Mem Cogn (2014) 42:1130–1142
DOI 10.3758/s13421-014-0422-1

Flexibility within working memory and the focus of attention for sequential verbal information does not depend on active maintenance

Joshua Sandry · Jeremy D. Schwark · Justin MacDonald

Abstract The focus of attention seems to be a static element within working memory when verbal information is serially presented, unless additional time is available for processing or active maintenance. Experiment 1 manipulated the reward associated with early and medial list positions in a probe recognition paradigm and found evidence that these nonterminal list positions could be retrieved faster and more accurately if participants were appropriately motivated—without additional time for processing or active maintenance. Experiment 2 used articulatory suppression and demonstrated that the underlying maintenance mechanism cannot be attributed to rehearsal, leaving attentional refreshing as the more likely mechanism. These findings suggest that the focus of attention within working memory can flexibly maintain nonterminal early and medial list representations at the expense of other list representations even when there is not additional time for processing or active maintenance. Maintenance seems to be accomplished through an attentional refreshing mechanism.

Keywords Working memory · Attention · Focus of attention · Maintenance · Rehearsal · Refreshing

J. Sandry (✉)
Neuropsychology and Neuroscience Laboratory, Kessler Foundation, 300 Executive Dr., Suite 70, West Orange, NJ 07052, USA
e-mail: joshsandry@gmail.com

J. Sandry
Department of Physical Medicine and Rehabilitation, Rutgers New Jersey Medical School, Newark, NJ, USA

J. D. Schwark · J. MacDonald
Department of Psychology, New Mexico State University, Las Cruces, NM, USA

Introduction

When information is presented sequentially with no additional time for processing or active maintenance of memory representations, do humans have the ability to maintain previous, nonterminal items in the focus of attention (FoA) even when actively attending to new information? Or is it possible to maintain nonterminal items in the FoA while actively attending to new information only if there is additional time available for processing or active maintenance? A number of different embedded process models of memory (Cowan, 1995, 2005; McElree, 1998, 2006; Oberauer, 2002) deal directly with the structure of working memory (WM) and the FoA and may help answer these questions.

The focus of attention

Although there are subtle differences between theories, embedded process models typically represent memory as varying levels of activation associated with different memory states or representations. The differences between models tend to center around the parameters of the embedded processes. The models do agree that a special component of attention resides within and interacts directly with activated memory; however, the quantitative restraint associated with this region is less clear. This area is commonly referred to as the FoA.

Cowan (1995, 2005) suggests that a multiitem FoA (three to four items) is embedded in activated long-term memory. McElree (1998, 2001, 2006) suggests that a single-item FoA is embedded within activated long-term memory. Oberauer's (2002) model is situated between these models and makes more refined assumptions regarding the structure of memory. He suggests that there are three active states: A highly activated FoA (capable of holding a single item) is embedded within the region of direct access (restricted to about three items), which is embedded further in activated long-term memory. The combination of the FoA and region of direct access in Oberauer's model is similar to Cowan's multiitem view and has recently been referred to as the *broad focus* (Oberauer & Hein, 2012).

A large body of research has investigated the structural and functional parameters of the FoA for simultaneously presented visual information (Luck & Vogel, 2013; Ma, Husain, & Bays, 2014). There has been less research directed at understanding the FoA for sequentially presented verbal information. Some studies that have investigated memory for sequential information have used variants of the Sternberg (1966) probe recognition paradigm. In the probe recognition paradigm, a sequential list of to-be-remembered words or letters are rapidly presented to participants, followed by a mask and then a discrimination task where participants decide whether a probe is from the list or whether it is a novel lure. Responses to later memory representations are faster and more accurate than those to earlier representations (nonterminal items). This has been interpreted as evidence that the last list item holds a special status in the FoA. By using a probe recognition procedure that is presented very rapidly, with the entire trial lasting on the order of only a few seconds, researchers assume fast[1] presentation lessens the chance of rehearsal, grouping, or chunking strategies (Nee & Jonides, 2008, 2011; Öztekin, Güngör, & Badre, 2012; Öztekin, McElree, Staresina, & Davachi, 2009). This particular paradigm has been increasingly used to make inferences relating neural activation to behavioral responses in order to differentiate between embedded process models (for reviews, see Cowan, 2011; LaRocque, Lewis-Peacock, & Postle, 2014; Nee & Jonides, 2013).

Although the last item in the list is the fastest and most accurate item retrieved, an attentional mechanism should be able to keep older information in an active and accessible state so that it is available for processing (McElree, 2001, 2006). It does appear that the FoA can maintain an earlier representation in an available state in tasks such as the *n*-back task. However, evidence suggests that this is possible only when individuals have additional time available for an active maintenance control processes—for example, rehearsal (McElree, 2001). Other research has further tested the flexibility hypothesis while allowing additional time for processing or rehearsal. A six-item list was serially presented, and the set of first three and second three words came from their own distinct categories (e.g., *cat*, *moose*, *wolf*; *doctor*, *lawyer*, *cop*). List presentation was followed by a category cue (animals or professions) to encourage participants to restore information from that category into their FoA. When participants received a cue and had 1 s available for processing, there was no advantage for the cue. When participants received a cue and had 3 s available for processing, there was an advantage for words from the first category. This provided support for FoA flexibility only when additional time was given to process the information (McElree, 2006), perhaps because rehearsal (a time-consuming process) was necessary to reactivate or recirculate through the information.

Furthermore, on the basis of Baddeley's (1986) model of WM, the phonological loop holds information for 1.5–2 s, and the central executive must rehearse that information to keep it active. When participants were given additional time and encouraged to actively rehearse a list of five consonants, earlier items could be maintained in an active state. In one condition, participants had 2 s to rehearse, and in another condition, they had 4 s to rehearse. The data mapped directly onto the prediction that when probed in the 2-s-rehearsal condition, participants should be near the second serial position of the five-item list, essentially circulating through representations stored in memory. In fact, the response times (RTs) for the second and third nonterminal serial positions were 22 and 106 ms shorter, respectively, than that for the last/terminal serial position. The retrieval advantage shifted from the last serial position to the medial serial position with active rehearsal but returned to the last serial position in the 4-s condition, presumably because participants' rehearsal had returned to the end of the set (McElree, 2006). The FoA does seem to be a flexible resource that can maintain information in an active state; however, past research suggests that this is possible only when additional time is given to process or rehearse the information.

Resources and working memory

Perhaps it is possible to hold earlier representations in an available state without additional processing time if individuals are sufficiently motivated. Some evidence suggests that people have control over how they allocate their cognitive resources to information from competing modalities. Over the course of three experiments, participants completed a hybrid auditory and visual memory task with an associated financial reward. In the manipulation of interest, information presented in one modality had a higher fiscal value than did information presented in the other modality. When visual information was associated with a larger payout than auditory information, participants held more visual information in WM, and vice versa. Evidence from both traditional frequentist analyses and Bayesian modeling suggests that people have a unique ability to flexibly allocate their attention resources between auditory and visual information in WM (Morey, Cowan, Morey, & Rouder, 2011). On the basis of these experiments, it seems plausible that participants may also have the ability to flexibly allocate attention to information that is presented in a single modality, if they are motivated to do so.

---

[1] We use the terms "fast" and "rapid" to remain consistent with prior literature (McElree & Dosher, 1989). Interpretation of how fast the presentation actually was remains relative to the cognitive paradigm being studied.

Present experiments

It may be an artifact of the sequential experimental paradigm that the last item in the list is retrieved the fastest; this item should be high in activation while levels of activation to earlier list items fade. This fading might be due to temporal decay (Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007; Barrouillet, De Paepe, & Langerock, 2012) or interference (Oberauer & Lewandowsky, 2013); however, the mechanism behind forgetting is not the focus of the present article. Presently, we are interested in whether it is possible to flexibly maintain sequentially presented nonterminal items in the FoA when there is not additional time for processing or active maintenance strategies. A paradigm where participants are particularly motivated to keep older (nonterminal) list items at a high state of activation may reveal faster and more accurate responses to those nonterminal items, even without additional time for processing or active maintenance strategies.

Experiment 1 manipulated the reward associated with various list positions in a probe recognition paradigm using a task that minimizes the opportunity to rehearse, group, or chunk items (Nee & Jonides, 2008, 2011; Öztekin, Davachi, & McElree, 2010; Öztekin et al., 2009) in order to discern whether a performance benefit can be found for early and medial list items. During some trials, a letter in the list was presented in red font and was worth more points than letters presented in black. Participants were instructed to keep the letters in red font in the "front of their memory," but these letters were no more likely to be probed than letters in black font [*p* (Red Probe | Red Letter in the List) = .33]. Attention should serve to strengthen information held in memory (Cowan & Morey, 2006), and rewarding participants for allocating attention to certain list items on the basis of a feature (color) may serve to direct or orient attention to those items. Experiment 2 tested whether maintenance of early items was possible when active maintenance (in particular, rehearsal) was further prevented via articulatory suppression. Articulatory suppression also allowed us to distinguish between rehearsal and refreshing as possible maintenance mechanisms. Other studies have used long lists of to-be-remembered items in order to test for distinctions between long-term memory, WM, and the FoA. Since we were particularly interested in how the FoA operates in WM, we used small list lengths to measure this construct (Nee & Jonides, 2008; Öztekin et al., 2012). We advance two hypotheses related to the flexible allocation of resources within the FoA.

Flexible FoA

If the FoA is a flexible resource, rewarding participants for remembering single letters in beginning and medial list positions, without allowing additional time for processing, may reduce or eliminate the privileged status of the last letter in the list, while also speeding responses or increasing accuracy to the high reward position.

Static FoA

If the last item in the list maintains a special status in the FoA, rewarding participants for remembering single letters in beginning and medial list positions, without allowing additional time for processing, should not affect their speed of retrieval and/or accuracy to the last item in the list.

Evidence that the FoA is a flexible resource when no additional time is given would lead to an additional hypothesis related to active maintenance and whether the benefit is due to (1) rehearsal or (2) attentional refreshing during list presentation.

Experiment 1

Method

Participants

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study (Simmons, Nelson, & Simonsohn, 2012).We estimated needing 20 participants, on the basis of prior work (Nee & Jonides, 2008, 2011; Öztekin et al., 2010; Öztekin et al., 2009). Our stopping rule was to advertise time slots at the beginning of each week, end enrollment after reaching or exceeding our minimum recruitment goal, and then analyze the full data set. Twenty-four undergraduates (17 females and 7 males) from New Mexico State University participated for partial course credit. The mean age was 21.00 years (*SD* = 5.87).

Materials and design

The experiment was run using E-Prime 2.0 on computers with a 19-in. monitor with a resolution of 1,280 × 1,024 pixels set at a distance of approximately 22 in. Each trial involved the sequential presentation of three letters randomly selected without replacement from the set B, F, G, H, J, L, M, Q, R, T, and Y, in order to minimize phonological similarity. Vowels were removed to reduce the likelihood of chunking strategies. The study letters were presented on a silver background in either red or black 24-point lowercase Times New Roman typeface. The words on the choice screen were presented in the same font and size, but they were presented in uppercase to lessen the chance of recognition by similarity and reduce the likelihood of participants adopting a visual matching strategy based on case (Nee & Jonides, 2011). A 4 × 3 within-subjects design was used, with orientation position (a red letter in the first, medial, or last serial position or no red letter at all [control]) and probe position (first, medial, or last) as the independent variables.

Procedure

The task was a probe recognition procedure with a motivation manipulation. Participants played a memory game in which they saw three letters presented sequentially and had to identify the letter that had appeared in the list. Participants gained points for correct answers and lost points for incorrect answers and were informed that they should attempt to attain the highest point total possible. On three quarters of trials, one of these letters appeared in red font. These red letters were worth 25 points, instead of the standard 3 points for black letters (Table 1). Participants were given a general overview and sample of the experiment, as well as practice trials, before beginning the experimental trials.

Trials began with a blank intertrial interval (250 ms), followed by a fixation asterisk (500 ms), three sequentially presented to-be-remembered letters (500 ms each), a mask (#####: 500 ms), and then the probe screen (2,500 ms) that contained one letter from the list and one novel lure. Participants identified the letter from the list via keypress. The correct answers appeared on the left and right an equal number of times and had an equal probability of occurring in either location (Fig. 1). After making a selection, participants were shown a feedback screen (1,500 ms) that indicated whether they were correct in their decision and displayed a running tally of their accumulated points.

Participants completed 10 practice trials (with an optional repetition), followed by 300 experimental trials. Thirty-second breaks were provided every 50 trials; on the break screen, participants saw their point and accuracy totals from the prior blocks along with their current points and accuracy for that block. List letters and novel lure letters were drawn randomly from the predetermined set. Both orientation and probe position were manipulated within subjects, and each serial position had an equal probability of being presented in red font and being probed, rendering an average of 25 trials in each cell of the design. The experiment lasted approximately half an hour, and the experimenter monitored participants throughout the task. Accuracy and RTs were collected and used as dependent variables in analyses.

Table 1 Example of point breakdown for all trials in the experiment

	Correct Answer	Incorrect Answer
Black font	+3	−3
Red font	+25	−25

Note. This table was also presented to participants on the final instruction screen

Results

The following procedure was used across all experiments. The analysis on RT was conducted on accurate trials only. RTs less than 300 ms or greater than the individual participant's mean by three standard deviations in each experimental condition were considered outliers (see Oberauer, 2002). Outlier removal resulted in elimination of 1.38 % of all trials. Alpha was set at .05 for all comparisons.

Response time

The results were analyzed using a 4 × 3 (orientation position × probed position) repeated measures ANOVA. There was no main effect of orientation position, $p = .86$. The main effect of probed position was significant, $F(2, 46) = 7.75$, $p = .001$, $\eta_p^2 = .25$. A follow-up test of the main effect revealed a significant quadratic trend[2] across the first, medial, and last serial positions, $F(1, 23) = 10.70$, $p = .003$, $\eta_p^2 = .32$ (*M*s = 717, 773, 761). The quadratic trend was driven by a strong primacy effect and plateau between serial positions 2 and 3, reflective of the pattern observed in the control condition. The interaction between orientation position and probed position was significant, $F(6, 138) = 16.00$, $p < .001$, $\eta_p^2 = .41$ (see Fig. 2), and was investigated further.

The simple effect of reward orientation, as compared with the control (red vs. black text), was examined at each of the three serial positions. Participants responded faster to oriented (red) probes, as compared with control (all black) probes, at the first, medial, and last probed positions (Table 2, row A). We also compared reward orienting and recency effects by comparing RTs for the red probe in the first or medial serial position with black probes in the last serial position of the same trials. Participants responded faster to the red probe when it was in the first serial position and medial serial position than to the black probes in the last serial position (Table 2, row B).

In an additional set of comparisons, we tested whether the amount of resources devoted to the task was distributed between the list positions. We compared the last probed item from the control condition with the last probed item when the first or medial serial position was oriented to. The RTs for responses made to the last serial position when the first serial position was red and when the medial serial position was red were significantly longer than RTs for responses to the last

---

[2] The linear trend was also significant, $F(1, 23) = 6.30$, $p = .02$, $\eta_p^2 = .22$; however, the quadratic trend accounted for more variance, so we interpret the latter.

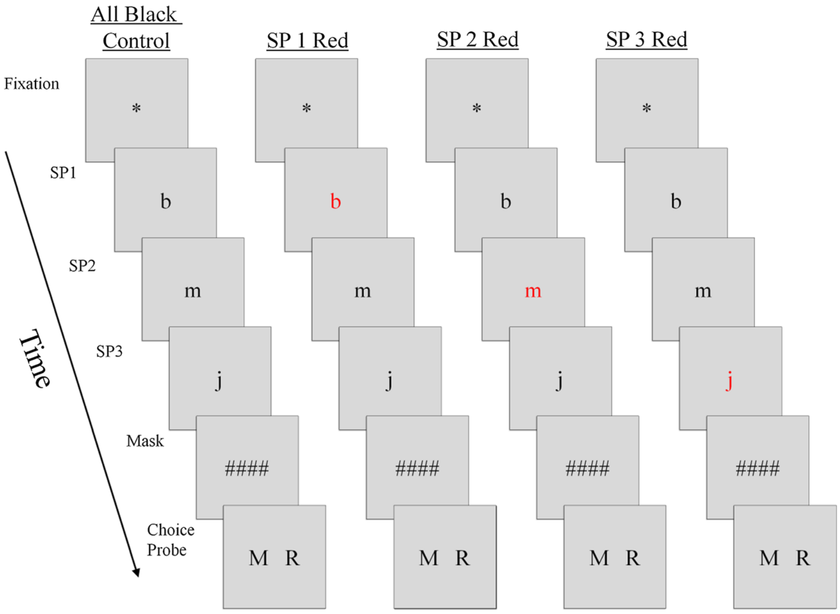


Fig. 1 Procedure used in Experiments 1 and 2. Intertrial interval (250 ms), followed by a fixation asterisk (500 ms), three to-be-remembered letters (serial positions 1, 2, and 3) in the study list (500 ms each), and a mask (500 ms,) followed by the probe screen (2,500 ms). Participants were instructed to indicate whether the letter that was in the list appeared on the left or right of the probe screen using the "F" and "J" keys, respectively. SP = serial position

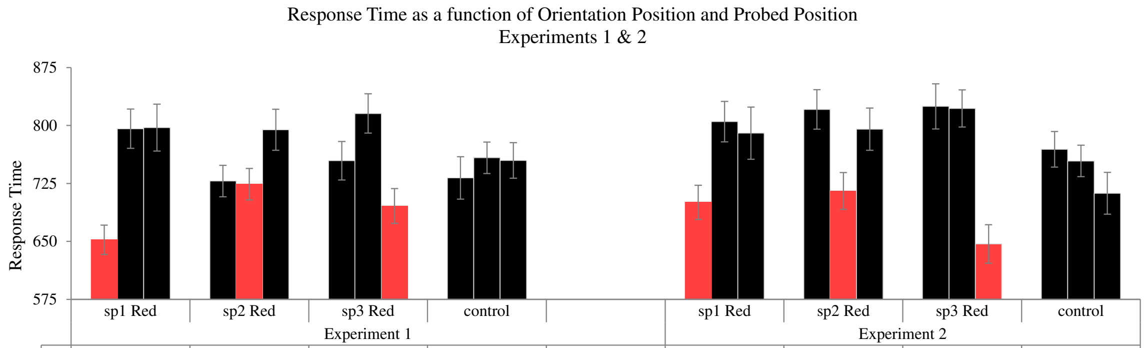
serial position on control trials (Table 2, row C). This analysis suggests that there is a limited amount of available resources that can be directed to the task and those resources can be (and were) shared between the list positions.

Accuracy

The accuracy data were analyzed in the same manner as the RT data. The main effect of orientation position, $p = .12$, and the main effect of probed position, $p = .14$, were not significant. The interaction between orientation position and probed position was significant, $F(6, 138) = 2.99$, $p = .009$, $\eta_p^2 = .12$. None of the same simple comparisons performed on the RT data reached significance in the accuracy data (all *ps* > .10). Overall accuracy was rather high ($M = .93$), which limits interpretation of the interaction due to a ceiling effect (see Fig. 3). To foreshadow, Experiment 2 eliminates the ceiling effect in accuracy.

Discussion

Overall, the RT analysis suggests that nonterminal information can be accessed more quickly within WM without the necessity of additional time for processing or active maintenance. When motivated with high reward, participants were able to orient their attention to early, nonterminal list items, effectively keeping those items in the forefront of their memory and available for rapid retrieval. Typically, serial position



	Experiment 1 sp1 Red	Experiment 1 sp2 Red	Experiment 1 sp3 Red	Experiment 1 control		Experiment 2 sp1 Red	Experiment 2 sp2 Red	Experiment 2 sp3 Red	Experiment 2 control
sp1	652	728	754	732		701	821	825	769
sp2	796	724	816	758		805	715	822	754
sp3	797	795	696	755		790	795	647	712

Probed Position x Orientation

Fig. 2 Experiment 1 and Experiment 2 response times (in milliseconds) as a function of orientation position and probed position.. The red colored bars represent the list positions oriented to in red, and the black colored bars represent the list positions oriented to in black. Error bars represent standard errors of the means. SP = serial position

Table 2 *t* test comparisons for different orientation and serial position (sp)

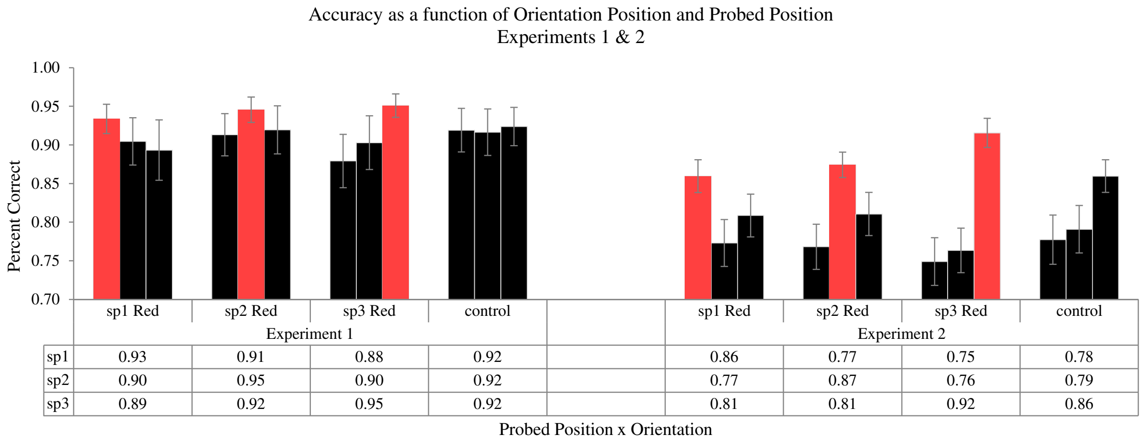
		Experiment 1			Experiment 2						Analysis Across Experiments 1 & 2					
		Response Time			Response Time			Accuracy			Response Time			Accuracy		
		t(23)	*p*	*d*	*t*(29)	*p*	*d*	*t*(29)	*p*	*d*	*t*(53)	*p*	*d*	*t*(53)	*p*	*d*
A	sp1 red: sp1 vs. control: sp1	3.91	.001	0.87	3.25	.003	0.59	3.20	.003	0.61	4.99	.001	0.70	3.10	.003	0.46
	sp2 red: sp2 vs. control: sp2	2.22	.037	0.45	2.02	.053	0.38	3.15	.004	0.62	3.45	.001	0.49	3.26	.002	0.54
	sp3 red: sp3 vs. control: sp3	2.84	.009	0.58	3.73	.001	0.68	3.43	.002	0.67	3.49	.001	0.49	3.59	.001	0.49
B	sp1 red: sp1 vs. sp3	4.80	.001	1.03	2.75	.010	0.52	1.86	.070	0.40	5.05	.001	0.72	2.35	.020	0.31
	sp2 red: sp2 vs. sp3	3.17	.004	0.67	2.75	.010	0.51	2.60	.020	0.50	4.03	.001	0.55	2.72	.009	0.46
C	sp1 red: sp3 vs. control: sp3	3.15	.004	0.76	2.59	.015	0.48	2.16	.040	0.56	3.49	.001	0.49	2.79	.007	0.41
	sp2 red: sp3 vs. control: sp3	2.78	.011	0.58	3.43	.002	0.63	2.11	.020	0.40	4.24	.001	0.58	2.09	.040	0.32

Row A comparisons are between oriented serial positions and control trials at the same serial position. Row B comparisons are between orienting and recency effects on similar trials. Row C comparisons are between the last probed item from the control condition and the last probed item when the first or medial position was oriented to in red.

Note. All Cohen's *d* estimates of effect size are based on the average standard deviation for both means and are corrected for dependence between means (Morris & DeShon, 2002, Equation 8), using the online calculator available at http://www.cognitiveflexibility.org/effectsize/.

experiments report superb retrieval for the first (primacy) and last (recency) serial positions, with a reduced retrieval benefit for information in the middle of the list. In the present experiment, RTs were shorter for the medial serial position when it was worth more points, similar to the first and last serial positions under the same circumstances. This ability seems to come at a cost to the other list items, evident from the simple comparisons in the RT analysis comparing the recency positions with no red items in the list versus the recency position with a red item in the list.

When attention was oriented to the nonterminal first or medial list position (serial positions 1 and 2), these items were retrieved faster than the last terminal list position (serial position 3). This is similar to studies that encouraged rehearsal *with* additional processing time (McElree, 2001, 2006). The last list item may still maintain a special status; however, the effect of orienting to the red list item was stronger than the recency effect. We did not find a strong recency effect and special status for the last list item in the control trials, but we did find a strong primacy effect. The recency effect may have been attenuated due to the relative ease of the task (only three list positions), which seems plausible given the high level of accuracy. Whether this is a result of the present paradigm or a spurious effect will be evaluated and discussed further if a similar finding emerges in Experiment 2. Overall, the data from Experiment 1 support the hypothesis that the FoA is flexible even when the presentation duration of the task is brief, minimizing the chances of rehearsal, grouping, or chunking strategies (Nee & Jonides, 2008, 2011; Öztekin et al., 2010; Öztekin et al., 2009).



	Experiment 1: sp1 Red	Experiment 1: sp2 Red	Experiment 1: sp3 Red	Experiment 1: control		Experiment 2: sp1 Red	Experiment 2: sp2 Red	Experiment 2: sp3 Red	Experiment 2: control
sp1	0.93	0.91	0.88	0.92		0.86	0.77	0.75	0.78
sp2	0.90	0.95	0.90	0.92		0.77	0.87	0.76	0.79
sp3	0.89	0.92	0.95	0.92		0.81	0.81	0.92	0.86

Fig. 3 Experiment 1 and Experiment 2 accuracy (in percent correct) as a function of orientation position and probed position. The red colored bars represent the list positions oriented to in red, and the black colored bars represent the list positions oriented to in black. Error bars represent standard errors of the means. SP = serial position

Experiment 2

The data from Experiment 1 provide support for the ability to flexibly orient the FoA to representations of nonterminal early and medial list items held in WM. There are some issues associated with Experiment 1 that are corrected in Experiment 2. The task was extremely rapid, with information presentation occurring within a few seconds, in order to lessen the use of rehearsal and chunking strategies (Nee & Jonides, 2008, 2011; Öztekin et al., 2010; Öztekin et al., 2009). However, Experiment 2 took further measures to determine whether an active maintenance strategy was being utilized when orienting to list items.

Active maintenance could be the mechanism responsible for keeping oriented information in a highly active state by rehearsal (subvocalization), which could lead to (1) recirculating list representations by means of rehearsal (Baddeley, 1986) or (2) the creation of a phonological code (Baddeley, Lewis, & Vallar, 1984). Subvocal rehearsal seemed plausible, on the basis of informal conversation with some participants after completing the task ("I said the letters to myself") and experimenter strategies while programming and testing the experiment. An alternative mechanism could be attentional refreshing by directing attention toward that oriented item (Barrouillet, Bernardin, & Camos, 2004; Barrouillet et al., 2007; Barrouillet & Camos, 2001; Camos, Mora, & Oberauer, 2011; Cowan, 1999, 2005; Johnson, 1992; Johnson et al., 2005; Raye, Johnson, Mitchell, Greene, & Johnson, 2007; Raye, Johnson, Mitchell, Reeder, & Greene, 2002). The marked difference between rehearsal and refreshing is that rehearsal processes (and the creation of a phonological representation) are blocked by vocal articulation, while refreshing processes are not (Hudjetz & Oberauer, 2007). Interestingly, past work suggests that people can selectively choose between these two maintenance processes based on task demands (Camos et al., 2011).

It is possible that participants in Experiment 1 were using an active maintenance strategy, which could account for the findings and would be congruent with prior work (McElree, 2001, 2006). Experiment 2 investigates the role of subvocal rehearsal with respect to the orientating reward manipulation in order to assess a possible mechanism responsible for more attentional resources being directed at oriented list items. Accordingly, we included an articulatory suppression requirement (Baddeley, 1986; Baddeley & Hitch, 1974; Baddeley et al., 1984) in Experiment 2 to determine whether an active maintenance mechanism, subvocal rehearsal, was responsible for the flexible allocation of resources. Articulatory suppression is useful because it serves to disrupt information held in WM (Allen, Baddeley, & Hitch, 2006). If participants are asked to repeat the irrelevant word "the" out loud throughout the study, they should not be able to articulate the target letters at the same time. Convergent findings between Experiments 1 and 2 would provide a strong case for a flexible FoA for sequentially presented information that does not depend on an active maintenance strategy. Alternatively, if the effect of orienting to a red item is attenuated when articulatory suppression is introduced, this would suggest that an active maintenance mechanism is underlying the higher activation and would be informative for studies that assume that the rapid presentation of serial items avoids rehearsal processes (in particular, recent neuroimaging studies).

Articulatory suppression serves an additional purpose beyond preventing active maintenance. In Experiment 1, significant differences in accuracy were not found across conditions, possibly due to the overall high levels of performance. In order to investigate accuracy, it is necessary to make the task more challenging and lower accuracy enough so that trends become apparent and interpretable. High cognitive load (associated with cognitive control processes) typically has deleterious effects on the ability to focus attention, while high perceptual load tends to enhance this ability (Lavie, 2010). Articulatory suppression is one way to increase the amount of cognitive load placed on WM, effectively consuming resources that would otherwise be available for processing (Soto & Humphreys, 2008).

Method

Participants

On the basis of Experiment 1, we estimated needing a minimum of 24 participants and used the same stopping rule as Experiment 1. Final participant enrollment resulted in 30 (13 females and 17 males) undergraduates from New Mexico State University who received partial course credit for participation. The mean age was 20.13 years (*SD* = 3.20).

Materials, design, and procedure

The materials and design were identical to those in Experiment 1; however, an articulatory suppression task was added. Participants said the word "the" during each experimental trial out loud at a pace of 2 times per second. Participants began the experiment after demonstrating sufficient articulatory suppression behavior at the proper pace during a familiarization period. An experimenter monitored participants to ensure articulatory suppression compliance.

Results

Response time

The analysis on RT was conducted using a 4 × 3 (orientation position × probed position) repeated measures ANOVA. Outlier removal resulted in elimination of 1.46 % of all trials.

The main effect of orientation position was significant, $F(3, 87) = 2.76, p = .047, \eta_p^2 = .08$. This effect appears to be driven by shorter RTs on control trials ($M = 745$, $SD = 104$) than on oriented trials ($M = 769$, $SD = 111$), $t(29) = 2.41, p = .02$. The main effect of probed position was significant, $F(2, 58) = 4.82, p = .012, \eta_p^2 = .14$. A follow-up test of the main effect revealed a significant linear trend[3] across the first, medial, and last serial positions, $F(1, 29) = 4.96, p = .03, \eta_p^2 = .15$ (Ms = 779, 774, 736), suggesting a recency effect. The interaction between orientation position and probed position was also significant, $F(6, 174) = 15.50, p < .001, \eta_p^2 = .35$ (see Fig. 2). The same simple effects tests of the interaction corroborated the findings from Experiment 1 (see Table 2).

Accuracy

Overall accuracy ($M = .81$) was reduced, as compared with Experiment 1. Accuracy was analyzed with the same repeated measures ANOVA as RT. The main effect of orientation position, $p = .85$, was not significant. The main effect of probed position, $F(2, 58) = 10.67, p < .001, \eta_p^2 = .27$, was significant, and a follow-up test of the main effect revealed a significant linear trend across the first, medial, and last serial positions (Ms = .79, .80, .85), $F(1, 29) = 15.11, p < .001, \eta_p^2 = .34$, suggesting a recency effect, similar to the pattern in the RT data. The interaction between orientation position and probed position was also significant, $F(6, 174) = 11.77, p < .001, \eta_p^2 = .29$. The findings from the analyses of accuracy in Experiment 2 suggest that the additional cognitive load associated with articulatory suppression served to reduce accuracy. The interaction in accuracy was investigated using the same sets of simple effects tests as for RT (Fig. 3).

Participants responded more accurately to the probed position when it was oriented to in the first, medial, and last serial positions, as compared with the probed position in the control condition (Table 2, row A). Participants responded more accurately to the first serial position when it was red[4] and the medial serial position when it was red than to the last serial position when it was black (Table 2, row B). When the first serial position or medial serial position was oriented to in red, the last serial position was responded to less accurately than the last serial position of the control trials (Table 2, row C).

Discussion

In Experiment 2, the effect of the orienting task was noticeable in both the RT and accuracy data, suggesting that articulatory suppression served to make the task more demanding, reducing the ceiling effect in accuracy found in Experiment 1. When a list item was worth more, participants responded faster and more accurately. Congruent with the findings from Experiment 1, these results suggest that participants were able to keep earlier list representations at a higher level of activation even when there was no additional time for processing or active maintenance and subvocalization was further blocked with articulatory suppression. Additionally, because the effect remained even when participants were repeating the word "the" throughout the trials, it is unlikely that rehearsal is the underlying mechanism associated with heightened activation. The findings from Experiment 2 leave attentional refreshing as the more likely mechanism.

The absence of a significant main effect for orientation position in the accuracy data has implications for fixed capacity models of WM. If there is a fixed amount of attention resources or a fixed number of slots within WM, directing more attention to one item should come at the expense of other items. A consequence of a constant capacity model in the present paradigm is to expect that the overall percent correct across the orientation conditions should not differ from that in the control condition (percent correct should not change when a red-letter cue is introduced and rehearsal is not possible). Alternatively, if the effect of the incentive manipulation differs between the orientation conditions and the control condition, this should be taken as evidence that the effect of orienting is not the same as the effect of the terminal list position in the control condition. The average percent correct when serial position 1 was red, serial position 2 was red, and serial position 3 was red did not differ from the control condition (Ms = .81, .82, .81, and .81, respectively). This implies that the FoA is a constant-capacity resource and improved performance for red items comes at the *expense* of other items. Convergent evidence for fixed capacity and flexibility comes from the comparisons presented in Table 2C, which suggest that a limited amount of available resources are shared between list positions.

One divergent trend was observed between Experiments 1 and 2 related to the main effect of probe position. In Experiment 1, the main effect was a quadratic function, suggesting a primacy effect in memory. In Experiment 2, this changed to a linear decrease—that is, a stronger recency effect. We had no a priori hypothesis regarding primacy effects in WM; however, the addition of the articulatory suppression task may have reduced the strength of the primacy effect. Experiment 2 was more challenging to participants and past research shows minimized primacy effects when there is less opportunity to rehearse the information (Rundus, 1971; Tan & Ward, 2000).

Some of the simple comparisons in Experiment 2 only reached marginal levels of significance; however, they were all in the predicted direction for the flexibility hypothesis. The pattern of results did replicate the results in Experiment 1. The

---

[3] The quadratic trend was also significant, $F(1, 29) = 4.23, p = .05, \eta_p^2 = .13$; however, the linear trend accounted for more variance, so we interpret the latter.

[4] Marginal effect (see Table 2).

weaker effects may have been due to the increased variability resulting from an increased cognitive load associated with articulatory suppression. We address the issue of power in the next section.

Analysis across Experiments 1 and 2

Aside from articulatory suppression, the designs of Experiments 1 and 2 were identical. This allowed us to compare across the experiments to better discern the effect of suppression on flexibility and further investigate the interaction between orientation position and probed position. Although the trends in Experiments 1 and 2 were in the direction of supporting the flexibility hypothesis, some of the simple tests of the interaction fell just short of statistical significance. Combining the data from the experiments resulted in nearly double the sample size, thereby increasing statistical power while also allowing for the investigation of the role of articulatory suppression across studies.

We conducted a comparison across studies using a mixed ANOVA with orientation position (first, medial, or last serial position or a no orientation control) and probed position (first, medial, or last) as repeated measures factors and suppression (with suppression [Experiment 1] or without suppression [Experiment 2]) as the between-subjects factor. We present these analyses for the combined data for both RT and accuracy.

Response time

The main effect of orientation position (p = .16), and the interaction between orientation position and suppression (p = .22) were not significant. The main effect of probed position, $F(2, 104) = 3.77, p = .03, \eta_p^2 = .07$, was significant, with a significant quadratic trend, $F(1, 52) = 15.35, p < .001, \eta_p^2 = .23$. The interaction between probed position and suppression, $F(2, 104) = 8.50, p < .001, \eta_p^2 = .14$, was also significant, as was the interaction between orientation position and probed position, $F(6, 312) = 28.04. p < .001, \eta_p^2 = .35$. The three-way interaction between orientation position, probed position, and suppression (p = .65) and the between-subjects factor of suppression (p = .65) were not significant.

We investigated the interaction between orientation position and probed position with the same simple effects used in Experiments 1 and 2. The same effects emerged for these comparisons, surpassing the preset criterion value (see Table 2).

Accuracy

The main effect of orientation position (p = .35) and the interaction between orientation position and suppression (p = .71) were not significant. The main effect of probed position, $F(2, 104) = 10.39, p < .001, \eta_p^2 = .17$, was significant, and a trend analysis revealed a significant linear trend, $F(1, 52) = 15.10, p < .001, \eta_p^2 = .24$. The interaction between probed position and suppression, $F(2, 104) = 5.54, p = .005, \eta_p^2 = .10$, was also significant, as was the interaction between orientation position and probed position, $F(6, 312) = 12.78, p < .001, \eta_p^2 = .20$, and the three-way interaction between orientation position, probed position, and suppression, $F(6, 312) = 2.52, p = .02, \eta_p^2 = .05$ (analysis of the three-way interaction is presented as the main analyses in Experiments 1 and 2). The between-subjects factor of suppression was also significant, $F(1, 52) = 9.91, p = .003, \eta_p^2 = .16$. Follow-up tests of the interaction between orientation position and probed position mirrored those of the RT data (see Table 2).

The between-subjects factor of suppression was of particular interest for accuracy. The general trends across experiments held when suppression was entered as a factor in the analysis for both RT and accuracy. The significant main effect of suppression in the accuracy data was likely a result from blocking rehearsal processes from occurring and increasing the cognitive load associated with the task. Interestingly, suppression did not interact with the other two factors when RT was the dependent measure, providing further support that attention resources were directed to early and mid-list items in a similar fashion across experiments. The analysis across studies suggests that the mechanism responsible for faster and more accurate responses to the oriented item was not from an active maintenance process, leaving refreshing as the likely mechanism. Although both processes can affect WM (Camos et al., 2011), the present data suggest that active maintenance is unnecessary to keep information in the FoA at a high state of activation, available for quick and accurate access.

General discussion

We tested whether individuals would be able to flexibly maintain early list representations when there was no additional time given for control processes such as processing or the use of an active maintenance strategy. The RT and accuracy measures from Experiments 1 and 2 and the comparison across experiments provide support for the flexibility hypothesis over the static hypothesis. Participants were able to direct their attention to earlier list items when motivated. Moreover, the evidence suggests that this flexibility could be extended to nonterminal items (both the first and the medial serial positions) in the list. The findings seem even more impressive because points were used instead of monetary rewards (cf. Morey et al., 2011). We suspect that a pecuniary manipulation may serve to increase motivation and lead to larger effect sizes than those presently observed, a possibility for future research. The findings from the present study replicate prior research that demonstrated that it was possible to maintain early information (McElree, 2001, 2006); however, the findings show new evidence that suggest rapid and accurate retrieval of nonterminal items from the FoA is possible even when there is not additional time for active maintenance.

We cannot discuss memory representations outside of WM (i.e., activated long-term memory) because the number of items in the list was relatively small. The present experiments made use of a small list because of the goal of understanding how the FoA operates within WM. Cowan et al. (2005) proposed that the FoA could act similarly to a camera lens with an ability to adjust focus, effectively zooming in and out on the basis of task demands (see also Eriksen & St James, 1986). The present data support the idea of an adjustable focus; it appears that the FoA is a resource tied to WM and this resource can be flexibly allocated between limited numbers of items. It is possible that multiple items are maintained in WM and the FoA rapidly shifts (on the order of nanoseconds) between these items (Cowan, 2011). An adjustable FoA is not a stretch from theories that define WM capacity as an individual difference in controlling attention (Engle, 2002, 2010; Engle & Kane, 2004; Kane, Conway, Hambrick, & Engle, 2007), and the data presented here do support the assumption that individuals have control over their attention. What was additionally interesting about the present experiments is that there seemed to be a set amount of resources that could be devoted to the task and those resources were spread across the list positions at the expense of other list positions. On the basis of the reward manipulation, participants were flexibly adjusting which list positions they retrieved quickly and accurately. One recent set of experiments provides corroboratory support for a flexible FoA in a probe recognition paradigm (Morrison, Conway, & Chein, 2014).

Given the varied nature of the cognitive processes that contribute to WM (Shipstead, Lindsey, Marshall, & Engle, 2014; Unsworth, Fukuda, Awh, & Vogel, 2014), it is possible that flexibility in the FoA is associated with various subprocesses: capacity or attentional control (zooming in or out [cf. Cowan et al., 2005], updating [Oberauer, 2002], secondary memory retrieval [Unsworth & Engle, 2007], binding [Halford, Cowan, & Andrews, 2007]) or an interaction of these various subprocesses. Future research will be necessary in order to better understand how efficient people are at flexibly adjusting their FoA to longer lists of items or multiple list positions and, further, how individual differences affect flexibility. One possible test would be to increase the number of list items or the number of oriented positions; however, such a task would be difficult for a few reasons. First, the more list positions that are oriented to, the longer the experiment becomes as a result of the additional trials. Second, as list length increases, so does the demand placed on WM and executive function. If WM is limited to only a small number of items, then when that capacity limit is exceeded, performance may significantly break down. Increasing the size of the list may serve to affect the precision of the memory representation. It may be that participants are efficient only when orienting to a small number of list positions (not exceeding the three to four item capacity limit of WM; Cowan, 2005). Any of these findings will be interesting for competing theories regarding the structure of WM.

The idea of the flexible allocation of attention within WM is not new; there is a robust literature on the topic in visual WM. These models assume that resources can be flexibly allocated to different representations within memory and this allocation comes at a cost to other representations (Ma et al., 2014). A fundamental difference between models is that some models assume a fixed capacity with an upper limit on the number of representations that can be maintained (e.g., the discrete resource model; Zhang & Luck, 2008), where WM is made up of a limited number of slots (*k* slots) and the number of items that can be maintained in WM is limited to *k*. Alternative models assume an unlimited capacity where resources in WM are not tied to a fixed limit; instead, resources are distributed among all representations (e.g., the continuous resource model; Bays & Husain, 2008; Fougnie, Suchow, & Alvarez, 2012; Keshvari, van den Berg, & Ma, 2013).

The present experiments are congruent with the view that attention is flexible; furthermore, it seems that the amount of resources was limited regardless of whether there was a red letter in one list position, as evidenced by the support for the constant capacity hypothesis in the accuracy data from Experiment 2 (percent correct remained fixed across all four conditions regardless of whether or not there was a red cue). Congruent with the discrete resource model, the precision of the oriented representation was improved, and this may have been because the oriented item took up an additional slot in WM (Zhang & Luck, 2008) or because resources were distributed differently across *k* slots (Barton, Ester, & Awh, 2009). Importantly, future work is necessary to further test these models with the present paradigm, ideally with longer list lengths.

Maintenance mechanism

On the basis of prior research, two possible mechanisms could account for nonterminal items being maintained in a high state of activation: (1) rehearsal (Baddeley, 1986) and/or the creation of a phonological representation (Baddeley et al., 1984) and (2) refreshing (Barrouillet et al., 2004; Barrouillet et al., 2007; Barrouillet & Camos, 2001; Camos et al., 2011; Cowan, 1999, 2005; Johnson, 1992; Johnson et al., 2005; Raye et al., 2007; Raye et al., 2002). When we blocked the ability to rehearse information, accuracy decreased; however, participants were still able to maintain late list items in a highly accessible state. This suggests that rehearsal was not responsible for the shorter RTs and higher accuracy that came from the effect of orienting, leaving refreshing as the more likely maintenance mechanism. This extends prior work (McElree, 2001, 2006) that demonstrated maintenance of nonterminal items when individuals used a controlled rehearsal processes (Seamon & Wright, 1976).We did not directly measure refreshing (typically, measurement of refreshing is done through designs and assumptions associated with neuroimaging; cf. Johnson et al., 2005; Raye et al., 2007; Raye et al., 2002), so it remains possible that an additional, unidentified maintenance mechanism contributed to the higher activation of oriented items.

Fast and accurate retrieval of the oriented nonterminal item implies that the oriented item was not forgotten from memory. Recent theories of forgetting and consolidation suggest that consolidation is a limited resource (Wixted, 2004), much similar to the assumption that the FoA is a capacity-limited resource in embedded process models of memory (Cowan, 1995, 2005). The revised cognitive model of forgetting (Dewar, Cowan, & Della Sala, 2010) suggests that during the initial period of memory consolidation, the memory trace becomes strengthened through a process of synaptic consolidation (Dudai, 2004) and long-term potentiation (Frey & Morris, 1997). The construct of attentional refreshing may serve as a behavioral correlate to the very early and initial stages of neural synaptic consolidation. It is possible that the nonterminal oriented items, held active through attentional refreshing, received a larger proportion of the available neural resources and that resulted in the strengthening and binding of information into the FoA (synaptic consolidation). This account is not contradictory to attentional refreshing but, instead, implicates a role of attentional refreshing in synaptic consolidation.

Concerning the strategy that participants used, we consider it unlikely that participants used a chunking or grouping strategy (Gilchrist & Cowan, 2011). First, we eliminated vowels from the stimuli list in order to reduce the likelihood that letter strings would be able to be formed into a meaningful chunk. Second, grouping typically occurs with temporal boundaries (Hitch, Burgess, Towse, & Culpin, 1996) or categorized items (McElree, 1998), and neither of these design considerations were present in the present study. Third, it is an assumption that the relatively fast rate of presentation in the probe recognition paradigm reduces the likelihood of grouping or chunking (Nee & Jonides, 2008, 2011). Additionally, if the information was grouped or chunked into a single unit, it would need to be unpacked before participants made their response, likely resulting in longer RTs. Unpacking a chunk seems unlikely to have occurred.

The present findings have related implications for recent neuroimaging studies that have used probe recognition paradigms (Morrison et al., 2014; Nee & Jonides, 2008, 2011; Öztekin et al., 2010; Öztekin et al., 2009; Talmi, Grady, Goshen-Gottstein, & Moscovitch, 2005), as well as recent research on neurologically impaired populations (López-Frutos, Poch, García-Morales, Ruiz-Vargas, & Campo, 2014). Researchers using this type of paradigm may make the assumption that the rapid presentation of information discourages grouping, rehearsal, or chunking strategies. Up until now, this assumption—specifically, with respect to rehearsal—has not been directly tested. On the basis of the present findings, it does appear that participants have the ability to rehearse information even if the information is rapidly presented; however, rehearsal does not seem to be necessary for maintenance. Researchers should remain cognizant of active maintenance strategies when conducting future behavioral, neurological, and neuroimaging studies that assume that rapid probe recognition paradigms minimize the likelihood of rehearsal strategies.

Limitations

One important difference between prior research and the present study is that McElree (2001, 2006) used a response deadline method that takes the strength of the memory trace into account (McElree & Dosher, 1989). The present findings directly speak to RT and accuracy. However, this does not rule out the possibility that high-reward associated with the oriented items led to a better representation in memory or stronger encoding, perhaps the oriented item was more distinct, which lessened the chances of it being forgotten (Nairne, 2002; Surprenant & Neath, 2009). In the future, when lab resources are available, this new reward paradigm should be extended and replicated with a response deadline procedure. This would lead to identification of whether the fast and accurate behavioral responses to the oriented item can be attributed to differences in asymptotic accuracy, differences in dynamics, or some combination of differences in asymptotic accuracy and dynamics. Although this limitation will need to be investigated in future work, this should not minimize what we have found: evidence that fast and accurate access to nonterminal items does not depend on active maintenance strategies.

Conclusion

Findings from two experiments suggest that, when motivated, the FoA is a flexible resource that is not governed by active maintenance but, instead, relies on attentional refreshing. The results support the hypothesis that people are not restricted to maintaining the last, nonterminal item of a sequence in their FoA but can maintain earlier items at a high level of activation even when there is no additional time for processing or active maintenance. Maintenance of nonterminal items does seem to come at a cost to the other items in the list, and the amount of resources seems to be constant, regardless of the list representation being oriented to. To return to the question posed in the Introduction, it does seem likely that humans are able to maintain nonterminal information while receiving new information; however, this comes at a cost to the new information.

Acknowledgments The authors wish to thank Marilyn Jay and Jessica Lopez for their assistance collecting data and Michael J. Kane and two anonymous reviewers for comments on an earlier draft of the manuscript. J.S. was supported by a National Science Foundation GK–12 Fellowship under Award DGE-0947465, and J.D.S. was supported by a Howard Hughes Medical Institute Scientific Teaching Fellowship under Award 52006932.

References

Allen, R. J., Baddeley, A. D., & Hitch, G. J. (2006). Is the binding of visual features in working memory resource-demanding? *Journal of Experimental Psychology: General, 135*(2), 298.

Baddeley, A. D. (1986). *Working Memory.* Oxford: Oxford University Press.

Baddeley, A. D., & Hitch, G. J. (1974). Working Memory. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 8, pp. 47–89). New York: Academic Press.

Baddeley, A. D., Lewis, V., & Vallar, G. (1984). Exploring the articulatory loop. *The Quarterly journal of experimental psychology, 36*(2), 233–252.

Barrouillet, P., & Camos, V. (2001). Developmental increase in working memory span: Resource sharing or temporal decay? *Journal of Memory and Language, 45*(1), 1–20.

Barrouillet, P., Bernardin, S., & Camos, V. (2004). Time constraints and resource sharing in adults' working memory spans. *Journal of Experimental Psychology: General, 133*(1), 83.

Barrouillet, P., Bernardin, S., Portrat, S., Vergauwe, E., & Camos, V. (2007). Time and cognitive load in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*(3), 570.

Barrouillet, P., De Paepe, A., & Langerock, N. (2012). Time causes forgetting from working memory. *Psychonomic Bulletin & Review, 19*(1), 87–92.

Barton, B., Ester, E. F., & Awh, E. (2009). Discrete resource allocation in visual working memory. *Journal of Experimental Psychology: Human Perception and Performance, 35*(5), 1359.

Bays, P. M., & Husain, M. (2008). Dynamic shifts of limited working memory resources in human vision. *Science, 321*(5890), 851–854.

Camos, V., Mora, G., & Oberauer, K. (2011). Adaptive choice between articulatory rehearsal and attentional refreshing in verbal working memory. *Memory & Cognition, 39*(2), 231–244.

Cowan, N. (1995). *Attention and memory: An integrated Framework. (Vol. 26)*. New York: Oxford University Press.

Cowan, N. (1999). An embedded-process model of working memory. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 62–101). Cambridge: Cambridge University Press.

Cowan, N. (2005). *Working Memory Capacity.* Hove: Psychology Press.

Cowan, N. (2011). The focus of attention as observed in visual working memory tasks: Making sense of competing claims. *Neuropsychologia, 49*(6), 1401–1406.

Cowan, N., & Morey, C. C. (2006). Visual working memory depends on attentional filtering. *Trends in Cognitive Sciences, 10*(4), 139–141.

Cowan, N., Elliott, E. M., Scott Saults, J., Morey, C. C., Mattox, S., Hismjatullina, A., & Conway, A. R. (2005). On the capacity of attention: Its estimation and its role in working memory and cognitive aptitudes. *Cognitive Psychology, 51*(1), 42–100.

Dewar, M., Cowan, N., & Della Sala, S. (2010). Forgetting due to retroactive interference in amnesia: Findings and implications. *Forgetting, 185–209*.

Dudai, Y. (2004). The neurobiology of consolidations, or, how stable is the engram? *Annual Review of Psychology, 55,* 51–86.

Engle, R. W. (2002). Working memory capacity as executive attention. *Current directions in psychological science, 11*(1), 19–23.

Engle, R. W. (2010). Role of working-memory capacity in cognitive control. *Current Anthropology, 51*(S1), S17–S26.

Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. *Psychology of Learning and Motivation, 44,* 145–200.

Eriksen, C. W., & St James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics, 40*(4), 225–240.

Fougnie, D., Suchow, J. W., & Alvarez, G. A. (2012). Variability in the quality of visual working memory. *Nature Communications, 3,* 1229.

Frey, U., & Morris, R. G. (1997). Synaptic tagging and long-term potentiation. *Nature, 385*(6616), 533–536.

Gilchrist, A. L., & Cowan, N. (2011). Can the focus of attention accommodate multiple, separate items? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*(6), 1484.

Halford, G. S., Cowan, N., & Andrews, G. (2007). Separating cognitive capacity from knowledge: A new hypothesis. *Trends in Cognitive Sciences, 11*(6), 236–242.

Hitch, G., Burgess, N., Towse, J., & Culpin, V. (1996). Temporal grouping effects and working memory: The role of the phonological loop. *Quarterly Journal of Experimental Psychology A, 49,* 116–139.

Hudjetz, A., & Oberauer, K. (2007). The effects of processing time and processing rate on forgetting in working memory: Testing four models of the complex span paradigm. *Memory & Cognition, 35*(7), 1675–1684.

Johnson, M. K. (1992). MEM: Mechanisms of recollection. *Journal of Cognitive Neuroscience, 4*(3), 268–280.

Johnson, M. K., Raye, C. L., Mitchell, K. J., Greene, E. J., Cunningham, W. A., & Sanislow, C. A. (2005). Using fMRI to investigate. *Cognitive, Affective, & Behavioral Neuroscience, 5*(3), 339–361.

Kane, M. J., Conway, A. R., Hambrick, D. Z., & Engle, R. W. (2007). Variation in working memory capacity as variation in executive attention and control. *Variation in Working Memory, 21–48.*

Keshvari, S., van den Berg, R., & Ma, W. J. (2013). No evidence for an item limit in change detection. *PLoS Computational Biology, 9*(2), e1002927.

LaRocque, J. J., Lewis-Peacock, J. A., & Postle, B. R. (2014). Multiple neural states of representation in short-term memory? It'sa matter of attention. *Frontiers in Human Neuroscience, 8*.

Lavie, N. (2010). Attention, distraction, and cognitive control under load. *Current Directions in Psychological Science, 19*(3), 143–148.

López-Frutos, J. M., Poch, C., García-Morales, I., Ruiz-Vargas, J. M., & Campo, P. (2014). Working memory retrieval differences between medial temporal lobe epilepsy patients and controls: A three memory layer approach. *Brain and Cognition, 84*(1), 90–96.

Luck, S. J., & Vogel, E. K. (2013). Visual working memory capacity: from psychophysics and neurobiology to individual differences. *Trends in Cognitive Sciences, 17*(8), 391–400.

Ma, W. J., Husain, M., & Bays, P. M. (2014). Changing concepts of working memory. *Nature Neuroscience, 17*(3), 347–356.

McElree, B. (1998). Attended and non-attended states in working memory: Accessing categorized structures. *Journal of Memory and Language, 38*(2), 225–252.

McElree, B. (2001). Working memory and focal attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*(3), 817.

McElree, B. (2006). Accessing Recent Events. In B. H. Ross (Ed.), *The psychology of learning and motivation* (Vol. 46). San Diego: Academic Press.

McElree, B., & Dosher, B. A. (1989). Serial position and set size in short-term memory: The time course of recognition. *Journal of Experimental Psychology: General, 118*(4), 346.

Morey, C. C., Cowan, N., Morey, R. D., & Rouder, J. N. (2011). Flexible attention allocation to visual and auditory working memory tasks: Manipulating reward induces a trade-off. *Attention, Perception, & Psychophysics, 73*(2), 458–472.

Morris, S. B., & DeShon, R. P. (2002). Combining effect size estimates in meta-analysis with repeated measures and independent-groups designs. *Psychological Methods, 7*(1), 105.

Morrison, A. B., Conway, A. R., & Chein, J. M. (2014). Primacy and recency effects as indices of the focus of attention. *Frontiers in Human Neuroscience, 8*.

Nairne, J. S. (2002). Remembering over the short-term: The case against the standard model. *Annual Review of Psychology, 53*(1), 53–81.

Nee, D. E., & Jonides, J. (2008). Neural correlates of access to short-term memory. *Proceedings of the National Academy of Sciences, 105*(37), 14228–14233.

Nee, D. E., & Jonides, J. (2011). Dissociable contributions of prefrontal cortex and the hippocampus to short-term memory: Evidence for a 3-state model of memory. *Neuroimage, 54*(2), 1540–1548.

Nee, D. E., & Jonides, J. (2013). Trisecting representational states in short-term memory. *Frontiers in Human Neuroscience, 7*.

Oberauer, K. (2002). Access to information in working memory: exploring the focus of attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28*(3), 411.

Oberauer, K., & Hein, L. (2012). Attention to information in working memory. *Current Directions in Psychological Science, 21*(3), 164–169.

Oberauer, K., & Lewandowsky, S. (2013). Evidence against decay in verbal working memory. *Journal of Experimental Psychology: General, 142*(2), 380.

Öztekin, I., McElree, B., Staresina, B. P., & Davachi, L. (2009). Working memory retrieval: Contributions of the left prefrontal cortex, the left posterior parietal cortex, and the hippocampus. *Journal of Cognitive Neuroscience, 21*(3), 581–593.

Öztekin, I., Davachi, L., & McElree, B. (2010). Are representations in working memory distinct from representations in long-term memory? Neural evidence in support of a single store. *Psychological Science, 21*(8), 1123–1133.

Öztekin, I., Güngör, N. Z., & Badre, D. (2012). Impact of aging on the dynamics of memory retrieval: A time-course analysis. *Journal of Memory and Language, 67*(2), 285–294.

Raye, C. L., Johnson, M. K., Mitchell, K. J., Reeder, J. A., & Greene, E. J. (2002). Neuroimaging a single thought: Dorsolateral PFC activity associated with refreshing just-activated information. *Neuroimage, 15*(2), 447–453.

Raye, C. L., Johnson, M. K., Mitchell, K. J., Greene, E. J., & Johnson, M. R. (2007). Refreshing: A minimal executive function. *Cortex, 43*(1), 135–145.

Rundus, D. (1971). Analysis of rehearsal processes in free recall. *Journal of Experimental Psychology, 89*(1), 63.

Seamon, J. G., & Wright, C. E. (1976). Generative processes in character classification: Evidence for a probe encoding set. *Memory & Cognition, 4*(1), 96–102.

Shipstead, Z., Lindsey, D. R., Marshall, R. L., & Engle, R. W. (2014). The mechanisms of working memory capacity: Primary memory, secondary memory, and attention control. *Journal of Memory and Language, 72,* 116–141.

Simmons, J. P., Nelson, L. D., & Simonsohn, U. (2012). A 21 Word Solution. *Dialogue: The Official Newsletter of the Society for Personality and Social Psychology, 26*(2), 4–7.

Soto, D., & Humphreys, G. W. (2008). Stressing the mind: The effect of cognitive load and articulatory suppression on attentional guidance from working memory. *Perception & Psychophysics, 70*(5), 924–934.

Sternberg, S. (1966). High-speed scanning in human memory. *Science, 153*(3736), 652–654.

Surprenant, A., & Neath, I. (2009). *Principles of memory*. New York: Psychology Press.

Talmi, D., Grady, C. L., Goshen-Gottstein, Y., & Moscovitch, M. (2005). Neuroimaging the Serial Position Curve A Test of Single-Store Versus Dual-Store Models. *Psychological Science, 16*(9), 716–723.

Tan, L., & Ward, G. (2000). A recency-based account of the primacy effect in free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*(6), 1589.

Unsworth, N., & Engle, R. W. (2007). The nature of individual differences in working memory capacity: active maintenance in primary memory and controlled search from secondary memory. *Psychological Review, 114*(1), 104.

Unsworth, N., Fukuda, K., Awh, E., & Vogel, E. K. (2014). Working memory and fluid intelligence: Capacity, attention control, and secondary memory retrieval. *Cognitive Psychology, 71,* 1–26.

Wixted, J. T. (2004). The psychology and neuroscience of forgetting. *Annual Review of Psychology, 55,* 235–269.

Zhang, W., & Luck, S. J. (2008). Discrete fixed-resolution representations in visual working memory. *Nature, 453*(7192), 233–235.