Psychological Research (2014) 78:124–135
DOI 10.1007/s00426-013-0479-7

ORIGINAL ARTICLE

Working memory effects in speeded RSVP tasks

Beatriz Gil-Gómez de Liaño · Mary C. Potter · Carmen Rodríguez

Received: 18 August 2012 / Accepted: 16 January 2013 / Published online: 9 February 2013

Abstract The present paper examines the effects of memory contents and memory load in rapid serial visual presentation (RSVP) speeded tasks, trying to explain previous inconsistent results. We used a one target (Experiment 1) and a two-target (Experiment 2) RSVP task with a concurrent memory load of one or four items, in a dual-task paradigm. A relation between material in working memory and the target in the RSVP impaired the identification of the target. In Experiments 3 and 4, the single task was to determine whether any information in memory matched the target in the RSVP, while varying the memory load. A match was detected faster than a non-match, although only when there was some distance between targets in the RSVP (Experiment 4). The results suggest that memory contents automatically capture attention, slowing processing when the memory contents are irrelevant to the task, and speeding processing when they are relevant.

Introduction

The relationship between attention and working memory in rapid serial visual presentation (RSVP) tasks is an unresolved issue. There have been several studies of memory effects in RSVP tasks to see whether information in working memory modulates attentional processes. As we review below, there is a diversity of results depending on different variables manipulated in the studies. We propose that if information maintained in memory is relevant to the attentional task, it will determine whether and in what way memory contents and memory load affect attentional processes. Therefore, in the present work, we study how the relationship between memory and attention may differently affect attentional processes in RSVP tasks, from simple tasks (with only one target to be detected in the RSVP stream) to more complex tasks (adding another target to study the time course of attention in an AB-like paradigm). We vary the memory load, manipulating the similarities between memory contents and attentional targets, and we compare conditions in which the memory task is separate from the attentional task and conditions in which the information in working memory is required for the attentional task.

Although there are few exceptions (Gil-Gómez de Liaño & Botella, 2011; Visser, 2010, Experiment 5), most of the studies looking for relations between memory and attention in RSVP have used an AB procedure (e.g., Akyürek & Hommel, 2005, 2006; Olivers & Nieuwenhuis, 2006; Visser, 2010). However, the studies have not obtained consistent results. In particular, some have found that although overall performance in RSVP tasks was impaired by a concurrent memory task, the attentional blink effect was little changed (Akyürek & Hommel, 2005, 2006). Likewise, Nieuwenstein, Johnson, Kanai, and Martens (2007) also found similar AB effects under memory load conditions, although they found stronger interference when information in WM fitted T2 in the RSVP (Experiment 2). In other work, Akyürek, Hommel, and Jolicœur (2007)

B. Gil-Gómez de Liaño (✉)
Departamento de Psicología Social y Metodología,
Facultad de Psicología, Universidad Autónoma de Madrid,
C/Ivan Pavlov, 6, 28049 Madrid, Spain
e-mail: bgil.gomezdelianno@uam.es

M. C. Potter
Department of Brain and Cognitive Sciences,
Massachusetts Institute of Technology, Cambridge, USA

C. Rodríguez
Departamento de Psicolobiología,
Universidad Autónoma de Madrid, Madrid, Spain

found that memory loads of increasing size enlarged AB effects under active memory processing situations. However, they also found (Akyürek, Abedian-Amiri, & Ostermier, 2011) smaller AB effects when priming T2 with memory contents. Others like Olivers and Nieuwenhuis (2006) also reported reduction of the AB effect with a concurrent memory task, as well as in similar situations where the participants had to perform task irrelevant mental activity such as viewing pictures of positive affective content, or were instructed to focus less on the task. In the same vein, Potter, Wyble, and Olejarczyk (2011) found that simultaneously reading a sentence reduced the attentional blink for digit targets.

In those studies, several variables have been proposed to explain the conflicting results. For instance, to explain the lack of memory load effects in AB tasks, Akyürek et al. (2007) suggested that the processing bottleneck that causes the AB may not arise from limits in storage capacity but from limits in processing capacity (where AB modulation is in fact found). The storage-processing hypothesis would explain the variability found in some results, but not in others where just memory load in a secondary task (not processing demands) impaired the detection of T2 in the RSVP (Visser, 2010). Visser (2010) proposed that the use of a T1 mask could be one of the reasons to find variability in the studies: omitting the T1 mask revealed the relationship between WM load and the AB. However, different AB effects have been reported using a T1 mask (e.g. Akyürek et al., 2011).

The relationship between working memory contents and targets in the RSVP has also been an important variable trying to explain conflicting results not only in RSVP tasks (e.g. Akyürek et al., 2011; Nieuwenstein et al., 2007), but also in other attentional tasks (Gil-Gómez de Liaño, Umilta, Stablum, Tebaldi, & Cantagallo, 2010; Gil-Gómez de Liaño, Botella, & Pascual-Ezama, 2011; Kim, Kim, & Chun, 2005; Olivers, 2009). According to results found in visual search and attentional capture studies, items in WM enhance selection of matching items when they are targets in the attentional task (Desimone & Duncan, 1995; Downing, 2000; Gil-Gómez de Liaño et al., 2011; Olivers, Meijer, & Theeuwes, 2006; Soto, Heinke, Humphreys, & Blanco, 2005). However, WM enhancement of attention does not always occur. Nieuwenstein et al. (2007) found extended AB effects when memory contents were the same as T2 in the RSVP task. On the other hand, Akyürek et al. (2011) found smaller AB effects when T2 matched the contents of memory. Notably, in Nieuwenstein et al. (2007) memory and attention were separate tasks, while in Akyürek et al. (2011), participants had to maintain 2 or 4 digits in memory and decide if T1 matched any of those digits and then report T2, another digit that sometimes matched one of the memory set. That is, in Nieuwenstein et al. (2007), the two tasks were separate: the memory set was probed after T1 and T2 were reported. In Akyürek et al. (2011), there was a single RSVP-AB task that required participants to give a response mediated by the information maintained in memory. It seems that the way the memory response is tested is important: if the task is to detect a memory item in the RSVP, the repetition of the item will generate a facilitation effect, whereas if the memory recognition test is separate, repeating a memory item as a target will generate an interference with the RSVP task.

In the present work, we will study the effect of the relationship between working memory contents and RSVP detection using separate tasks (Experiments 1 and 2) or a single, combined task (Experiments 3 and 4). We use a one-target RSVP task (Experiments 1 and 3) or a two-target AB task (Experiments 2 and 4). In the first experiment, the participants have to identify one target in an RSVP stream, while maintaining some information in working memory. According to Nieuwenstein et al. (2007) (see also Akyürek & Hommel, 2005), we should find worse RSVP performance for those trials where memory contents are related to the target in the RSVP. That is, when similar memory information "competes" for different tasks (memory task vs. RSVP task), there is impairment on the attentional selection in the form of an error. In our experiment, we decided not only to measure accuracy, but also use RTs as a dependent measure. Although there are a few exceptions (Akyürek et al., 2007; Gil-Gómez de Liaño & Botella, 2011; Visser, 2010, Experiment 5), very little RSVP work has used RT measures. Using RTs as dependent measure gives us an "online" measure of the given response.

In Experiment 2, we added one more target (T1, non-speeded report) to increase difficulty and to study the AB effect under those circumstances. Finally, Experiments 3 and 4 study the effects of memory contents in RSVP, but using a single task that required the participant to decide whether the RSVP target matched an item in the memory set. Although the task of the participants changed, stimuli and exposure times were the same as in the previous experiments. In Experiment 4, there was an added T1 (as in Experiment 2) which required an unspeeded response at the end of the trial. Contrary to Experiments 1 and 2, now the participant had to match the memory contents to the target in the RSVP, so there was no competition between memory and detection as in the previous experiments and in Nieuwenstein et al. (2007). According to results found in visual search and attentional capture studies, items in WM enhance selection of matching items when they are targets in the attentional task (Desimone & Duncan, 1995; Downing, 2000; Gil-Gómez de Liaño et al., 2011; Olivers et al., 2006; Soto et al., 2005), so we expect to find an advantage in the detection of the target for those conditions in which memory contents fit the target in the RSVP.

Experiment 1

In Experiment 1, participants made a speeded choice response to a single-target image, classifying it as a face or house, while retaining a memory load of one or four images that could be in the same category as the RSVP target, or the other category. The distractors in the RSVP stream were animal images.

Method

A brief sketch of the procedure is shown in Fig. 1. There were two conditions of load, a low load (LL) of one image or a high load (HL) of four images (all in the same category). The image or images were tested for recognition at the end of each trial by showing one image, which was in the memory set on half of the trials. The speeded RSVP task was carried out between presentation of the memory set and presentation of the recognition probe. Participants viewed an RSVP sequence of 14 animal images plus one target image (a house or a face) presented for 120 ms per item, and had to respond to the target as fast as possible by pressing K (face) or M (house) on the keyboard. The target was presented in serial positions 5, 8 or 11 and on 50 % of the trials it was the same image-type (face versus house) as the memory set, generating the Related (R) condition, although the target was never identical to an image in the memory set. In the Non-Related (NR) condition, the target was a member of the other set (e.g., if a house was presented in the memory set, a face was presented in the RSVP stream).

Participants

Fourteen volunteers of the Autónoma University of Madrid participated in the experiment. They were given an extra credit for their participation. The sample was composed of 11 women and three men with a mean age of 18.14 (range 18–20). All of them had normal or normal-corrected vision and all had given informed consent.

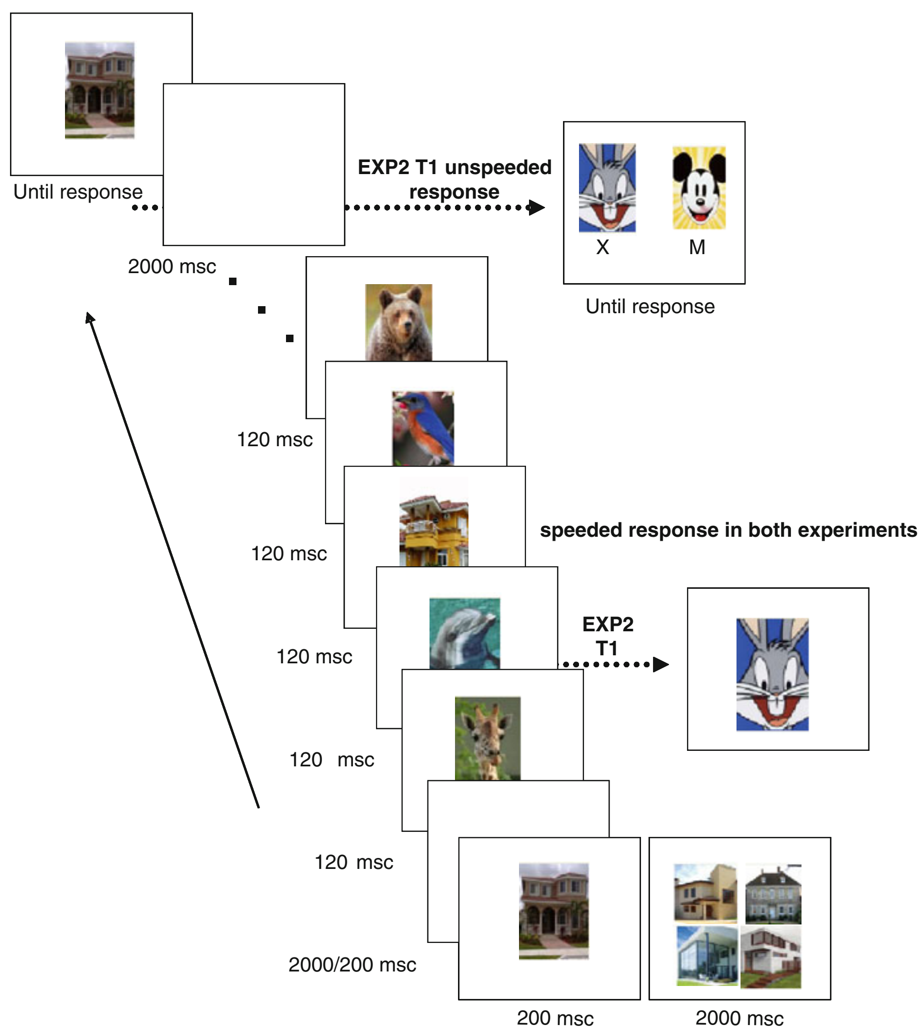

Fig. 1 Example of experimental procedure for Experiments 1 and 2

Stimuli

The stimuli were presented using a desktop computer controlled by software written in E-Prime (Schneider, Eschman, & Zuccolotto, 2002). Eight different animal images were used as distractors in the RSVP. For the targets, six face images (three men and three women) and six different houses were used (see Fig. 1 for examples of the images used). All of them were shown in the center of the screen on a white background. Participants looked at the screen from a distance of 50 cm and stimuli subtended a visual angle of 4.35° × 5.16°.

Procedure

The experiment had a total of 240 trials plus 16 practice trials. The trials were blocked for the LL and HL conditions, and the order of the blocks was counterbalanced across participants. In each half, there were 8 practice trials and 120 experimental trials.

Participants were placed about 50 cm from the screen. A sketch of what they saw is shown in Fig. 1. They started by pressing the space bar when ready. After a blank screen for 1,500 ms, the image or images of the memory set were shown. In the LL condition, they saw one image in the center of the screen for 200 ms, while in the HL condition they saw the four images in a square in the center of the screen for 2,000 ms. The images shown were selected randomly from the set of images (faces and houses), with the restriction that in each load condition half of the trials were in the R and half in the NR condition. Then, another blank screen remained for 2,000 ms in the LL condition, and 200 ms in the HL, in order to maintain a constant interval between the onset of the memory set and the onset of the RSVP sequence. In the RSVP sequence, each item was presented at the center of the screen for 120 ms, with no ISI. Participants were instructed to respond as fast and accurately as possible to the only face or house image in the RSVP stream. If the image was a house, they pressed the "M" key in the keyboard with the index finger of the right hand. If it was a face, they pressed the "K" key with the middle finger of the right hand. They were instructed to respond as fast as they could, regardless of the following items. At the end of the RSVP stream, a 2,000 ms blank screen appeared. Then, the memory probe was presented. The probe image was selected randomly with the restriction that the memory probe was in the set 50 % of the time for each of the R and NR conditions, separately for each load condition (HL and LL).

Results and discussion

Repeated measures ANOVAs were carried out on the proportion of correct target responses and RTs of correct responses, with two within-subjects variables: Load (one and four images) and Relation (R and NR). We included in the analysis (in this and the later experiments) only those trials with a correct response in the memory load task and with RTs between 200 and 3,000 ms. Table 1 shows mean and SD for target accuracy and for RTs in each condition, as well as for accuracy in the memory task. There were no significant effects in the accuracy of target report. On the RT analysis, there was a main effect of Relation [$F(1,13) = 12.21$; $p = .004$; $\mu^2 = .48$]: responses are faster for the NR trials ($M = 663$ ms) than for the R ones ($M = 713$ ms). Neither the effect of memory load nor the interaction was significant.[1]

Table 1 Mean proportion correct responses in memory task, in target detection in RSVP and mean RTs in correct responses detected in RSVP in Experiment 1

	Proportion correct in memory task		Proportion correct in RSVP		Mean RT in RSVP	
	LL	HL	LL	HL	LL	HL
R	.93/.09	.77/.11	.91/.06	.91/.03	712/117	713/124
NR	.93/.09	.75/.10	.93/.04	.90/.09	660/104	666/83

Mean/SD

In an analysis of the proportion of correct responses in the recognition memory task (conditioned on a correct response to the target in the RSVP task), only a main effect of load was found [$F(1,13) = 86.88$; $p = .000$; $\mu^2 = .87$]. As expected, it is easier to remember one image ($M = .93$) than four ($M = .76$).

The results show that memory contents indeed influence detection: when information maintained in WM is in the same category (faces or houses) as the target, attentional selection is slowed. According to Nieuwenstein et al. (2007), when similar memory information "competes" for different tasks (memory task vs. RSVP task), there is impairment in the attentional selection in the form of errors. In the present case, the effect is on RT to categorize the target, not errors. Memory contents thus seem to interact with attentional selection in a dual memory-RSVP attentional task. As said, no effects for accuracy were found. On one hand, it could be explained by the difference between the materials used by Nieuwenstein et al. (2007) and our materials: they used alphanumeric stimuli instead

[1] To see if the effects could be bigger, we also analyzed both accuracy and RTs not conditioned to correct responses in the memory task (as more trials were excluded in the HL condition than in the LL condition). Again, no effects were found for accuracy. The same ANOVA for RTs showed a slightly greater Relation effect [$F(1,13) = 25.47$; $p < .001$; $\mu^2 = .66$]: again, responses are faster for the NR trials ($M = 657$ ms) than for the R ones ($M = 715$ ms). Neither the main effect of memory load nor the interaction was significant.

of pictures, which may be more difficult to identify. In fact, performance is quite high overall, thus limiting accuracy effects, close to ceiling. On the other hand, in the RSVP task, the participants were asked for a speeded response for a single target, whereas Nieuwenstein et al. (2007) asked for unspeeded responses for two targets in an AB paradigm task. In Experiment 2, we added a target (T1) to increase the difficulty, but maintained a speeded response to T2 to examine the effects on response time. The AB can also be studied by manipulating the temporal distance between T1 and T2, making the task more similar to that of Nieuwenstein and colleagues.

Experiment 2

In Experiment 2, we used the same paradigm as in Experiment 1, but added a target with a non-speeded response as T1 (see Fig. 1), for two reasons. First, the single target in Experiment 1 may not have been difficult enough to generate detection errors: in Nieuwenstein et al. (2007), there were two targets in the RSVP in an AB paradigm. Second, adding T1 allows us to study AB effects, and also compare them to those found in Nieuwenstein et al. (2007). However, there are a few important differences between our study and Nieuwenstein's that must be taken into account. First, as we pointed before, they used alphanumeric characters, while we are using pictures. Second, they repeated actual exemplars from the WM set while we repeat same category types, not exactly the same exemplars. Third and probably the most important difference is that we are using a speeded response to T2 that they did not use; thus, there may be not only a modulation in accuracy for T2, but also a modulation in response times in the form of slowed RTs during the AB interval. The RSVP task now included two lags (2 and 5) between the two targets; an AB-like effect measured by RTs would be reflected in lower accuracy or a longer RT at Lag 2 than at Lag 5.

Method

Participants

Sixteen volunteers of the Autónoma University of Madrid participated in the experiment. They were given extra credits for their participation. Two of them were removed from the analysis because they did not reach the minimum accuracy requirements (75 % correct responses in each condition, for report of T1, report of T2, and response to the memory probe).The final sample was composed of three men and 11 women with a mean age of 18.07 (range 18–19). All of them had normal or normal-corrected vision and informed consent was obtained.

Stimuli and procedure

The method was the same as in Experiment 1, except that T1 (Bugs Bunny or Mickey Mouse) appeared in positions 3, 4 or 5 within the RSVP stream and was followed at Lag 2 or 5 by T2 (a house or a face). The participant made a speeded response to the category of T2 and then reported (unspeeded response) whether Bugs ("X" on the keyboard) or Mickey ("M" on the keyboard) had appeared. Finally, there was a recognition test of the memory set, as in Experiment 1. The sequence in the RSVP included two targets plus 13 animal images (see Fig. 1). Everything else remained the same as in Experiment 1.

Results and discussion

The mean and SD for the different measures and conditions are shown in Table 2, separately for the memory task, T1, and T2.

T1 analysis

A repeated-measures ANOVA was conducted on T1 accuracy response, with: Load (one and four images),

Table 2 Mean proportion correct responses in memory task, in target (T1) identification in RSVP and target (T2) detection in RSVP (when T1 was correctly reported) and mean RTs in correct responses detected in RSVP for T2 in Experiment 2

	Proportion correct in memory task		T1 Proportion correct in RSVP		T2 Proportion correct in RSVP		Mean RT in RSVP	
	LL	HL	LL	HL	LL	HL	LL	HL
Lag 2								
R	.90/.08	.68/.14	.82/.08	.82/.11	.90/.07	.89/.09	868/192	865/253
NR	.89/.08	.70/.13	.86/.09	.86/.10	.90/.09	.91/.12	774/154	775/218
Lag 5								
R	.84/.12	.70/.18	.78/.06	.80/.08	.89/.12	.87/.10	695/170	702/139
NR	.91/.11	.71/.13	.80/.09	.83/.08	.88/.08	.92/.05	662/151	659/176

Mean/SD

Relation (R and NR), and Lag (2 and 5); only trials on which the memory response was correct were included. Only a main effect of lag was found [$F(1,13) = 6.33$; $p = .026$; $\mu^2 = .33$]; it was easier to report T1 when T2 appeared at Lag 2 ($M = .84$) than at Lag 5 ($M = .81$). T1 performance is shown in Fig. 2.

T2 analysis

For T2 accuracy, the repeated-measures ANOVA with Load, Relation, and Lag as variables (conditional on correct responses to the memory probe and T1) found no significant main effects or interactions (Table 2). However, the analysis of RTs for correct responses to T2 did show interesting effects. There was a main effect of Lag [$F(1,13) = 28.28$; $p < .001$; $\mu^2 = .69$] with shorter RTs for Lag 5, showing an AB-like effect for RTs in all conditions (for Lag 2, $M = 821$ ms and for Lag 5 $M = 679$ ms; see also Fig. 3). There was also a main effect of Relation [$F(1,13) = 7.31$; $p = .01$; $\mu^2 = .36$], as in Experiment 1, with longer RTs for the R condition ($M = 782$ ms) than for the NR condition ($M = 718$ ms). No other significant effects or interactions were found.

Memory recognition

An ANOVA was conducted on the proportion of correct responses in the memory load recognition task (conditioned to a correct response to T1 and T2). There was the expected effect of load [$F(1,13) = 38.63$; $p < .001$; $\mu^2 = .75$]. It was again easier to remember one image ($M = .88$) than four ($M = .70$). No other effects were found.

Altogether, the results replicate Nieuwenstein et al.'s (2007) finding that matching information in memory increases the difficulty of responding to T2, but in the form of a slower response rather than an inaccurate response. We also observed that relatedness tends to increase the AB effect for correct response RTs, although the interaction

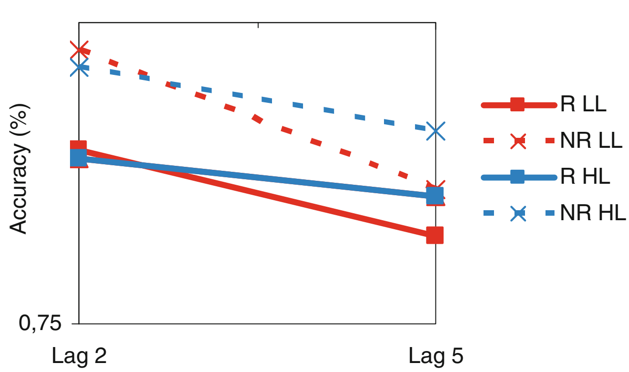

Fig. 2 T1 Accuracy in Experiment 2 for each condition

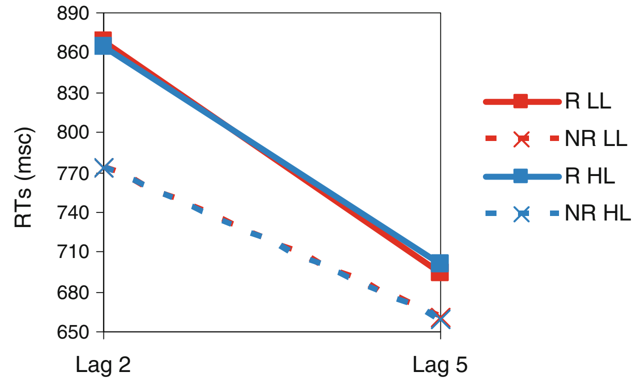

Fig. 3 T2 RTs in Experiment 2 for each condition

between lag and relatedness was not significant ($p = .08$). As in Experiment 1, we did not find effects for error rate[2] but instead for RTs: there was an AB-like effect for RTs showing that the detection of T2 is slower when T1 and T2 are close in time (typical AB effect). According to the Nieuwenstein et al. (2007) hypothesis, related (R) trials need more time to be processed than non-related (NR) ones, but in the present experiments not in the form of a *cross-task repetition amnesia,* but in the form of an *interference* (as shown by differences in correct response RTs but not on accuracy). Rather than a "cross-task repetition amnesia" as Nieuwenstein et al. (2007) proposed, the present results show that memory contents may drive attentional selection and so create a *cross-task repetition interference*.

Experiment 3

In Experiment 3, the participants had to decide if any of the images maintained in memory was exactly the same as the one in the RSVP stream, in a same-different speeded task. In this case, there is no competition between different tasks in the use of memory information for different tasks: the memory test is now the speeded response to the target in the RSVP task. According to competition bias theories, WM information enhances selection of matching items (e.g. Desimone & Duncan, 1995; Duncan & Humphreys, 1989). That is, there should be faster and more efficient responses when WM contents and targets in the RSVP match than when they do not.

[2] All the variability was found for RTs and no AB effect was found for accuracy measures. We found similar results in a pilot using letters instead of images. Moreover, very small effects (Wong, 2002, exp 3B) or no effects (Jolicœur & Dell'Acqua, 1999, exp 1) in accuracy measures have been reported in similar tasks, while the effects have shown up in RTs.

Method

Participants

Nine volunteers (seven women and two men) of the Autónoma University of Madrid participated in the experiment. They were given extra credits for their participation. The mean age was 18.44 (range 18–22), all of them had normal or normal-corrected vision and informed consent was obtained.

Stimuli and procedure

The stimuli were the same as those in Experiment 1, except that the target was always in the same category (face or house) as the item(s) in the memory set, and exactly matched one of the memory set items on half the trials. Again, there were two conditions of load, a low load of one image or a high load of four images (all faces or houses). The RSVP stream included 14 animal images plus one target image, a house or a face. The participant made a speeded response to indicate whether or not the target was identical to any of the memory stimuli. For "same", they pressed "S" (the matching condition); for "different," they pressed "X" (the no-matching condition), both with the left hand. As soon as there was a response in the RSVP, another trial started after a blank frame of 1,500 ms. Again, the target was presented in serial positions 5, 8 or 11.

There were 120 trials for each blocked memory load condition (120 for LL and another 120 for HL conditions), and the order of the blocks was counterbalanced between subjects. All exposure times of stimuli remained the same as in previous experiments.

Results and discussion

Table 3 shows mean and SD for target accuracy and for RTs in each condition. In the ANOVA of accuracy with Load (one–four images) and Match (Matching—M and No Matching—NM) as variables, there was a main effect of Load [$F(1,8) = 49.33$; $p < .001$; $\mu^2 = .86$] with better performance in LL condition ($M = .88$) than in the HL one ($M = .72$). The main effect of Match did not reach significance [$F(1,8) = 2.56$; $p = .15$; $\mu^2 = .24$]. There was, however, a significant interaction [$F(1,8) = 20.59$; $p = .002$; $\mu^2 = .72$] showing that the effect of Match, with higher accuracy for matching than mismatching trials, only appeared under high memory load conditions ($p = .03$); not under LL ones ($p = .85$).

In the RT analysis, the main effect of Match was significant [$F(1,8) = 9.53$; $p = .01$; $\mu^2 = .54$], with faster responses for matching trials ($M = 662$ ms) than for non-matching ones ($M = 720$ ms). There was again a main effect of Load, with responses with a low load faster ($M = 624$ ms) than with a high load ($M = 757$ ms) [$F(1,8) = 9.37$; $p = .01$; $\mu^2 = .54$]. There was no interaction ($F < 1$).

Table 3 Mean proportion correct responses in target detection in RSVP and mean RTs in correct responses detected in RSVP in Experiment 3

	Proportion correct in RSVP		Mean RT in RSVP	
	LL	HL	LL	HL
M	.88/.06	.78/.10	599/151	724/274
NM	.87/.13	.65/.18	650/141	790/237

Mean/SD

Thus, there was an effect of load for both accuracy and RT analyses, and the Matching effect was present for both errors and RTs, except that accuracy was unaffected by match when there was a low load. The results of present experiment show that there is again a modulation of attention by memory contents in a simple speeded RSVP task, but in the opposite direction to that found in Experiment 1. Now, the typical matching effect shows up (faster RTs for trials in which memory contents fit targets in the RSVP) both under high and low memory load conditions, and for accuracy only in High memory load conditions. That is, when the task is a hybrid memory-attentional task where memory contents may match the target in the RSVP, the selection of the target is easier when it matches, and the effect is even stronger when memory is highly loaded. That the matching condition is faster and more accurate in the low load than the high load condition would be expected if the participant had to compare the target serially with each item in the memory set until one matched, before responding. In the case of a single memory item, just one comparison would be required, whether or not there is a match. When there were four items in the memory set, a match would be made, on average, after just two comparisons, whereas a mismatch could be determined only after all four memory items had been compared with the target, assuming serial, self-terminating search (Sternberg, 1966). Notably, however, there was no interaction between match and load effects on RT, suggesting that the RT in the high load condition was not proportionally longer in the mismatch condition. Moreover, the search time hypothesis would predict little or no difference between match and mismatch in the low-load condition, contrary to what was observed. Although using a slightly different design (different materials, only accuracy dependent measures…), the data are also fully in line with the previous results found by Akyürek et al. (2011); and importantly, not only for accuracy but also replicated for speeded responses.

Experiment 4

In Experiment 4, we added a target in the RSVP (T1 unspeeded) to study possible AB effects, as in Experiment 2. We expected to find AB effects although they could be attenuated when items match memory contents.

Method

Participants

Twenty-two volunteers participated in the study. Two of them were removed from the analysis because they did not reach the minimum accuracy requirements (as the task was very difficult, mainly for the HL condition, the minimum requirement to be included in the sample was at least a 65 % correct responses in each condition, for report of T1 and T2 in the LL condition).The final sample was composed of four men and 16 women with a mean age of 21.5 (range 18–23). All of them had normal or normal-corrected vision and informed consent was obtained.

Stimuli and procedure

The stimuli were the same as those in Experiment 2, except that T2 was always in the same category (face or house) as the item(s) in the memory set, and exactly matched one of the memory set items on half the trials. The participant first made a speeded same-different response to T2, as in Experiment 3, and then made an unspeeded response to T1, reporting whether Bugs Bunny or Mickey Mouse had been presented.

Results and discussion

The mean and SD for the different measures and conditions are shown in Table 4, separately for the T1 and T2.

T1 analysis

A repeated-measures ANOVA was conducted on the accuracy of the response to T1, with Load (one and four images), Match (match and mismatch), and Lag (2 and 5) as variables. There was a main effect of Lag [$F(1,19) = 10.49$; $p = .004$; $\mu^2 = .36$], with T1 being easier to detect at Lag 2 ($M = .81$) than in Lag 5 ($M = .77$), as in Experiment 2 (Fig. 4).

T2 analysis for accuracy

The repeated-measures ANOVA of T2 accuracy, with Load, Match, and Lag as variables (conditional on correct responses to T1) found a significant main effect of Load

Table 4 Mean proportion correct responses in target (T1) identification in RSVP and target (T2) detection in RSVP (when T1 was correctly reported) and mean RTs in correct responses detected in RSVP for T2 in Experiment 4

	T1 Proportion Correct in RSVP		T2 Proportion Correct in RSVP		Mean RT in RSVP	
	LL	HL	LL	HL	LL	HL
Lag 2						
M	.78/.12	.83/.08	.76/.14	.59/.15	1167/387	1269/438
NM	.81/.12	.84/.08	.87/.12	.64/.17	1200/376	1286/456
Lag 5						
M	.78/.12	.80/.10	.77/.13	.62/.19	962/285	1173/419
NM	.73/.10	.77/.14	.89/.08	.63/.17	1064/314	1192/391

Mean/SD

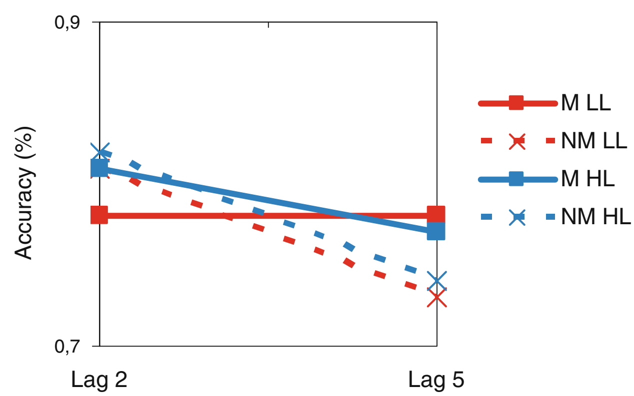

Fig. 4 T1 Accuracy in Experiment 4 for each condition

[$F(1,19) = 49.84$; $p < .001$; $\mu^2 = .72$], showing that it is easier to respond to T2 when memory is low loaded ($M = .82$) than when memory is high loaded ($M = .62$). It also shows that there is a great interference of T1 for T2 detection under high memory load conditions if we compare results found for low ($M = .88$) and high memory ($M = .87$) in the single task of Experiment 3.

There was a main effect of Match [$F(1,19) = 5.16$; $p = .03$; $\mu^2 = .21$], but in the opposite direction from that in Experiment 3: it is easier to respond correctly to T2 in NM conditions ($M = .76$) than in M ones ($M = .68$). In fact, making comparisons between data of E3 and E4 in an overall ANOVA using the Experiment as a between-subjects factor, those differences are statistically significant: there is a significant interaction between Experiment and Match [$F(1,27) = 4.33$; $p = .04$; $\mu^2 = .13$] showing that detecting a positive match is much less accurate ($M = .68$) in Experiment 4 than in Experiment 3 ($M = .83$) ($p = .002$), whereas detecting a mismatch is equally accurate in Experiment 4 ($M = .76$) as in Experiment 3 ($M = .76$) ($p = .75$). It seems that encoding T1 (for those trials when T1 is correctly reported) decreases the ability to perceive a T2 match (especially in the high-load condition). When we analyse the results of T2 accuracy not conditioned to T1 accuracy, the same pattern of results shows up. No other effects were found.

T2 analysis for RTs

In the repeated-measures ANOVA with Load, Match, and Lag as variables for RTs (given correct responses for T1 and T2), there was a main effect of Lag [$F(1,19) = 43.95$; $p < .001$; $\mu^2 = .70$] showing longer RTs for Lag 2 ($M = 1230$) conditions than for Lag 5 ($M = 1098$), so a standard attentional blink effect for RTs was found (Fig. 5).

There is also a marginal effect of Load [$F(1,19) = 4.05$; $p = .059$; $\mu^2 = .18$] showing shorter RTs for LL conditions ($M = 1098$) than for HL ones ($M = 1230$) as expected. There was also an interaction between Load and Lag [$F(1,19) = 7.68$; $p = .01$; $\mu^2 = .29$]: differences of Load (again shorter RTs for LL than HL) are larger in Lag 5 ($p = .01$) than in Lag 2 ($p = .22$).

Interestingly, although the interaction between Match and Lag was not significant [$F(1,19) = 2.27$; $p = .14$; $\mu^2 = .11$], there was a trend of matching effects in Lag 5 that did not appear in Lag 2, as can be seen in Fig. 5. In fact, there is a trend of bigger AB effects for match conditions (Lag 2–Lag 5 = 151 ms) than for non-match ones (Lag 2–Lag 5 = 114 ms).

Because accuracy was near chance in some HL conditions, we decided to do an ANOVA for RTs only for LL conditions with Lag and Match as independent variables. There were again main effects of Lag [$F(1,19) = 44.21$; $p < .001$; $\mu^2 = .70$] in the same direction (showing AB-like effects for RTs; M Lag 2 = 1,184; M Lag 5 = 1013), and also main effects of Match [$F(1,19) = 6.53$; $p = .02$; $\mu^2 = .26$]; now longer RTs for NM ($M = 1{,}132$) than for M conditions ($M = 1{,}064$). More importantly, there was an interaction of Match and Lag [$F(1,19) = 4.46$; $p = .04$; $\mu^2 = .19$] showing the same pattern of results found before (although the interaction was not significant including HL conditions): bigger AB effects for M conditions (Lag 2–Lag 5 = 205 ms) than for NM ones (Lag 2–Lag 5 = 135 ms) appeared. As before, it was due to the presence of matching effects in Lag 5 ($p < .001$) that did not appear in Lag 2 ($p = .406$) as also can be seen in Fig. 5.

Taking the results of Experiment 4 all together, there is an AB-like effect found for RTs both under HL and LL conditions. This effect is modulated by matching effects, at least for LL conditions. Performance is greatly impaired by the inclusion of T1: T2 accuracy drops and RTs increase considerably compared with Experiment 3, and the benefit of matching disappears, particularly in the high-load

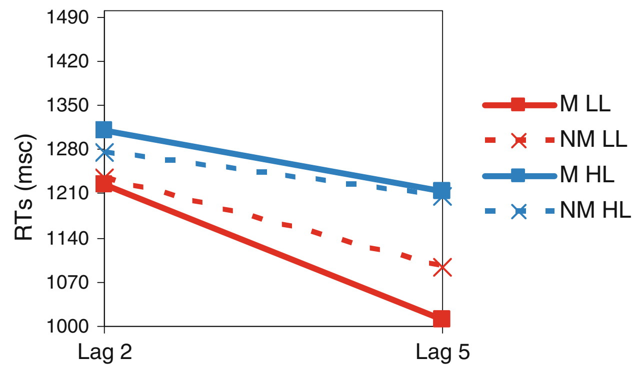

Fig. 5 T2 RTs in Experiment 4 for each condition

condition. Given that accuracy is near chance with a high load, the disappearance of a benefit for a match is perhaps not surprising. However, for RTs, this matching advantage is also shown as a trend in Experiment 4 but only when there is enough distance between T1 and T2 (Lag 5 conditions). Although the interaction was not significant including HL conditions, it was significant only for LL ones showing the same pattern of results: when attentional processes have enough time to be "recovered", the matching effects found in Experiment 3 show up. For those situations where T1 and T2 are so close in time, the attentional system seems to be clearly inaccurate and no matching effects for RTs are shown.

General discussion

The present experiments study the effects of memory contents and memory load in RSVP speeded responses in two different situations: when memory and attentional tasks must be performed separated in a dual-task paradigm (Experiments 1 and 2) and when they are part of the same memory-attentional task (Experiments 3 and 4).

Experiment 1 was a single-target identification RSVP task with a high or low secondary memory load task. We found a clear effect of the relation between information in WM and the target in the RSVP: non-category-related targets were classified faster than category-related ones. It seems that when information is the same category as that one maintained in memory, there is an interference (shown by longer RTs) probably due to the fact that the same information competes for two different tasks (Nieuwenstein et al., 2007). Although no effects of load were found for RTs in the response to the target in the RSVP, the typical memory load effect was found for the memory test in Experiment 1; that is, it is easier to remember one image than four. The second experiment added one more target in the RSVP (T1, unspeeded response target) and also manipulated the distance between targets to study the AB effect. An AB effect was replicated for speeded responses to T2 (Arnell & Duncan, 2002; Jolicœur, 1998; Jolicœur, 1999; Jolicœur & Dell'Acqua, 1999; Wong, 2002), as shown by the marked effect of Lag (slower RT at Lag 2 than Lag 5). Moreover, the same relation effect found in Experiment 1 was also found in Experiment 2: longer RTs for related conditions. That is, when information maintained in working memory is the same category as that shown as T2, performance is highly speed impaired. Nieuwenstein et al. (2007) found a similar result using accuracy measures, which they termed "cross-task repetition amnesia": items maintained in WM may interfere with items tagged as targets in another task. We did not replicate this result for accuracy (probably due to several differences in the design used and pointed out before such as the use of pictures instead of alphanumeric characters, or the use of same category stimuli and not the very same item in working memory) but we did replicate it for RTs (in both Experiments 1 and 2), showing that rather than a "cross-task repetition amnesia" it looks like a "cross-task repetition interference". The items are in fact identified, but it takes longer to give a response when it is the same category as an item in the other task, creating longer RTs, rather than errors ("repetition amnesia"). Therefore, present data replicate those found by Nieuwenstein et al. (2007), but with a new important finding: it can be generalized to speeded responses in the form of a "cross-task repetition interference". Finally, although no memory load effects were found for responses to T2, the effect of memory load in the memory recognition task was as expected: better recognition for LL conditions; just as in Experiment 1.

Experiments 3 and 4 used a hybrid memory-attentional task: participants decided whether any item maintained in memory was the same as the only target shown (Experiment 3) or as T2 (Experiment 4) in the RSVP. In Experiment 3, there was a matching benefit for RTs both in LL and HL conditions: when information in memory was the same as the target in the RSVP, the correct response was faster. (As we discussed earlier, the RT matching benefit in the high-load condition could have been due to a shorter search for a match than for a mismatch, but that would not account for the RT difference in the one-item low load condition.) This RT matching benefit also appeared for accuracy (higher percentage of correct responses for matching trials) but only under HL conditions; no accuracy differences were found in LL conditions. In fact and as we have seen in the introduction, Akyürek et al. (2011) also found smaller AB effects when priming a target (T2) with memory contents, although using a slightly different paradigm (different material, non-speeded responses…). Yet, there is an essential similarity between our design and theirs: both were done within an hybrid memory-attentional task where participants did not have to perform two different tasks for working memory and RSVP but to decide if a given material that must be maintained in working memory was the same as the target (T2 in their case) in the RSVP. On the other hand, with the inclusion of T1 in Experiment 4, accuracy in comparing T2 to the memory set decreased and for the HL condition approached chance (the task was really difficult, as can be seen in Table 4). There was an AB-like effect found for RTs (but not accuracy) both under HL and LL conditions, with faster RTs at Lag 5. As in Experiment 2 and other experiments in the AB field using RTs (Jolicœur & Dell'Acqua, 1999, exp 1; Wong, 2002, exp 3B), it seems not to be unusual to see AB effects in RTs that do not show up for accuracy when speeded responses are demanded (even in our case where the task was quite difficult). Then again, the addition of T1 in Experiment 4 clearly increases overall errors and RTs, but only for Matching conditions: as we have seen in the results, comparing *accuracy* between Experiments 3 and 4, the inclusion of T1 impairs T2 identification in the Matching conditions (Exp 3, $M = .83$; Exp 4, $M = .68$; $p = .002$) but not in the No-Matching ones ($M = .76$ in both experiments; $p = .75$), as shown in the significant interaction found between Match and Experiment. The impairment of T2 identification only for matching conditions when T1 is included both in Lags 2 and 5 could be explained by the fact that when the task is difficult enough (which is in fact the case; according to our results for accuracy in Experiment 4 just shown, and more evidently under HL matching conditions), it is harder to give a match response. Probably T1 interferes with memory maintenance of the item/s in working memory. Then, when T2 appears after T1, and a matching response must be given, the subject is not sure about the response (as he/she has momentarily attended to T1 to encode it) and is no longer focused on the memory set. As the subjects have lost memory contents and do not know the correct response for T2, probably they tend to give more "no matching" responses as the default response because they infer that a matching item would have been detected, explaining the better performance found for no matching conditions.

However, for those responses correctly identified the RT results show different modulations of matching. In fact, the matching effect appears for RTs: LL matching conditions are faster (Experiments 3 and 4). This result did not reach significant for Experiment 4, but it was significant when HL trials were excluded from the analysis (which accuracy was near chance) and LL only were taken into account: the same effect found in Experiment 3 was found in Lag 5 (not in Lag 2) conditions of Experiment 4 for LL (see Fig. 5). According to our hypothesis that WM contents enhance attentional target selection, the AB effect found in Experiment 4 for RTs is modulated by typical matching effects, at least for LL conditions. There were in fact no differences between matching and no matching conditions in Lag 2, but the matching effect appears for Lag 5 (see Fig. 5, LL conditions). As we pointed out before, it seems that when attention to the memory set has time to be "recovered", the matching effects found in Experiment 3 may show up, and the advantage of matching conditions over non-matching ones explains bigger AB effects for matching conditions in LL (Fig. 5). So, it appears that although AB effects for matching are slightly bigger (we would have expected smaller AB effects for matching), they are due to an advantage of matching items when there is enough distance between T1 and T2 (which is the effect that should appear according to biased competition theories; e.g. Desimone & Duncan, 1995; Duncan & Humphreys, 1989). However, like in Experiment 3, the advantage of matching items in Experiment 4 could also be explained because search terminates sooner than in no matching conditions. Although as we pointed out before the results of Experiment 3 seem to support our interpretation instead of that one based on the presence of fewer items to search through when there is a match, further research using T1 as the probe instead of T2 could shed more light on this issue for Experiment 4 and, therefore, better clarify the interplay between memory load and attention in the AB effect.

Taking the results of present work together, there is a remarkable and important effect found in all of the experiments: there is in fact a modulation of attentional processes in RSVP tasks (either with one or two targets) due to the relationship between memory contents and the target in the attentional task. As we have just seen, the results found in all experiments are consistent with those theories claiming that WM contents interact with target detection in an attentional task (e.g. Desimone & Duncan, 1995; Duncan & Humphreys, 1989), although these results have recently been questioned in other visual attentional tasks (Woodman & Luck, 2007). Whereas in Experiments 3 and 4, it leads to an advantage (targets that were in WM were generally detected faster), in Experiment 2 that modulation generated interference because WM information competing in two different tasks (memory and RSVP attentional task). Importantly, present findings replicate others (Akyürek et al., 2011; Nieuwenstein et al., 2007) but with new evidence in the form of speeded responses: the present study replicates previous findings using response time as a new dependent measure in the study of memory effects in RSVP tasks. Therefore, according to these results we can say that holding a representation in visual working memory automatically leads to the selection of similar items, that, in the first two experiments generate interference, and in Experiments 3 and 4, facilitation. Moreover, recent similar results have been found not only for working memory guidance of attention, but also for long-term memory automatic capture of attention (Olivers, 2011), supporting more general memory driven effects in attentional tasks. The present results point out that memory contents can differently drive attentional processes depending on several factors such as whether one is in a dual task or a single memory-attentional task.

Acknowledgments The present study was carried out during Beatriz Gil-Gómez de Liaño's research stay at the Massachusetts Institute of Technology under the "José Castillejo" Grant financed by the "Ministerio de Educación, Programa Nacional de Movilidad de Recursos Humanos del Plan Nacional de I-D+i 2008–2011". Data collection was made possible thanks to the financed research project by the "Ministerio de Ciencia e Innovación. Plan Nacional I+D+i 2008–2011. Ref. PSI2010-20175". This work was also supported by MH47432. We would like to thank Paula Briales, Maria Quirós and Maria Eugenia Rubio for their help in data collection.

References

Akyürek, E. G., Abedian-Amiri, A., & Ostermeier, S. M. (2011). Content-specific working memory modulation of the attentional blink. *PLoS ONE, 6*(2), e16696.

Akyürek, E. G., & Hommel, B. (2005). Short-term memory and the Attentional Blink: Capacity versus content. *Memory & Cognition, 33*, 654–663.

Akyürek, E. G., & Hommel, B. (2006). Memory operations in rapid serial visual presentation. *European Journal of Cognitive Psychology, 18*, 520–536.

Akyürek, E. G., Hommel, B., & Jolicœur, P. (2007). Direct evidence for a role of working memory in the attentional blink. *Memory & Cognition, 35*, 621–627.

Arnell, K. M., & Duncan, J. (2002). Separate and shared sources of dual-task cost in stimulus identification and response selection. *Cognitive Psychology, 44*, 105–147.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience, 18*, 193–222.

Downing, P. E. (2000). Interactions between visual working memory and selective attention. *Psychological Science, 11*(6), 467–473.

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review, 96*, 433–458.

Gil-Gómez de Liaño, B., & Botella, J. (2011). Concurrent memory load can make RSVP search more efficient. *Psicológica, 32*, 13–30.

Gil-Gómez de Liaño, B., Botella, J., & Pascual-Ezama, D. (2011). The types of stimuli loaded in memory modulate its effects on visual search. *Journal of Cognitive Psychology, 23(5)*, 531–542. http://dx.doi.org/10.1080/20445911.2011.542747.

Gil-Gómez de Liaño, B., Umiltà, C., Stablum, F., Tebaldi, F., & Cantagallo, A. (2010). Attentional distractor interference may be diminished by concurrent working memory load in normal participants and traumatic brain injury patients. *Brain & Cognition, 74*(3), 298–305. doi:10.1016/j.bandc.2010.08.009.

Jolicœur, P. (1998). Modulation of the attentional blink by on-line response selection: Evidence from speeded and unspeeded Task1 decisions. *Memory & Cognition, 26*(5), 1014–1032.

Jolicœur, P. (1999). Concurrent response-selection demands modulate the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 25*(4), 1097–1113.

Jolicœur, P., & Dell'Acqua, R. (1999). Attentional and structural constraints on visual encoding. *Psychological Research, 62*, 154–164.

Kim, S. Y., Kim, M. S., & Chun, M. M. (2005). Concurrent memory load can reduce distraction. *PNAS, 102*(45), 16524–16529.

Nieuwenstein, M. R., Johnson, A., Kanai, R., & Martens, S. (2007). Cross-task repetition amnesia: Impaired recall of RSVP targets held in memory for a secondary task. *Acta Psychologica, 125*, 319–333.

Olivers, C. N. L. (2009). What drives memory-driven attentional capture? The effects of memory type, display type, and search type. *Journal of Experimental Psychology: Human Perception and Performance, 35*(5), 1275–1291.

Olivers, C. N. L. (2011). Long-term visual associations affect attentional guidance. *Acta Psychologica, 137*, 243–247.

Olivers, C. N. L., Meijer, F., & Theeuwes, J. (2006). Feature-based memory-driven attentional capture: Visual working memory content affects visual attention. *Journal of Experimental Psychology: Human Perception and Performance, 32*, 1243–1265.

Olivers, C. N. L., & Nieuwenhuis, S. (2006). The beneficial effects of additional task load, positive affect, and instruction on the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 32*(2), 364–379.

Potter, M. C., Wyble, B., & Olejarczyk, J. (2011). Attention blinks for selection, not perception or memory: Reading sentences and reporting targets. *Journal of Experimental Psychology: Human Perception and Performance, 37*(6), 1915–1923.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime user's guide*. Pittsburgh: Psychology Software Tools.

Soto, D., Heinke, D., Humphreys, G. W., & Blanco, M. J. (2005). Early, involuntary top-down guidance of attention from working memory. *Journal of Experimental Psychology: Human Perception and Performance, 31*(2), 248–261.

Sternberg, S. (1966). High-speed scanning in human memory. *Science, 153*(3736), 652–654. doi:10.1126/science.153.3736.652.

Visser, T. A. W. (2010). Memory reloaded: Memory load effects in the attentional blink. *The Quarterly Journal of Experimental Psychology, 63*(6), 1085–1103.

Wong, K. F. E. (2002). The relationship between Attentional Blink and Psychological Refractory Period. *Journal of Experimental Psychology: Human Perception and Performance, 28*(1), 54–71.

Woodman, G. F., & Luck, S. J. (2007). Do the contents of visual working memory automatically influence attentional selection during visual search? *Journal of Experimental Psychology: Human Perception and Performance, 33*, 363–377.