

# How memory mechanisms are a key component in the guidance of our eye movements: Evidence from the global effect

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**Abstract** Investigating eye movements has been a promising approach to uncover the role of visual working memory in early attentional processes. Prior research has already demonstrated that eye movements in search tasks are more easily drawn toward stimuli that show similarities to working memory content, as compared with neutral stimuli. Previous saccade tasks, however, have always required a selection process, thereby automatically recruiting working memory. The present study was an attempt to confirm the role of working memory in oculomotor selection in an unbiased saccade task that rendered memory mechanisms irrelevant. Participants executed a saccade in a display with two elements, without any instruction to aim for one particular element. The results show that when two objects appear simultaneously, a working memory match attracts the first saccade more profoundly than do mismatch objects, an effect that was present throughout the saccade latency distribution. These findings demonstrate that memory plays a fundamental biasing role in the earliest competitive processes in the selection of visual objects, even when working memory is not recruited during selection.

**Keywords** Visual working memory · Eye movements and visual attention · Attentional capture · Selective attention

## Introduction

Attention is often considered to be a gateway to memory, since attended stimuli are typically remembered better than those that are ignored (Broadbent 1958). However, Desimone and

Duncan (1995) argued that memory mechanisms are a key component in selecting which stimuli to attend. In any visual scene of multiple objects there are neuronal representations that compete for attention, a competition in which working memory (WM) content will often determine a winner.

A main reason to assume a tight bidirectional relationship between memory and attention is the strong overlap in the structure and functions of these mechanisms (Awh and Jonides 2001; Desimone 1996, 1998). In target selection, mechanisms of competition presumably serve to cope with the severe capacity limitations of visual perception (Kastner and Ungerleider 2001; Luck and Vogel 1997). Objects within a visual field therefore fight to be selected by attention and cancel each other out during the process. Those objects within a visual field that are relevant are enhanced by the prefrontal cortex such that they are more likely to be selected (Buschman and Miller 2007; Kastner and Ungerleider 2001). Similarly, the prefrontal cortex maintains WM representations by enhancing related patterns of neuronal activity (Braver et al. 1997; Miller et al. 1996). When no such enhancement takes place, competition among neuronal patterns leads WM representations to fade away. On top of that, WM representations can be used to search for particular objects, which even led Desimone (1996) to suggest that attention, at least in part, is derived from memory mechanisms.

A promising way to uncover the exact role of memory representations in this process of competition is to study eye movements. Even though the saccade's actual landing position has turned out to be independent, at least to some degree, from the focus of visual attention, saccade programming and visual attention are tightly linked, both temporally and spatially (Deubel and Schneider 1996). A saccade's landing position can therefore be taken to be a rather direct reflection of the location of visual attention, allowing us to investigate visual attention at an early stage and gain insight about a potential influence of WM. Accordingly, a number of prior studies have already illustrated an important role for memory

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mechanisms in visual attention (Downing 2000; Huang and Pashler 2007) and saccade programming (Hollingworth et al. *in press*; Olivers et al. 2006; Soto et al. 2005; Soto and Humphreys 2009). For instance, memorizing certain content can have a profound impact on response times and eye movements in a consecutive search task. Even in conditions in which it is of no predictive value, memory content appears to function as a cue (Carlisle and Woodman 2011a; Soto et al. 2005). Furthermore, the abrupt onset of a stimulus is more likely to induce attentional and/or oculomotor capture when the color of this stimulus matches WM content (Mannan et al. 2010; Olivers et al. 2006; Wong and Peterson 2011), showing that WM content is able to interact with stimulus-driven processes, an effect that has also been found in a gaze correction paradigm (Hollingworth and Luck 2009).

In previous studies in which the influence of WM content on oculomotor selection was studied, participants were explicitly instructed to aim at a specific target. Since it is well known that WM is recruited when oculomotor competition needs to be resolved (Mitchell et al. 2002; Van der Stigchel 2010), the influence of WM content on oculomotor competition might be driven by the activation of the target template required to perform the oculomotor selection task. Although Hollingworth et al. (*in press*, Experiment 5) recently showed that the reaction time of a saccade to a single target is lower when the color of the target matches WM content, this experiment did not assess oculomotor competition, since there was only a single target. In the other experiments in this study, WM was recruited to perform the oculomotor selection task.

To investigate whether WM influences oculomotor competition even when WM is not recruited to perform the oculomotor selection task, one should leave out the instructions about a particular target. A paradigm that can be used to do exactly that is the global effect paradigm (for a review, see Van der Stigchel and Nijboer 2011). The global effect is observed when participants initiate an eye movement toward a set of objects presented in close proximity and with a simultaneous onset. Instead of hitting one particular object right on, the initial saccade generally lands in between the objects, an endpoint that is likely to reflect the unresolved competition between their representations (Tipper et al. 1997). A unique feature of this paradigm is that participants are generally not instructed to aim for a specific target and are simply told to move their eyes as quickly as possible toward the information that appears on the screen. Eye movements are therefore initiated without the necessary involvement of WM.

If we still find that memory representations influence the global effect despite the absence of any memory requirements, memory mechanisms will have been shown to be an obligatory factor in oculomotor competition. To this end, an eye movement task designed to induce the global effect was embedded in a WM subtask. We expected the first saccade to be attracted by a colored object that matched WM content,

since WM may give matching objects an advantage in the competitive processes of visual attention. Furthermore, the effect should be observable for saccades of all latencies, if memory indeed affects visual attention fundamentally.

## Method

### Participants

Ten volunteers (50% female), between 20 and 27 years of age ( $M = 23.7$ ,  $SD = 2.36$ ), participated at Utrecht University, the Netherlands. They reported having normal or corrected-to-normal vision, and none reported colorblindness.

### Materials

An Eyelink 1000 eyetracker system was used. The task consisted of two separate objectives: (1) While participants were memorizing a particular color, (2) eye movements had to be made toward a pair of target objects. To explicitly dissociate between these two subtasks, colored squares (sized  $1.9^\circ$ ) were used as memory objects, whereas the target objects were always colored circles (sized  $1.9^\circ$ ). The colors were selected from among 18 different shades, 6 shades of red, green, and blue. These shades were all of a similar luminance, so that the global effect would be as balanced as possible (Deubel et al. 1984). Within the test display of the memory subtask, however, the incorrect alternatives could differ from the standard luminance to prevent the task from becoming too difficult.

In the eye movement subtask, pairs of target objects were presented near one of the four corners of the screen, as if located around a circle (distanced  $17.1^\circ$  from the center of the screen). The objects of a pair were situated  $6.7^\circ$  apart.

### Design

There were two main conditions (within subjects, randomly alternating trial to trial): (1) a condition in which one of the targets matched with WM content, the *match* condition, and (2) a condition in which none of the two targets matched with WM content, the *nonmatch* condition. Crucially, the match condition actually consisted of two subconditions. On 50% of the trials in the match condition, the matching object was not exactly equal to the color that had to be held in WM but consisted of a different shade of the same color category. Consequently, participants would not benefit from focusing primarily on matching targets. The participants were made aware of this important fact, such that it was unlikely that participants dealt with the task as if certain objects were more relevant than others (Woodman and Luck 2007).

Furthermore, to ensure that differences between the conditions truly related to WM, a control condition was included in

which participants simply observed a color without attempting to memorize it. If a predisplayed color also was able to affect the initial movements of the eye, even though the color might not be actively stored in WM, systematic effects found in the WM conditions would be attributable to more basic mechanisms such as priming (Theeuwes et al. 2006). The trials with and without a WM subtask were blocked and counterbalanced.

At the beginning of each trial, a memory object was presented for 1,000 ms. This object was preceded by a 500-ms fixation cross and followed by a 3,000-ms blank interval (see Fig. 1). The interval forced participants to actually store and maintain a color representation. After the blank interval, the eye movement subtask began with the presentation of a fixation cross that lasted a constant 1,000 ms. However, the onset of the target objects varied randomly, relative to the moment the fixation cross disappeared (between  $-100$  and  $100$  ms), to induce a wider range of saccade latencies for further analysis (McSorley et al. 2006; Ross and Ross 1980; Saslow 1967). The target objects appeared in pairs at one of the four corners of the screen, randomly varying across trials. The target objects were shown for 1,000 ms.

Finally, at the end of a trial, WM was tested with a display containing three colored objects that were aligned horizontally. One of these was correct, consisting of the exact same color as the initial memory object presentation, while the other two were incorrect alternative shades of the same color. Importantly, using shades of the same color category at test made it difficult for participants to effectively use verbal labels

during the task. Feedback was given after a keypress response, which remained on the screen until the participant indicated being ready for the next trial.

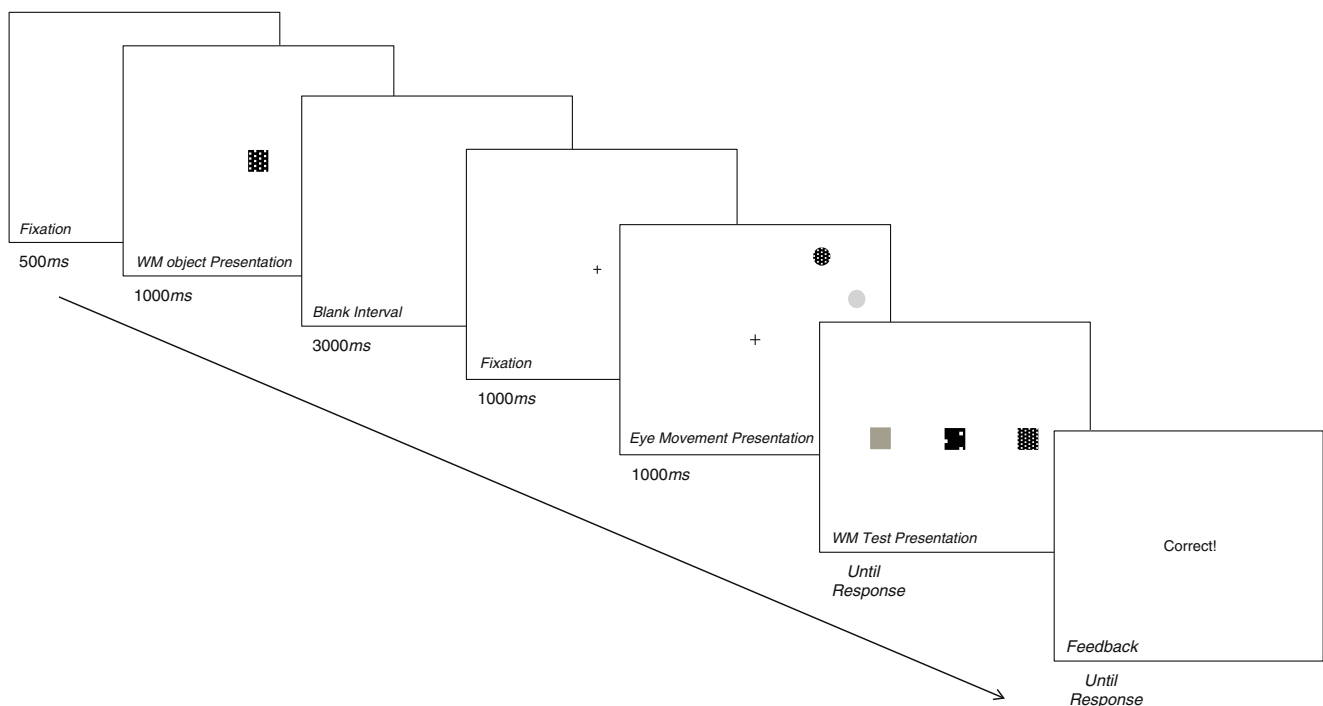
## Procedure

The main experiment consisted of 288 trials subdivided into four blocks. The WM conditions were conducted in three of these blocks, whereas a fourth block consisted of non-WM control trials (presented in randomized counterbalanced order).

## Analyses

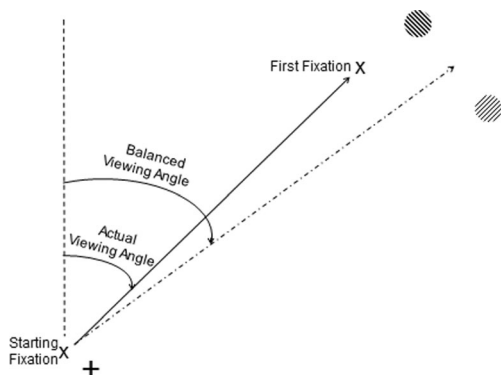
When a first saccade is performed relatively quickly, it should generally end up in the middle of the two targets, reflecting a perfectly balanced global effect. Hence, to examine whether WM content is a factor that influences the global effect, we contrasted the actual saccades against an imaginary perfectly balanced movement ending up exactly in the middle of the targets (see Fig. 2).

The difference between the balanced and the actual viewing angles, the viewing-angle deviation, was calculated such that deviations toward one target, object 1, were treated as positive deviations, while deviations toward the other, object 2, were treated as negative. In the match conditions, the matching target was always assigned to object 1. This way, it was possible to investigate whether eye movements were



**Fig. 1** Is an illustration of the trial design including timing information. Importantly, the exact timing of the appearance of the eye movement targets was not fixed, but fluctuated around fixation-display offset with

100ms. Therefore, occasionally, there could be a short black interval between display 4 and 5, or the fixation cross could still be present within display 5 for maximally 100ms



**Fig. 2** shows how the experiment’s main calculation is performed. The actually measured viewing angle is contrasted against a balanced version of the viewing angle

systematically drawn toward matching targets instead of mismatch targets. In the nonmatch conditions, similar to the match conditions, the locations of object 1 or 2 were assigned to a particular color, so that, overall, each of the three colors that were used in this experiment was assigned to objects 1 and 2 an equal number of times.

Importantly, latency was included as a factor in the analyses. The trials were subdivided into four bins for each of the participants individually, based on the four quartiles of the ranges of latency measures within each condition.

Before this categorization, trials that included anomalies were removed: trials that involved an inaccurate timing, falling outside a time period between 100 and 600 ms relative to target onset, and trials that included a first fixation that landed beyond a limit of two times the standard deviation of the average saccade end position. In the eye movement subtask, 8.6% of the trials were removed.

**Results**

The global effect was influenced by WM content, since the match condition showed a positive and significantly larger viewing-angle deviation, as compared with the nonmatch condition,  $F(1, 9) = 11.02$ ,  $\eta_p^2 = .55$ ,  $p < .01$ . The match condition deviated on average by  $2.3^\circ$  ( $SD = 0.7^\circ$ ) toward the matching target, whereas eye movements in the nonmatch condition landed closer to the intermediate location between the two targets, deviating by a mere  $0.6^\circ$  ( $SD = 1.4^\circ$ ). Saccades thus generally ended up nearer to the match object, while in the absence of a match, saccades showed a less pronounced attraction of certain colors, as reflected by a more balanced global effect.

Within the match condition, there were two types of matches; the target could be an exact match or could match the color category. Saccades deviated toward similar colors to the same extent as exact matches,  $F(1, 9) = 0.375$ ,  $\eta_p^2 = .04$ . These deviations are shown in Table 1.

**Table 1** Shows the angular deviation in the Match and Non Match conditions per color category (and standard deviations)

Color Category	Systematic Deviation	
	Match	Nonmatch
Blue	2.10 (1.21)	0.09 (0.95)
Green	2.51 (1.66)	1.01 (1.10)
Red	2.15 (1.75)	-1.09 (0.85)

Importantly, in the block of non-WM trials, the difference between the match and nonmatch conditions was absent,  $F(1, 9) = 0.06$ ,  $\eta_p^2 = .01$ . On top of that, the interaction between the presence of the WM task and the effect of a match color was significant,  $F(1, 9) = 21.642$ ,  $\eta_p^2 = .71$ ,  $p < .05$ . When a color simply had to be observed instead of memorized, the effects of a matching target on the first saccade were absent.

The latency category did not influence the end position of a fixation directly,  $F(3, 27) = 0.37$ ,  $\eta_p^2 = .04$ , and the interaction between condition and latency category was merely a trend,  $F(3, 27) = 2.83$ ,  $p = .06$ ,  $\eta_p^2 = .24$  (see Table 2). Also, conversely, the conditions did not lead to different saccade latencies,  $t(9) = 1.279$ .

The mean saccade amplitude was  $13.6^\circ$  and did not differ significantly when a match was present or absent,  $t(9) = 1.446$ . The absolute angular deviation for all trials was  $4.07^\circ$  ( $SD = 1.21^\circ$ ). A larger absolute deviation was found when there was a WM match present, as compared with when there was no match with working memory,  $F(1, 9) = 5.193$ ,  $\eta_p^2 = .37$ ,  $p < .5$ . Similar to the nonabsolute angular deviation, saccade latency did not interact with the absolute angular deviation,  $F(3, 27) = 0.710$ ,  $\eta_p^2 = .07$ .

Finally, each participant scored significantly above chance on the WM subtask, with an overall average of 70.5% accuracy. Thereby, WM can truly be assumed to be employed during the eye movement subtask. Furthermore, WM performance was not influenced by the colors that were used in the eye movement task, because nonmatching colors, an exact matching color, or a color that matched the WM color category did not lead to significant differences in WM performance,  $F(2, 18) = 0.128$ ,  $\eta_p^2 = .01$ .

**Table 2** Shows the average cutting points of the four latency bins and the associated angular deviations for the Match and Non Match conditions

Category	Latency Range	Systematic Deviation	
		Match	Nonmatch
1	100–289.7	2.02 (1.81)	1.14 (0.98)
2	289.7–344.6	1.86 (1.08)	1.11 (2.41)
3	344.6–420.3	2.26 (1.76)	0.07 (1.25)
4	420.3–600	2.87 (1.36)	0.21 (1.67)

## Discussion

The results of this experiment reveal that WM content is able to bias the competitive processes of selective attention, affecting the very first eye movement within a changed visual scene, even though participants were not instructed to search or aim at a target. First saccades ended up closer to a colored object that was congruent with WM content, as compared with a mismatch object, revealing that even when WM is not recruited, WM content nevertheless affects saccadic programming. Interestingly, the effect of WM was observed throughout the saccade latency distribution and cannot be explained by priming caused by the presentation of the to-be-remembered color at the start of the trial (Theeuwes et al. 2006). It is not competition alone that determines the exact landing position of a saccade (Deubel and Schneider 1996), but the systematic preference of the saccades reveals that a WM match does have a fundamental competitive advantage, despite the lack of a clear goal to control the saccades.

An alternative conception to the biased competition point of view is that WM content automatically reprograms an *attentional set*. The attentional set is a preparatory state or template to efficiently find particular visual targets in visual scenes (Folk et al. 1992), a template that may function as a subcomponent within the WM system (Cowan 1998; Olivers et al. 2011). Accordingly, multiple WM representations can be maintained simultaneously in such a way that all these representations are readily available to us, but only one can be the main focus of attention. It is this single WM representation that reflects what we are looking for and what we currently think of. From this perspective, our findings suggest that the main representation in WM can automatically act as an attentional set to affect eye movements, even when the WM task is not relevant to the eye movement task.

This finding is in line with previous work that shows that an irrelevant WM task can interfere with a search task (Hollingworth et al. *in press*; Olivers et al. 2006; Soto et al. 2005; Soto and Humphreys 2009), even in the case of an additional memory representation that potentially eliminates the WM effects (Carlisle and Woodman 2011b; Olivers 2009; Olivers et al. 2011). However, the finding that WM's influence is still present even where there is absolutely no need for an attentional set is rather striking. Interestingly, it suggests that an attentional set is an obligatory mental state in which memory mechanisms are a fundamental component.

In contrast to previous findings (Findlay 1982; Ottes et al. 1985; Van der Stigchel and Theeuwes 2005), latency did not modulate the strength of the global effect significantly. Also, the effect of WM content appears similarly strong throughout the latency distribution, since the interaction between latency and the WM effect merely trended. Although these findings might be surprising given that saccades with longer latencies are known to be under the control of top-down information (e.g., Van Zoest et al. 2004), these findings can be explained

by the lack of a specific target instruction in the present paradigm; eye movements were initiated without a strong top-down component and were dominantly driven by bottom-up information. The lack of an effect of latency therefore validates that participants were indeed performing the task without a strong top-down component, which, in turn, demonstrates that the WM effect on oculomotor behavior is deeply rooted.

Taken together, information held in mind systematically affects the movements of the eyes even in the absence of a target goal. Thus, in an obligatory fashion, WM appears to bias the earliest competitive processes to select visual objects, revealing that memory mechanisms may indeed be a fundamental component of selective attention.

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## References

- Awh, E., & Jonides, J. (2001). Overlapping mechanisms of attention and working memory. *Trends in Cognitive Science*, 5, 119–126.
- Braver, T. S., Cohen, J. D., Nystrom, L. E., Jonides, J., Smith, E. E., & Noll, D. C. (1997). A parametric study of prefrontal cortex involvement in human working memory. *NeuroImage*, 5, 49–62.
- Broadbent, D. E. (1958). *Perception and communication*. New York: Pergamon Press.
- Buschman, T. J., & Miller, E. K. (2007). Top-down versus bottom-up control of attention in the prefrontal posterior parietal cortices. *Science*, 315, 1860–1862.
- Carlisle, N. B., & Woodman, G. F. (2011a). Automatic and strategic effects in the guidance of attention by working memory representations. *Acta Psychologica*, 137, 217–225.
- Carlisle, N. B., & Woodman, G. F. (2011b). When memory is not enough: Electrophysiological evidence for goal-dependent use of working memory representations in guiding visual attention. *Journal of Cognitive Neuroscience*, 23, 2650–2664.
- Cowan, N. (1998). *Attention and memory: An integrated framework*. Oxford, UK: Oxford University press, Inc.
- Desimone, R. (1996). Neural mechanisms for visual memory and their role in attention. *Proceedings of the National Academy of Sciences of the United States of America*, 93, 13494–13499.
- Desimone, R. (1998). Visual attention mediated by biased competition in extrastriate visual cortex. *Philosophical Transactions of the Royal Society of London B*, 353, 1245–1255.
- Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, 18, 193–222.
- Deubel, H., Wolf, W., & Hauske, M. (1984). The evaluation of the oculomotor error signal. In: A. G., & F. W. Johnson (Eds.), *Theoretical and applied aspects of oculomotor research*, Elsevier Science Publishers B. V. (North-Holland).
- Deubel, H., & Schneider, W. X. (1996). Saccade target selection and object recognition: Evidence for a common attentional mechanism. *Vision Research*, 36, 1827–1837.
- Downing, P. E. (2000). Interactions between visual working memory and selective attention. *Psychological Science*, 11, 467–473.
- Findlay, J. M. (1982). Global visual processing for saccadic eye movements. *Vision Research*, 22, 1033–1045.

- Folk, C., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 1030–1044.
- Hollingworth, A., Matsukura, M., & Luck, S. J. (in press). Visual working memory modulates rapid eye movements to simple onset targets. *Psychological Science*.
- Hollingworth, A., & Luck, S. J. (2009). The role of visual working memory (VWM) in the control of gaze during visual search. *Attention Perception & Psychophysics*, *71*, 936–949.
- Huang, L., & Pashler, H. (2007). Working memory and the guidance of visual attention: Consonance-driven orienting. *Psychonomic Bulletin and Review*, *14*, 148–153.
- Kastner, S., & Ungerleider, L. G. (2001). The neural basis of biased competition in human visual cortex. *Neuropsychologia*, *39*, 1263–1276.
- Luck, S. J., & Vogel, E. K. (1997). The capacity of visual working memory for features and conjunctions. *Nature*, *390*, 279–281.
- Mannan, S. K., Kennard, C., Potter, D., Pan, Y., & Soto, D. (2010). Early oculomotor capture by new onsets driven by the contents of working memory. *Vision Research*, *50*, 1590–1997.
- McSorley, E., Haggard, P., & Walker, R. (2006). Time course of oculomotor inhibition revealed by saccade trajectory modulation. *Journal of Neurophysiology*, *96*, 1420–1424.
- Miller, E. K., Erickson, C. A., & Desimone, R. (1996). Neural mechanisms of visual working memory in prefrontal cortex of the macaque. *The Journal of Neuroscience*, *16*, 5154–5167.
- Mitchell, J. P., Macrae, C. N., & Gilchrist, I. D. (2002). Working memory and the suppression of reflexive saccades. *Journal of Cognitive Neuroscience*, *14*, 95–103.
- 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*, 1275–1291.
- 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., Peters, J., Houtkamp, R., & Roelfsema, P. R. (2011). Different states in visual working memory: when it guides attention and when it does not. *Trends in Cognitive Sciences*, *15*, 327–334.
- Ottes, F. B., Van Gisbergen, J. A. M., & Eggermont, J. J. (1985). Latency dependence of colour-based target vs nontarget discrimination by the saccadic system. *Vision Research*, *25*, 849–862.
- Ross, L. E., & Ross, S. M. (1980). Saccade latency and warning signals: stimulus onset, offset, and change as warning events. *Perception & Psychophysics*, *27*, 251–257.
- Saslow, M. G. (1967). Effects of components of displacement-step stimuli upon latency for saccadic eye movement. *Journal of the Optical Society of America*, *57*, 1024–1029.
- 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*, 248–261.
- Soto, D., & Humphreys, G. W. (2009). Automatic selection of irrelevant object features through working memory. *Experimental Psychology*, *56*, 165–172.
- Theeuwes, J., Reimann, B., & Mortier, K. (2006). Visual search for featural singletons: No top-down modulation, only bottom-up priming. *Visual Cognition*, *14*, 466–489.
- Tipper, S. P., Howard, L. A., & Jackson, S. R. (1997). Selective reaching to grasp: evidence for distractor interference effects. *Visual Cognition*, *4*, 1–38.
- Van der Stigchel, S. (2010). The search for oculomotor inhibition. *Experimental Psychology*, *57*, 429–435.
- Van der Stigchel, S., & Nijboer, T. C. W. (2011). The global effect: what determines where the eyes land? *Journal of Eye Movement Research*, *4*, 1–13.
- Van der Stigchel, S., & Theeuwes, J. (2005). Relation between saccade trajectories and spatial distractor locations. *Cognitive Brain Research*, *25*, 579–582.
- Van Zoest, W., Donk, M., & Theeuwes, J. (2004). The role of stimulus-driven and goal-driven control in saccadic visual selection. *Journal of Experimental Psychology: Human Perception and Performance*, *30*, 746–759.
- 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.
- Wong, J. H., & Peterson, M. S. (2011). The interaction between memorized objects and abrupt onsets in oculomotor capture. *Attention, Perception & Psychophysics*, *73*, 1768–1779.