based on how important they are to you)
7. GENERAL TO SPECIFIC (i.e., you generated general categories and then specific items from those categories)
8. RHYME strategy (i.e., you listed items based on whether they rhymed)
9. ALPHABET strategy (i.e., you listed items in alphabetic order)
10. NO strategy, results were based on random responding (i.e., words just popped into your head)?
11. OTHER

Type in the number that best corresponds to what strategy you were just using and then press ENTER.

Similar to Experiment 1, the thought probes were based on prior retrospective strategy reports and strategy instruction studies (e.g., Gronlund & Shiffrin, 1986; Schelble et al., 2012; Unsworth et al., 2013, 2014; Whitten & Leonard, 1981). As noted previously, the general-to-specific and link-to-previous strategies were based on prior retrospective strategy reports from Unsworth et al. (2013) and conceptually similar strategies from Hills et al. (2015). For the autobiographical fluency tasks the visualization, chronological, and personal importance strategy responses were based on prior retrospective strategy reports and strategy instruction studies (e.g., Unsworth et al., 2013, 2014; Whitten & Leonard, 1981). Probes appeared after 5, 14, 20, 29, 38, 49, 61, 74, 82, 93, and 102 responses.

*Results*

Overall participants retrieved 45.59 ($SD = 11.82$) animals, 61.90 ($SD = 12.78$) super market items, 43.10 ($SD = 12.88$) friends, and 24.67 ($SD = 8.88$) teachers.

*Thought probe responses*

Examining animal fluency first suggested that participants reported using 2.85 ($SD = .96$) strategies. Of these, 8.3% of participants reported using only one strategy, 26.3% reported using two strategies, and 65.4% reported using more than two strategies. There were also differences among the different types of strategies used, $F(8,1248) = 45.17$, $MSE = .04$, $p < .001$, partial $\eta^2 = .23$. As shown in Fig. 2a, participants tended to use visualization, link-to-previous, and no strategies most frequently and to a lesser extent relied on semantic and general-to-specific strategies. Follow-up $t$-tests suggested that the link-to-previous strategy was used more frequently than the visualization, $t(156) = 4.38$, $p < .01$, $d = .37$, and there was a trend toward a difference between link-to-previous and no strategies, $t(156) = 1.75$, $p = .083$, $d = .14$. No strategy was reported more frequently than visualization, $t(156) = 2.66$, $p < .01$, $d = .21$. Additionally, all three of these strategies were used significantly more often than the other strategies, all $t$'s > 2.07, all $p$'s < .05, all $d$'s > .19. These results are broadly consistent with Experiment 1 with the current results suggesting that prior responses to the semantic strategy in Experiment 1 may have been using a link-to-previous strategy.

Similar to Experiment 1, the time course of the usage of different strategies was examined for the animal fluency task for the first five thought probes. There was a main effect of strategy type, $F(8,1248) = 46.08$, $MSE = .16$, $p < .001$, partial $\eta^2 = .23$. There was also a strategy type by probe response interaction, $F(32,4992) = 3.07$, $MSE = .23$, $p < .001$, partial $\eta^2 = .02$, suggesting that the use of different strategies changed during the course of the retrieval period (Fig. 2b).[1] Specifically, participants reported using no strategy more frequently than a link-to-previous strategy at the first probe, $t(156) = 2.16$, $p = .033$, $d = .16$, but by the third probe participants reported using a link-to-previous strategy more so than no strategy, $t(156) = 2.84$, $p = .005$, $d = .23$. Both reports of no strategy, $F(4,624) = 5.86$, $MSE = .14$, $p < .001$, partial $\eta^2 = .04$, and of a visualization strategy decreased during the retrieval period, $F(4,624) = 3.98$, $MSE = .10$, $p = .003$, partial $\eta^2 = .03$. Reports of link-to-previous, $F(4,624) = 1.97$, $MSE = .16$, $p = .098$, partial $\eta^2 = .01$, and semantic strategies tended to increase initially, $F(4,624) = 2.56$, $MSE = .06$, $p = .036$, partial $\eta^2 = .02$. Use of the general-to-specific strategy remained fairly constant during the retrieval period, $F(4,624) = .39$, $MSE = .07$, $p = .82$, partial $\eta^2 = .00$. The other strategies were not used very frequently and stayed at a low rate during the retrieval period. Similar to Experiment 1, when examining transition probabilities (Table 5) for the strategies suggested that participants tended to report using the same strategy on subsequent probes for the most part. At the same time, when transitions to different strategies occurred, participants tended to frequently report using the link-to-previous strategy.

Examining super market fluency suggested participants reported using 2.44 ($SD = 1.13$) strategies. Of these, 24.8% of participants reported using only one strategy, 28.7% reported using two strategies, and 46.5% reported using more than two strategies. There were differences among the different types of strategies used, $F(8,1248) = 33.05$, $MSE = .05$, $p < .001$, partial $\eta^2 = .18$. As shown in Fig. 3a, participants tended to use visualization, link-to-previous, and general-to-specific strategies most frequently and to a lesser extent relied on semantic and no strategies. Follow-up $t$-tests suggested that visualization, link-to-previous, and general-to-specific strategies were reported more frequently than semantic or no strategies

[1] Although many of the overall interactions are weak (small partial eta squares), it should be noted that when only examining the most frequently reported strategies during switches in strategies (differences between probe 1 and 2 for example) the overall effect sizes are larger. Thus, the small effect sizes associated with the overall interactions are partially due to the fact that many of the rarely used strategies (such as rhyme and alphabetic strategies) are not used much at all during the entire course of retrieval. The more frequently used strategies, however, do show changes during the course of retrieval.

**Table 5**
Transition probabilities between different types of strategies for the semantic fluency tasks.

| Strategy | Visual | Link | Personal | Gen-Spec | Semantic | Rhyme | Alpha | No | Other |
|---|---|---|---|---|---|---|---|---|---|
| *Animal* | | | | | | | | | |
| Visual | .37 | .29 | .03 | .08 | .09 | .00 | .03 | .09 | .02 |
| Link | .10 | .52 | .04 | .06 | .07 | .00 | .02 | .16 | .03 |
| Personal | .23 | .37 | .04 | .13 | .13 | .00 | .00 | .10 | .00 |
| Gen-Spec | .10 | .17 | .02 | .36 | .12 | .00 | .04 | .13 | .06 |
| Semantic | .15 | .15 | .04 | .10 | .29 | .00 | .04 | .19 | .04 |
| Rhyme | .00 | .50 | .00 | .00 | .00 | .00 | .00 | .50 | .03 |
| Alpha | .12 | .05 | .00 | .12 | .18 | .00 | .02 | .16 | .03 |
| No | .09 | .24 | .02 | .10 | .05 | .00 | .06 | .42 | .02 |
| Other | .05 | .35 | .10 | .00 | .05 | .00 | .05 | .20 | .20 |
| *Super market* | | | | | | | | | |
| Visual | .68 | .19 | .01 | .05 | .04 | .00 | .01 | .02 | .01 |
| Link | .11 | .61 | .01 | .12 | .06 | .01 | .00 | .06 | .02 |
| Personal | .08 | .20 | .40 | .20 | .08 | .00 | .00 | .04 | .00 |
| Gen-Spec | .08 | .16 | .02 | .56 | .11 | .00 | .00 | .06 | .01 |
| Semantic | .09 | .15 | .02 | .13 | .51 | .01 | .00 | .07 | .02 |
| Rhyme | .00 | .00 | .00 | .33 | .67 | .00 | .00 | .00 | .00 |
| Alpha | .57 | .14 | .00 | .00 | .00 | .00 | .14 | .14 | .00 |
| No | .04 | .13 | .00 | .07 | .08 | .00 | .00 | .68 | .00 |
| Other | .08 | .46 | .00 | .00 | .15 | .00 | .08 | .00 | .23 |

Note. Visual = visualization; Link = link-to-previous item; Gen-Spec = general-to-specific; alpha = alphabetic.

(all $t$'s > 2.63, all $p$'s < .01, all $d$'s > .22), and there were no differences among visualization, link-to-previous, and general-to-specific strategies (all $t$'s < 1.34, all $p$'s > .18, all $d$'s < .10). Additionally, there was no difference between semantic and no strategies, $t(156) = .41$, $p = .68$, $d = .03$, and both of these strategies were used more often than any of the lesser used strategies (all $t$'s > 3.88, all $p$'s < .01, all $d$'s > .30).

Examining time course suggested there was a main effect of strategy type, $F(10,1560) = 20.07$, $MSE = .15$, $p < .001$, partial $\eta^2 = .11$, and a strategy type by probe response interaction, $F(40,6240) = 4.95$, $MSE = .05$, $p < .001$, partial $\eta^2 = .03$. Specifically, as shown in Fig. 4b, the main result seemed to be that participants started out using visualization and general-to-specific strategies slightly more than the link-to-previous strategy on the first probe, $F(2,312) = 3.49$, $MSE = .24$, $p = .032$, partial $\eta^2 = .02$, but there was no difference for the second probe, $F(2,312) = .43$, $MSE = .24$, $p = .65$, partial $\eta^2 = .00$. Examining transition probabilities (Table 5) for the strategies suggested that, similar to animal fluency, participants tended to use the same strategy, but when transitions to different strategies occurred, participants tended to frequently report using the link-to-previous strategy.

Examining friend fluency suggested participants reported using 2.37 ($SD = .96$) strategies. Of these, 19.1% of participants reported using only one strategy, 38.9% reported using two strategies, and 42% reported using more than two strategies. There were differences among the different types of strategies used, $F(10,1560) = 19.99$, $MSE = .04$, $p < .001$, partial $\eta^2 = .11$. As shown in Fig. 4a, participants tended to use visualization (specifically visualization location), link-to-previous, personal, and no strategies most frequently. Follow-up $t$-tests suggested that link-to-previous was reported more frequently than all strategies (all $t$'s > 2.78, all $p$'s < .01, all $d$'s > .21), except for visualization location, $t(156) = 1.89$, $p = .06$, $d = .15$. There were no differences among visualization location, personal, and no strategies (all $t$'s < 1.14, all $p$'s > .25, all $d$'s < .08). Additionally, these three strategies were reported more frequently than any of the remaining strategies (all $t$'s > 2.00, all $p$'s < .05, all $d$'s > .19).

Examining time course suggested a main effect of strategy type, $F(10,1560) = 20.07$, $MSE = .15$, $p < .001$, partial $\eta^2 = .11$, and a strategy type by probe response interaction, $F(40,6240) = 4.95$, $MSE = .05$, $p < .001$, partial $\eta^2 = .03$. As shown in Fig. 4b, participants started out reporting that they relied on a personal strategy more frequently than the other main strategies, $F(3,468) = 7.69$, $MSE = .17$, $p < .001$, partial $\eta^2 = .05$, but by the second probe there were no differences between the other main strategies, $F(3,468) = 2.03$, $MSE = .15$, $p = .11$, partial $\eta^2 = .01$. Examining transition probabilities (Table 6) suggested that similar to the semantic fluency tasks, participants tended to use the same strategy, but when transitions to different strategies occurred, participants tended to frequently report using the link-to-previous strategy.

Examining teacher fluency suggested participants reported using 1.81 ($SD = .77$) strategies. Of these, 38.9% of participants reported using only one strategy, 43.3% reported using two strategies, and 17.8% reported using more than two strategies. There were differences among the different types of strategies used, $F(10,1560) = 18.08$, $MSE = .05$, $p < .001$, partial $\eta^2 = .10$. As shown in Fig. 5a, participants tended to use forward chronological, visual location, and no strategies most frequently. Follow-up $t$-tests suggested that forward chronological was reported the most frequently (all $t$'s > 1.99, all $p$'s < .05, all $d$'s > .15), and that visual location and no strategies were reported more frequently than the other strategies (all $t$'s > 2.38, all $p$'s < .02, all $d$'s > .21), but were not different from one another, $t(156) = .51$, $p = .61$, $d = .04$.

Examining time course suggested a main effect of strategy type, $F(10,1560) = 19.56$, $MSE = .09$, $p < .001$, partial

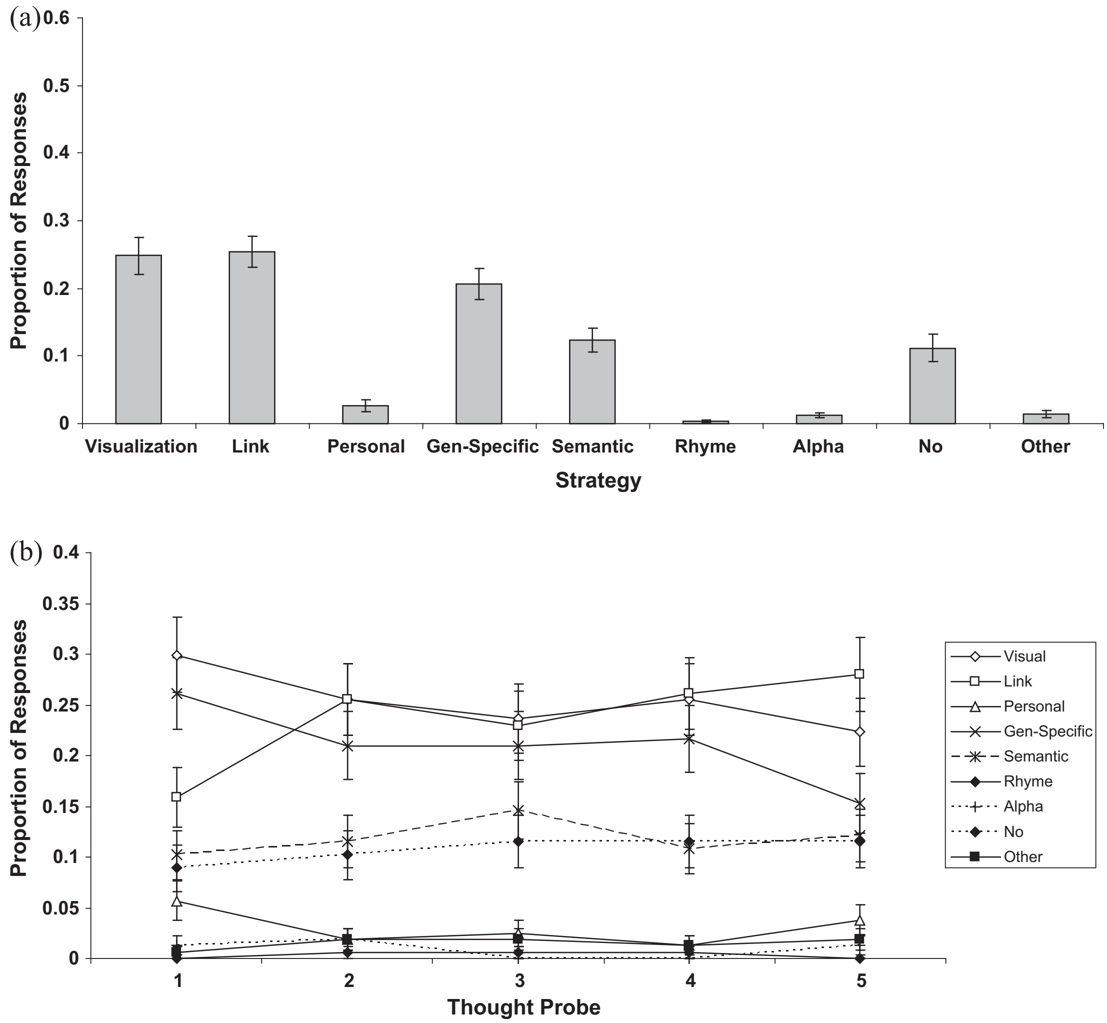


**Fig. 3.** (a) Proportions of reported strategy by strategy in the super market fluency task in Experiment 2. (b) Time course of reported strategy use for the first five thought probes in the super market fluency task in Experiment 2. Error bars reflect one standard error of the mean.

$\eta^2 = .11$, and a strategy type by probe response interaction, $F(40,6240) = 8.70$, $MSE = .04$, $p < .001$, partial $\eta^2 = .05$. Specifically, as shown in Fig. 5b, participants reported using the forward chronological strategy more than the visualization location and no strategy at the first probe, $F(2,312) = 12.92$, $MSE = .20$, $p < .001$, partial $\eta^2 = .08$, but by the third probe there was no differences in reported usage between these strategies, $F(2,312) = .32$, $MSE = .13$, $p = .73$, partial $\eta^2 = .00$. Examining transition probabilities (Table 6) for the strategies suggested that participants tended to report using the same strategy on subsequent probes for the most part.

*Individual differences*

First the semantic fluency tasks were examined by combining the fluency scores for the animal and supermarket scores into a composite variable. Consistent with Experiment 1 and prior research WMC and semantic fluency were correlated $r = .30$, $p < .001$. The total number of strategies used did not correlate with either the number of items retrieved, $r = .12$, $p > .13$, or with WMC, $r = .12$, $p > .13$. Shown in Table 7 are the correlations between each type of strategy with overall fluency scores and WMC. Frequency of using the link-to-previous or the semantic strategy was positively correlated with the total number of items retrieved, while frequency of using an alphabetic strategy was negatively correlated with the total number of items retrieved. In terms of WMC only the link-to-previous strategy was correlated with WMC. Given that WMC, frequency of using a link-to-previous strategy, frequency of using a semantic strategy, and frequency of using an alphabetic strategy all correlated with the total number of items retrieved, all four of these variables were entered into a regression predicting overall semantic fluency scores. Shown in Table 8 is the resulting regression analysis suggesting that WMC and frequency of using both a link-to-previous and a semantic strategy accounted for unique variance in semantic fluency scores. Frequency of

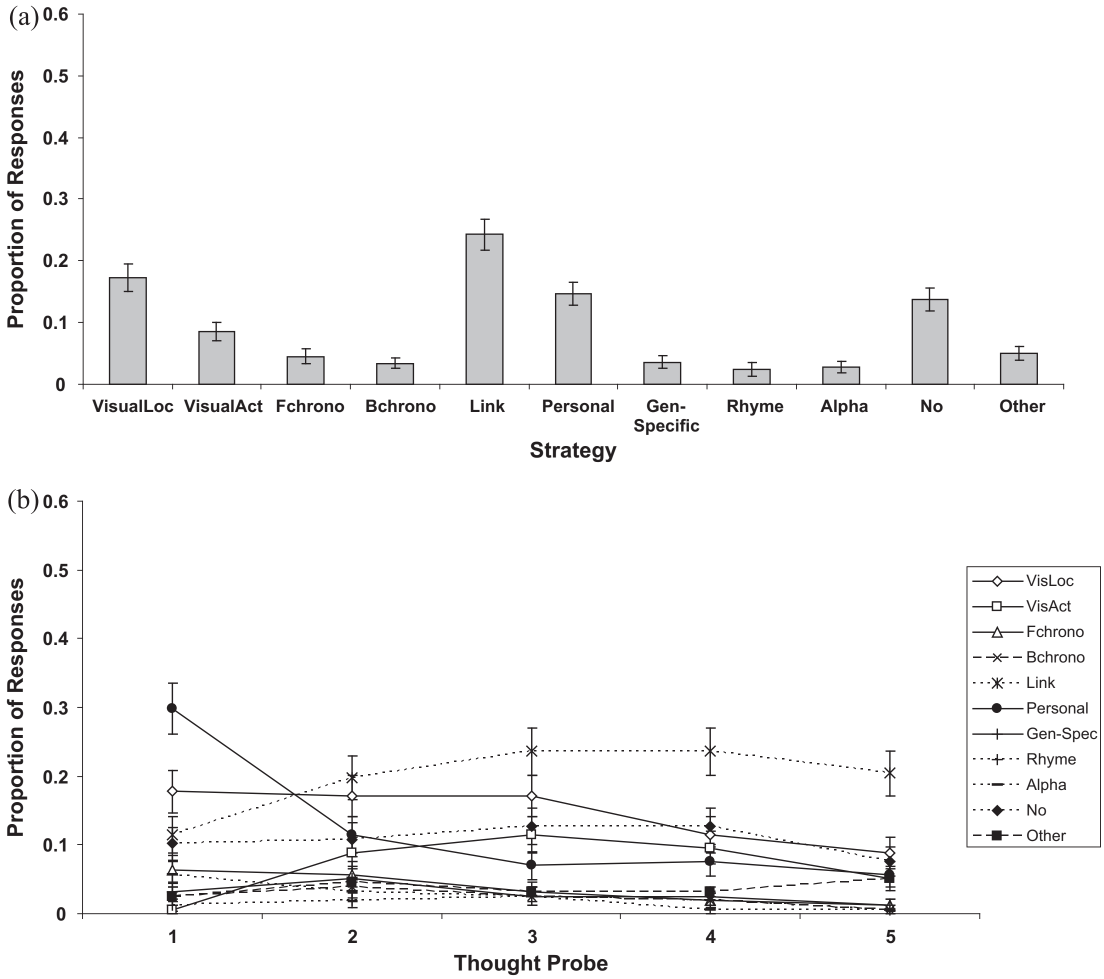


**Fig. 4.** (a) Proportions of reported strategy by strategy in the friend fluency task in Experiment 2. (b) Time course of reported strategy use for the first five thought probes in the friend fluency task in Experiment 2. Error bars reflect one standard error of the mean.

using an alphabetic strategy no longer accounted for significant variance in semantic fluency scores once the other strategies were taken into account.

Similar analyses were conducted with the autobiographical fluency tasks. Consistent with semantic fluency tasks, WMC and autobiographical fluency were correlated $r = .24$, $p = .002$. The total number of strategies used correlated with both the number of items retrieved, $r = .19$, $p = .02$, and with WMC, $r = .19$, $p = .02$. Shown in Table 9 are the correlations with the strategies. Frequency of using visual location, forward chronological, and link-to-previous strategies positively correlated with autobiographical fluency scores. Both forward and backward chronological strategies were positively correlated with WMC. Next, WMC, frequency of using visual location, forward chronological, and link-to-previous strategies were entered into a regression predicting overall autobiographical fluency scores. Shown in Table 10 is the resulting regression analysis suggesting that all of the variables accounted for unique variance in autobiographical fluency scores.

The final set of analyses examined an overall combined fluency composite given that the semantic fluency and autobiographical fluency composites were correlated, $r = .52$, $p < .001$, and given that many of the same strategies were reported across all tasks. Therefore, composites for the shared strategies shared across all tasks were formed. Note, for the visualization strategy the visualization location and visualization action strategies from the autobiographical tasks were combined into a single variable. The overall fluency composite and WMC were correlated, $r = .31$, $p < .001$. The total number of strategies used did not correlate with the number of items retrieved, $r = .14$, $p = .08$, but did with WMC, $r = .17$, $p = .03$. As shown in Table 11, frequency of using visualization and link-to-previous strategies positively correlated with overall fluency scores, while frequency of using an alphabetic strategy negatively correlated with overall fluency scores. Only the link-to-previous strategy was positively correlated with WMC. Next, WMC, frequency of using visualization, link-to-previous, and alphabetic strategies were entered into a regression predicting overall

**Table 6**
Transition probabilities between different types of strategies for the autobiographical fluency tasks.

| Strategy | VisL | VisA | FChron | BChron | Link | Person | Gen-Spec | Rhyme | Alpha | No | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Friend* | | | | | | | | | | | |
| VisL | .54 | .23 | .02 | .00 | .20 | .02 | .00 | .00 | .00 | .07 | .03 |
| VisA | .12 | .60 | .02 | .00 | .17 | .00 | .00 | .00 | .00 | .09 | .00 |
| FChron | .07 | .11 | .41 | .07 | .11 | .11 | .04 | .00 | .00 | .07 | .00 |
| BChron | .20 | .00 | .07 | .20 | .07 | .13 | .00 | .00 | .00 | .20 | .13 |
| Link | .09 | .03 | .00 | .03 | .68 | .06 | .02 | .00 | .00 | .04 | .03 |
| Person | .09 | .06 | .05 | .03 | .20 | .36 | .05 | .01 | .01 | .12 | .02 |
| Gen-Spec | .06 | .00 | .00 | .00 | .12 | .18 | .35 | .12 | .00 | .12 | .06 |
| Rhyme | .00 | .00 | .00 | .00 | .00 | .09 | .00 | .55 | .00 | .36 | .00 |
| Alpha | .00 | .06 | .00 | .00 | .11 | .06 | .06 | .06 | .56 | .06 | .06 |
| No | .08 | .10 | .02 | .00 | .16 | .03 | .05 | .00 | .00 | .52 | .05 |
| Other | .08 | .08 | .00 | .23 | .15 | .08 | .00 | .00 | .00 | .15 | .23 |
| *Teacher* | | | | | | | | | | | |
| VisL | .55 | .13 | .13 | .03 | .07 | .03 | .03 | .00 | .00 | .03 | .03 |
| VisA | .19 | .56 | .06 | .13 | .06 | .00 | .00 | .00 | .00 | .00 | .00 |
| FChron | .06 | .05 | .57 | .11 | .08 | .03 | .02 | .00 | .01 | .06 | .01 |
| BChron | .10 | .10 | .00 | .25 | .20 | .10 | .05 | .00 | .00 | .15 | .05 |
| Link | .04 | .11 | .11 | .00 | .44 | .00 | .07 | .00 | .00 | .22 | .00 |
| Person | .15 | .10 | .15 | .00 | .30 | .05 | .00 | .05 | .00 | .20 | .00 |
| Gen-Spec | .14 | .00 | .14 | .00 | .00 | .14 | .57 | .00 | .00 | .00 | .00 |
| Rhyme | .00 | .25 | .00 | .00 | .00 | .00 | .00 | .75 | .00 | .00 | .00 |
| Alpha | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| No | .03 | .00 | .03 | .03 | .09 | .09 | .00 | .00 | .00 | .74 | .00 |
| Other | .00 | .00 | .00 | .00 | .00 | .00 | .07 | .00 | .00 | .13 | .80 |

Note. VisL = visualization location; VisA = visualization action; FChron = forward chronological; BChron = backward chronological; Link = link to previous item; Gen-Spec = general-to-specific; alpha = alphabetic.

autobiographical fluency scores. Shown in Table 12 is the resulting regression analysis suggesting that WMC and frequency of using both a link-to-previous and a visualization strategy accounted for unique variance in overall fluency scores. Frequency of using an alphabetic strategy no longer accounted for significant variance in semantic fluency scores once the other strategies were taken into account. The individual differences results provide important information that variation in general retrieval abilities are partially due to individual differences in the use of search strategies and an individual's overall WMC.

### *Discussion*

The results from Experiment 2 replicated and extended the results from Experiment 1. Consistent with Experiment 1 when retrieving exemplars, participants reported using a number of different retrieval strategies and the use of different strategies changed over the course of the retrieval period. Importantly, some strategies were frequently reported across tasks whereas other strategies were more task-specific. The results from Experiment 2 further extend those of Experiment 1 in demonstrating that individual differences in retrieval strategies and WMC are major sources of individual differences in general retrieval abilities.

## General discussion

In two experiments the nature of strategic search from LTM was examined via a novel thought probe technique that allowed insights into the nature of in-the-moment retrieval strategies. Across both experiments it was found that participants reported using a variety of strategies, but depending on the task certain strategies were used more often than others. That is, some strategies were used more frequently in one task than another (for example using backward chronological search when retrieving teachers), but some strategies seemed to cut across tasks (e.g., visualization, link-to-previous, and relying on no strategy). Additionally, examining the time course of strategies suggested that participants often started off using one strategy (or no strategy), but then switched to using other strategies. These results provide evidence for the notion that when searching for information from LTM, participants use various retrieval strategies that are tailored to the task at hand and these strategies can and do change throughout the retrieval period. Thus, retrieval of information from LTM in these types of tasks occurs due to a dynamic strategic search process partially under the control of the individual.

Across all of the fluency tasks participants reported utilizing a number of strategies, while also acknowledging that at times retrieval occurred with no particular strategy, rather words randomly and spontaneously were retrieved (likely based on overall frequency, Hills et al., 2013). These findings are consistent with Nickerson's (1981) claim that retrieval of information from LTM occurs via a balance between automatic/random retrievals and more strategic/directed search. Importantly, the current results along with prior research (Gronlund & Shiffrin, 1986; Schelble et al., 2012; Unsworth et al., 2014; Walker & Kintsch, 1985; Whitten & Leonard, 1981; Williams & Hollan, 1981) suggests that retrieval from LTM does not just occur via automatic processes, but rather that the individual brings a number of different strategies to bear on the current task in an attempt to retrieve the desired information.

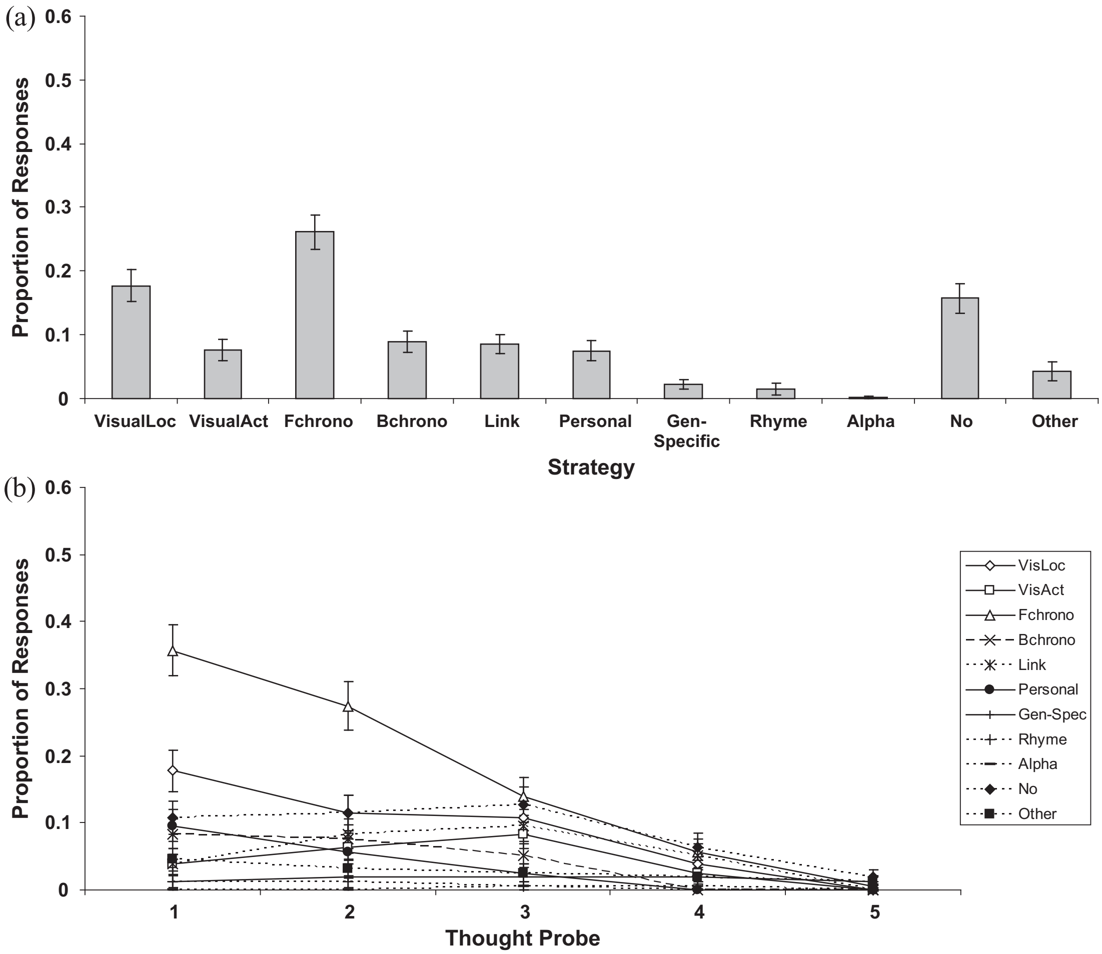


**Fig. 5.** (a) Proportions of reported strategy by strategy in the teacher fluency task in Experiment 2. (b) Time course of reported strategy use for the first five thought probes in the teacher fluency task in Experiment 2. Error bars reflect one standard error of the mean.

**Table 7**
Correlations between different types of strategies from the probes and overall semantic fluency scores and working memory capacity in Experiment 2.

| | Visual | Link | Personal | Gen-Spec | Semantic | Rhyme | Alpha | No |
|---|---|---|---|---|---|---|---|---|
| Fluency | .14 | .37* | .01 | .11 | .17* | −.04 | −.16* | .02 |
| WMC | .01 | .21* | .09 | .02 | .07 | −.11 | −.06 | −.08 |

Note. Visual = visualization; Link = link-to-previous item; Gen-Spec = general-to-specific; alpha = alphabetic; WMC = working memory capacity.
* $p < .05$.

**Table 8**
Simultaneous regression predicting semantic fluency scores in Experiment 2.

| Variable | *B* | *t* | $sr^2$ | $R^2$ | *F* |
|---|---|---|---|---|---|
| WMC | .20 | 2.80** | .05 | | |
| Link | .36 | 4.76** | .13 | | |
| Semantic | .22 | 3.01** | .06 | | |
| Alpha | −.07 | −.98 | .00 | .24 | 12.02** |

** $p < .01$.

Collectively the current results can be interpreted within prior search models that suggest that first participants determine a retrieval plan that includes selecting a retrieval strategy and then participants use the retrieval plan and selected retrieval strategies to generate cues to search LTM (Hills et al., 2012; Raaijmakers & Shiffrin,

**Table 9**
Correlations between different types of strategies from the probes and overall autobiographical fluency scores and working memory capacity in Experiment 2.

| | VisL | VisA | FChron | BChron | Link | Person | Gen-Spec | Rhyme | Alpha | No |
|---|---|---|---|---|---|---|---|---|---|---|
| Fluency | .16* | .15 | .32* | −.07 | .31* | .15 | .06 | .03 | −.03 | .02 |
| WMC | −.10 | .01 | .19* | .21* | .05 | .08 | −.05 | .12 | .01 | −.03 |

Note. VisL = visualization location; VisA = visualization action; FChron = forward chronological; BChron = backward chronological; Link = link to previous item; Gen-Spec = general-to-specific; alpha = alphabetic; WMC = working memory capacity.
* $p < .05$.

**Table 10**
Simultaneous regression predicting autobiographical fluency scores in Experiment 2.

| Variable | $B$ | $t$ | $sr^2$ | $R^2$ | $F$ |
|---|---|---|---|---|---|
| WMC | .19 | 2.77** | .04 | | |
| VisL | .29 | 4.10** | .08 | | |
| FChron | .31 | 3.01** | .09 | | |
| Link | .34 | 4.76** | .11 | .30 | 15.94** |

** $p < .01$.

**Table 11**
Correlations between different types of strategies from the probes and overall fluency scores and working memory capacity in Experiment 2.

| | Visual | Link | Personal | Gen-Spec | Rhyme | Alpha | No |
|---|---|---|---|---|---|---|---|
| Fluency | .18* | .40* | .07 | .10 | .02 | −.19* | .01 |
| WMC | −.03 | .18* | .11 | .01 | .09 | −.03 | −.07 |

Note. Visual = visualization; Link = link-to-previous item; Gen-Spec = general-to-specific; alpha = alphabetic; WMC = working memory capacity.
* $p < .05$.

**Table 12**
Simultaneous regression predicting overall fluency scores in Experiment 2.

| Variable | $B$ | $t$ | $sr^2$ | $R^2$ | $F$ |
|---|---|---|---|---|---|
| WMC | .25 | 3.54** | .07 | | |
| Visual | .24 | 3.44** | .07 | | |
| Link | .36 | 3.01** | .14 | | |
| Alpha | −.12 | −1.69 | .01 | .29 | 15.30** |

** $p < .01$.

1980; Reiser et al., 1985; Whitten & Leonard, 1981; Williams & Hollan, 1981). Depending on the task participants may start out recalling high frequency exemplars (e.g., Hills et al., 2013) based on fairly spontaneous passive recall (such as when searching for animals), or rely on more directed strategies early on (such as using personal importance when retrieving friends). However, given the prolonged nature of the task, participants will likely switch to additional strategies in an effort to generate different contexts to search in. In this case, participants will select from various retrieval strategies throughout the task that allow them to effectively search within a particular domain (e.g., search for animals or search for friends) and may use that information to conduct additional searches (such as using the last generated item to think of additional items). Thus, participants dynamically switch strategies throughout the task and frequently switch from using passive/random retrieval to more effortful/directed retrieval. Furthermore, it is likely that information will also be activated automatically that is associated with the information generated by the strategy so that both strategic and automatic processes are working together. Thus, it is not the case that conscious strategies are always dictating retrieval; but that these strategies generally facilitate retrieval by consciously generating various contexts to search and via automatic associations that are activated within the different contexts.

*Individual differences in memory search*

The current results also have important implications for understanding individual differences in general retrieval abilities. As noted previously, performance on a number of different fluency tasks have been shown to correlate and form a single higher-order general retrieval ability factor (Barnett et al., 2000; Carroll, 1993; Silvia et al., 2013; Unsworth et al., 2011). Thus, individuals who effectively retrieve information from one domain (such as animals) also tend to excel at retrieving information from other domains (such as teachers). Despite these relations, it has not been clear what aspects of retrieval are important for individual differences and for the fact that these individual differences cut across tasks. The current results shed new light on this issue by suggesting that both variation in

WMC and variation in retrieval strategies are important contributors to general retrieval abilities. Specifically, as we and others have suggested previously, the ability to generate and utilize particular search strategies is likely reliant on working memory control processes that allow one to self-generate various cues to search LTM with and to dynamically change search strategies when a particular search strategy is no longer working within a given retrieval task or across tasks (Hills & Pachur, 2012; Rosen & Engle, 1997; Schelble et al., 2012; Unsworth et al., 2013). Thus, a key aspect to the search process is the ability to self-generate cues via different strategies, and high retrieval ability and high WMC individuals are better able to select and use different search strategies to guide the search process than low retrieval ability and low WMC individuals. Furthermore, high retrieval ability and high WMC individuals seem better able to adapt their search to the task at hand and utilize task-appropriate retrieval strategies than low retrieval ability and low WMC individuals. Additionally, the fact that WMC was consistently related to the link-to-previous strategy (and this strategy predicted better retrieval) is consistent with the notion that a key aspect of search is the ability to maintain cues in active state and to use the prior retrieved items as cues to further guide the search process (Hills & Pachur, 2012; Hills et al., 2013). As noted previously, Hills and colleagues have suggested that cue-maintenance is critically important for efficient searches of LTM, and part of the reason that WMC is related to performance on fluency tasks. The current results provide important evidence for the cue-maintenance hypothesis and suggest that the ability to maintain cues and to dynamically switch to new strategies when the current cue is no longer generating items is an important determinant of overall general retrieval abilities.

Additionally, individual differences in the ability to select and use strategies independently of WMC (perhaps due to prior experience) are an important factor in determining overall retrieval abilities. A consistent finding was that various retrieval abilities predicted overall fluency scores over and above that accounted for by WMC. For example, in Experiment 2 overall fluency scores were predicted by unique variance in WMC, as well as by unique variance in using a visual strategy and unique variance in using the link-to-previous strategy. This suggests that individual differences in strategy selection and utilization, independent of WMC, are important contributors to general retrieval abilities. Thus, the current results suggest that variation in general retrieval abilities are partially due to differences in WMC (the ability to maintain and select particular retrieval cues) as well as differences in the efficacy of the particular retrieval strategies that are chosen. In the current work, these two factors accounted for roughly 30% of the variability in general retrieval abilities. Although there are clear individual differences in recall from LTM, future work is needed to better understand these differences. In particular, future work is needed to better examine the differential contributions of WMC and search strategies to general retrieval abilities as well to examine other important sources of variability (such as general knowledge for semantic tasks).

### *Limitations*

Finally, it would be remiss not to address several limitations of the current study. For example, in Experiment 1 possible reactivity effects were examined and a small difference between the control condition and the probe condition was found. As noted previously, this difference was likely due to the fact that answering the thought probes takes time, and thus in a timed task there is less time for retrieval. Importantly, the probe condition retrieved fewer overall items, suggesting that being exposed to the different strategies did not lead to an increase in overall performance. At the same time we cannot fully rule out the possibility that seeing the different strategies did not lead to a change in which strategies were used. That is, a participant may not have been using a visualization strategy, but upon seeing the probe response they could decide to try that strategy next. Future research could rely on more open ended probes where participants are required to type in which strategies they were just using. In prior research we had participants fill out an open ended questionnaire at the end of the task and found that participants provided fairly detailed reports of the strategies they had used (Unsworth et al., 2013). A similar method could be used for each probe. This would not only aid in reducing possible reactivity effects, but would also provide more details on exactly the different strategies participants actually use.

An additional limitation of the current research is that there are clear floor effects for many of the strategies. For example, participants very rarely reported using the rhyme and alphabetic strategies. The rare use of these strategies means that it is unlikely that participants will transition to or transition from these strategies leading to very low transitions probabilities that are seen. Furthermore, this necessarily reduces the ability to find any correlations between these rarely used strategies and overall performance and WMC given very little variability present. At the same time it should be noted that the correlations are not simply artifacts whereby the most frequently used strategies correlate with performance and WMC. For example, in both experiments a visualization strategy was one of the most frequently reported strategies in the semantic fluency tasks, but use of this strategy did not correlate with either overall performance or WMC. Furthermore, although the alphabetic strategy was rarely used, reported usage of this strategy correlated negatively with semantic and overall fluency scores. Thus, individual differences in some, but not all, reported strategies are related to individual differences in general retrieval abilities and WMC.

A final potential limitation of the current study is that we relied on typing responses and there are likely large individual differences in typing skills which could have influenced the results. In particular, individuals with faster typing skills could potentially record more responses than individuals with slower typing skills. Although the current data cannot rule out this possibility, it is important to note that prior research has suggested that individual differences in recall abilities and WMC are not correlated with individual differences in typing speed (Unsworth, 2009). Furthermore, although prior research has found that individual differences in processing speed are related to overall fluency scores, processing speed and WMC were not correlated and accounted for completely separate variance in overall fluency scores (Unsworth et al., 2011). Thus, differences in typing speed likely account for some of the individual differences variance, but that variance is likely independent of the variance accounted for by WMC and the various strategies. Future research is needed to better examine the relations among these various sources of individual differences and how they jointly or independently account for general retrieval abilities.

## Conclusions

Overall the current results provide important new information on the dynamic nature of strategic search processes when retrieving information from LTM. The results suggest that individuals dynamically switch search strategies within and between retrieval tasks and that individual differences in these strategic search processes are an important reason for individual differences in general retrieval abilities. In order to better understand the retrieval process, we need to understand the dynamic nature of LTM search.

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