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Visual and Verbal Working Memory Loads Interfere With Scene Viewing

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Abstract

Working memory is thought to be divided into distinct visual and verbal subsystems. Studies of visual working memory frequently use verbal working memory tasks as control conditions and/or use articulatory suppression to ensure visual load remains in visual memory. Using these verbal tasks relies on the assumption that the verbal working memory load will not interfere with the same processes as visual working memory. In the present study, participants maintained a visual or verbal working memory load while simultaneously viewing scenes. Because eye movements and visual working memory are closely linked, we anticipated the visual load would interfere with scene viewing (and vice versa), while the verbal load would not. Surprisingly, both visual and verbal memory loads interfered with scene viewing behavior, while scene viewing did not significantly interfere with performance on either memory task. These results suggest that a verbal working memory load *can* interfere with a visual task and contribute to the growing literature suggesting the visual and verbal subsystems of working memory are less distinct than previously thought. Our data also stands at odds with previous work suggesting that visual working memory is obligatorily recruited by saccadic eye movements.

Keywords: eye movements, scene viewing, visual working memory, verbal working memory, attention

Visual and Verbal Working Memory Loads Interfere with Scene Viewing

Frequently in daily life, a task requires that we attend to the visual world while maintaining verbal information in memory. For example, we might mentally rehearse a phone number while searching our surroundings for a pen or maintain a grocery list while scanning shelves at the store. These tasks require us to both move our eyes and engage working memory.

Working memory (WM) is thought to be made up of independent visual and verbal subsystems (Baddeley & Hitch, 1974; Baddeley, 1986; Luck & Vogel, 1997; Smith, et al., 1996). For this reason, verbal WM tasks are frequently used as control conditions for dual-task paradigms investigating visual WM (e.g., Cronin & Irwin, 2018; Hollingworth, Richard, & Luck, 2008). Further, articulatory suppression is frequently used in conjunction with visual WM tasks to prevent participants from offloading visual load into verbal memory (e.g., swapping a visual representation of the color green for the word 'green' in verbal memory; e.g., Schmidt, Vogel, Woodman, & Luck, 2002). Using verbal WM tasks as a control relies on the assumption that they will minimally interfere with visual WM processes.

Saccadic eye movements and visual WM are thought to be closely related (for a review, see Van der Stigchel & Hollingworth, 2018). The contents of visual WM can guide overt attention (Beck, Hollingworth, & Luck, 2012; Downing, 2000; Hollingworth, Matsukura, & Luck, 2013a,b; Hollingworth & Luck, 2009; Soto, Heinke, Humphreys, & Blanco, 2005; Soto & Humphreys, 2006), support perceptual stability across an eye movement (Cronin & Irwin, 2018; Hollingworth et al., 2008; Irwin, 1992a,b; Tas, Luck, & Hollingworth, 2016), and guide corrective saccades (Hollingworth et al., 2008). There is no evidence for a relationship between verbal WM and eye movements (Cronin & Irwin, 2018; Hollingworth, et al., 2008).

A defining feature of WM is its limited capacity: we can actively maintain only 3-4 items at a time in visual WM (Miller, 1956; Luck & Vogel, 1997; Cowan, 2005), either due to a limited number of discrete slots (e.g., Awh, Barton, & Vogel, 2007; Fukuda, Awh, & Vogel, 2010; Luck & Vogel, 1997;

Pashler, 1988) or due to a limited pool of dedicated resources (e.g., Wilken & Ma, 2004; Bays & Husain, 2008). Given this limitation of visual WM and the close relationship it has to saccadic eye movements, an interesting and open question is how loading visual WM affects scene viewing (and vice versa). Verbal WM is similarly limited in capacity, but it is unknown how a verbal WM load would influence scene viewing behavior. There is little reason to suspect that a verbal WM load would interfere with a visual scene-viewing task (but, see Soto & Humphreys, 2007, 2008).

The Present Study

The present study examined the effects of WM load on scene-viewing behavior and the effects of scene-viewing on WM load. Participants maintained a verbal or visual WM load while free-viewing scenes. The same participants also viewed scenes without a memory load (Figure 1). A separate set of participants performed the visual and verbal WM tasks without performing the free-viewing task. Based on the literature outlined above, we predicted the visual WM and free-viewing tasks would interfere with each other under dual-task conditions, while the verbal WM task and free-viewing task would not. In contrast with previous work, we found interference from both the visual and verbal WM tasks on scene viewing behavior and no evidence the free-viewing task interfered with either WM task.

Method

Participants

Fifty-eight experimentally naïve participants from the University of California, Davis participated for course credit. Four participants were replaced due to poor eye-tracking ($\geq 25\%$ data loss) and six participants were replaced due to below-chance memory task performance. Thus, 48 (31 female; mean age = 20.6y) participants' data are included in the subsequent analyses.

Due to time constraints, a memory-task only condition was collected with a separate group of 59 participants recruited from the same participant pool. Eleven subjects were dropped due to below-

chance performance on one or both memory tasks. Thus, 48 (38 female, mean age = 20.9y) participants' data are included in the analysis.

Apparatus and Stimuli

Dual-Task and Scene Viewing Conditions. Participants were seated 85cm from a 24.5" LCD display. Their head movements were limited by a chin and forehead rest. Scenes were displayed at their full resolution (1024 x 768 px) and subtended 26.5 x 20 degrees of visual angle. Eye movements were monitored with a tower-mounted EyeLink 1000 eye tracker sampling the right eye at 1000Hz (SR Research, 2010). Experimental stimuli were presented using the SR Research Experiment Builder software.

Ninety-six luminance-matched real-world scenes were presented to participants engaged in the free-viewing task. Each scene was presented once over the course of the experiment, with 24 scenes appearing in a random order in each condition. Across all participants, each scene appeared equally in each condition.

Single-Task Working Memory Control. Participants were seated 85cm from a 24.5" LCD display or a 21" CRT display. Head movements were limited by a chin and forehead rest.

Procedure

Dual-Task and Scene Viewing Conditions. There were four experimental task conditions: a visual WM task, a verbal WM task, and visual and verbal WM control conditions (Figure 1). Participants completed 24 trials for each task. The four task conditions were blocked and presented in a counterbalanced order across participants.

During the visual WM task, five colored squares were presented for 250 ms. Colors were chosen from a pool of 9 possible colors (red [RGB: 255,0,0], yellow [255,255,0], orange [255,124,27], light green [0,255,128], green [0,128,0], light blue [0,165,253], blue [0,0,255], pink [255,0,255], purple [128,0,128]). The squares subtended 0.4° x 0.4° and were presented on an invisible circle of radius 0.4° centered on

screen. After the memory array disappeared, the fixation cross remained for 500ms until scene onset. The scene remained for 3500ms. Participants were encouraged to free-view the scenes during the delay interval. After scene offset, another array of five colored squares appeared and remained visible until response. On 50% of trials, the color of one of the five squares was changed to one of the four colors not used in the original array. Participants responded to whether a color changed.

During the verbal WM task, 7 consonants were sequentially presented at fixation. Each consonant subtended 0.29° and was presented for 300ms. Participants were encouraged to verbalize, then rehearse the letters throughout the trial. After the 7th letter offset, a checkerboard mask was presented for 250ms, followed by a fixation cross for 250ms. Then, a scene appeared for 3500ms. After scene offset, a single letter was presented at the center of the screen. Participants responded to whether that letter was one of the 7 they saw at the beginning of the trial. We used 7 letters for this task as WM for articulated items is greater than memory for visual information (Miller, 1956). In this way, a 7 letter load more closely matches the difficulty of the visual task.

The visual and verbal control tasks proceeded in the same way as the visual and verbal WM tasks, but participants were not asked to respond to the memory items.

Single-Task Working Memory Control. A second group of participants completed the memory portion of our visual and verbal WM conditions with no intervening scenes. Participants viewed the memory stimuli and were tested on them as outlined above. The delay interval consisted of a gray screen with a fixation cross at center. The order in which participants completed the visual and verbal WM tasks was counterbalanced across participants.

Visual Load **No Load (Visual)** **Verbal Load** **No Load (Verbal)**

Figure 1. Task procedures for the four experimental conditions.

Results**Eye Movement Measures**

To determine whether a visual or verbal WM load interferes with participants' scene viewing behavior, we employed linear mixed models (LME) with load (load vs. no load) and load type (visual vs. verbal) as fixed effects and subject and scene as random effects. All p-values reported below are Bonferroni-adjusted to correct for family-wise error. Tests were completed using the R package lme4 (R

Core Team, 2019; Bates, Maechler, Bolker, & Walker, 2015). Means and standard deviations for each measure are reported in Table 1.

Table 1
Mean (*SD*) eye movement measures across task conditions.

	Visual		Verbal	
	No Load	Load	No Load	Load
Number of Fixations	9.65 (1.95)	7.29 (2.05)	9.46 (2.17)	8.36 (1.84)
Fixation Duration (ms)	327 (121)	422 (170)	360 (172)	375 (140)
Saccade Amplitude (°)	5.01 (1.10)	3.19 (1.42)	4.64 (1.20)	3.70 (1.30)
Scan path length (°)	44.32 (13.10)	21.95 (14.32)	41.71 (15.41)	28.82 (12.51)
Percent of scene fixated	4.43% (0.98)	2.82% (1.04)	4.26% (1.12)	3.34% (0.97)
Dispersion from center (pixels)	275 (37)	173 (47)	299 (36)	211 (40)

First, we tested whether a WM load influenced fixation-level behavior. Participants with a memory load made fewer fixations than participants without a memory load ($\chi(1) = 455.01$, $p_{adj} < 0.001$), with participants in the no load condition making nearly 2 more fixations in each scene than participants with a memory load. The effect of load-type was also significant: participants made 0.5 fewer fixations with a visual load compared to a verbal load ($\chi(1) = 31.24$, $p_{adj} < 0.001$).

There were also effects of load on fixation durations and saccade amplitudes, with participants tending to make longer fixations ($\chi(1) = 43.01$, $p_{adj} < 0.001$) and shorter saccades ($\chi(1) = 739.26$, $p_{adj} < 0.001$) when they were maintaining a memory load. The effect of load type was not significant for fixation durations ($\chi(1) = 0.82$, $p_{adj} = 1$) nor saccade amplitudes ($\chi(1) = 3.28$, $p_{adj} = 0.844$). Although the literature suggests a strong relationship between visual WM and saccadic eye movements, a verbal load and a visual load had a similar effect on fixation durations and saccade amplitudes in this experiment.

Next, we assessed how a memory load influenced scene viewing over the course of the entire 3.5s viewing period. We looked at the length of participants' scan paths, the percent of the scene fixated (Castelhano, Mack, and Henderson, 2009), and the dispersion of their fixations from the center of the screen (Anliker, 1976).

Scan paths were significantly shorter with a memory load ($\chi(1) = 1080, p_{adj} < 0.001$). Participants moved their eyes 18° less with a memory load compared to without. The type of load mattered: participants with a verbal load moved their eyes 2° further over the course of a trial than participants with a visual load ($\chi(1) = 19.04, p_{adj} < 0.001$).

The two measures of the spread of fixations through the scene reflected the same pattern. Participants with a memory load fixated less of the scene than participants without a memory load ($\chi(1) = 981.5, p_{adj} < 0.001$) and their fixations were less dispersed through the scene ($\chi(1) = 3505, p_{adj} < 0.001$). The type of load again influenced participants' eye movement behavior: participants in the visual memory load condition fixated less of the scene ($\chi(1) = 22.1, p_{adj} < 0.001$) than participants in the verbal load condition. A visual load also led to less dispersed fixations ($\chi(1) = 545.7, p_{adj} < 0.001$) than a verbal load (Figure 2).

Figure 2. Spread of participants' fixations through scenes in the four scene-viewing conditions. Blue points represent individual fixations.

Working Memory Measures

Participants in the dual-task experiment performed well on both the visual (accuracy $M = 71.18\%$, $SD = 10.09$) and verbal ($M = 76.65\%$, $SD = 8.92$) memory tasks. The difference in performance was significant ($t(94) = -2.813$, $p = 0.006$), suggesting that the verbal WM task was easier than the visual task.

To assess whether participants' WM performance was influenced by the concurrent scene-viewing task, a separate group of 48 participants completed just the WM tasks, with no intervening scene. Their performance on the visual ($M = 72.66\%$, $SD = 8.72$) and verbal ($M = 76.04\%$, $SD = 9.86$) WM tasks were statistically similar to dual task performance (visual: $t(94) = 0.767$, $p = 0.445$; verbal: $t(94) = 0.316$, $p = 0.752$). Whereas the memory task influenced eye movement behavior in the scene task, the free-viewing task did not significantly affect memory task performance.

General Discussion

In this study, participants viewed scenes while maintaining a WM load or with no WM load. The WM load was visual (remember 5 colors) or verbal (remember 7 letters). We saw profound differences in how overt attention moved through scene stimuli when participants maintained a memory load, regardless of the load modality. A working memory load influenced when participants moved their eyes (fixation durations) and where they moved them (saccade amplitudes, scan paths, percent fixated, dispersion; Figure 2). We found no differences between dual- and single-task performance on the WM tasks.

Effects of Working Memory Load on Eye Movements

Previous work has shown that visual WM and eye movement control are closely linked (e.g., Bahle, Beck, & Hollingworth, 2018; Cronin & Irwin, 2018; Irwin, 1991, 1992; Hollingworth & Luck, 2008; Hollingworth, et al., 2008; Tas, Moore, & Hollingworth, 2012). Given this literature, it is unsurprising that

scene viewing was impaired by a visual WM load in the present study. However, it is surprising that a *verbal* memory load also interfered with scene viewing.

Verbal WM tasks are frequently used as control conditions in studies of visual WM: either as a non-visual secondary task or for articulatory suppression. Our results call into question the use of verbal tasks as a control for studies of attention and visual WM: the verbal task may affect the baseline patterns of eye movement behavior despite relying on a different subsystem of WM.

Recently, the long-held assumption of independent verbal and visual WM subsystems has been challenged. Many studies have found interference between concurrent visual and verbal WM tasks (Allen, Baddeley, & Hitch, 2006; Hardman, Vergauwe, & Ricker, 2017; Makovski, Shim, & Jiang, 2006; Morey & Beiler, 2013; Morey & Cowan, 2004; Ricker, Cowan, & Morey, 2010; Sauls & Cowan, 2007; Vergauwe, Barrouillet, & Camos, 2010), including evidence that verbal WM contents can influence visual attention (Soto & Humphreys, 2007, 2008). Given that making an eye movement places a load on visual WM (e.g., Cronin & Irwin, 2018; Hollingworth, et al., 2008; Tas, et al., 2016), the results of the present study are consistent with this growing literature.

Bae and Luck (2018) proposed an explanation for the discrepancy between the classic understanding of WM structure and the recent evidence of verbal-visual interference. They suggest the verbal and visual subsystems are indeed distinct at the storage level, but the control mechanisms governing their allocation are shared. These control mechanisms may be the source of visual-verbal interference. Rephrased in terms of our verbal load condition, this proposal suggests the eye movements made during free-viewing (governed by visual WM) and the verbal load task share a common, modality-free control mechanism.

An alternative explanation for our eye movement results is that participants were less engaged in the free-viewing task when they had to simultaneously maintain a WM load. When attention is focused on internal information (i.e., a working memory load), attention to external information suffers

(Kiyonaga & Egner, 2013; Buetti & Lleras, 2016). Further, when engagement is high in a given task, changes to or onsets of task-unrelated stimuli go unnoticed (e.g., Fougne & Marois, 2007; Mack & Rock, 1998; Most et al., 2001; Neisser, 1979; Neisser & Becklen, 1975; Simons & Chabris, 1999). Here, participants may have been relatively insensitive to the scene stimuli while maintaining a WM load. The similar WM performance under dual- and single-task conditions fits with this interpretation, as does the difficulty level of our two WM tasks: the verbal task was slightly easier than the visual task, and impeded eye movements less. However, task difficulty does not necessarily equate to task-engagement (Buetti & Lleras, 2016).

Effects of Eye Movements on Working Memory Load

Regardless of the source of the eye movement differences between conditions in our study, it is interesting and surprising that visual WM performance was the same under dual- and single-task conditions. Recent evidence suggests that the saccade target is automatically and obligatorily placed in visual WM, overwriting other items already in memory (Cronin & Irwin, 2018; Hollingworth, et al., 2008; Tas et al., 2016). The present results contrast with that finding. Participants maintaining a visual WM load during free-viewing made around 7 eye movements during the 3.5 second memory delay period. However, their performance on the WM task was comparable to participants' who were not concurrently engaged in scene viewing. We find no evidence that participants' eye movements under dual-task conditions impaired their WM performance. Future work should explore the conditions under which eye movements rely on visual WM and the conditions under which they do not.

Conclusions

Our results suggest visual *and* verbal WM loads impede normal scene viewing behavior, influencing both the timing and spread of eye movements through a scene. This finding calls into question the use of verbal WM tasks and/or articulatory suppression as an effective control condition for visual WM tasks and contributes more evidence that the visual and verbal subsystems of working

memory are less distinct than previously thought. Our results also suggest eye movements may not necessarily tax visual WM, a stark contrast to the standing assumptions about the relationship between visual WM and overt attention.

Open Practices Statement

Data and materials for this experiment are available upon request. This experiment was not preregistered.

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, 298-313.
<https://doi.org/10.1037/0096-3445.135.2.298>
- Anliker, L. (1976). Eye movements: On-line measurement, analysis, and control. In R. A. Monty & J. W. Senders (Eds.), *Eye movements and psychological processes* (pp. 185-199). Hillsdale, NJ: Erlbaum.
- Awh, E., Barton, B., & Vogel, E.K. (2007). Visual Working Memory Represents a Fixed Number of Items Regardless of Complexity. *Psychological Science*, 18(7), 622-628.
- Baddeley, A.D. (1986). *Working Memory*. Oxford, UK: Clarendon.
- Baddeley, A.D. & Hitch, G.J. (1974). Working memory. In G.H. Bower (Ed.), *The Psychology of Learning and Motivation* (Vol. VIII, pp. 47-90). New York, NY: Academic Press.
- Bae, G.-Y. & Luck, S.J. (2018). What happens to an individual visual working memory representation when it is interrupted? *British Journal of Psychology*, 110, 268-287. doi:10.1111/bjop.12339
- Bahle, B., Beck, V. M., & Hollingworth, A. (2018). The architecture of interaction between visual working memory and visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, 44, 992-1011.
- Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, 67(1), 1-48. doi:10.18637/jss.v067.i01.
- Bays, P.M., Husain, M. (2008) Dynamic shifts of limited working memory resources in human vision. *Science*, 321, 851–854.
- Bays, P.M., Catalao, R.F.G., & Husain, M. (2009). The precision of visual working memory is set by allocation of a shared resource. *Journal of Vision*, 9(7). doi: 10.1167/9.10.7.
- Beck V.M., Hollingworth, A. & Luck, S.J. (2012). Simultaneous control of attention by multiple working

- memory representation. *Psychological Science*, 23, 887-898.
<https://doi.org/10.1177/0956797612439068>
- Buetti, S. & Lleras, A. (2016). Distractibility is a function of engagement, not task difficulty: evidence from a new oculomotor capture paradigm. *Journal of Experimental Psychology: General*, 145(10), 1382-1405. doi: 10.1037/xge0000213
- Castelhano, M. S., Mack, M., & Henderson, J. M. (2009). Viewing task influences eye movement control during active scene perception. *Journal of Vision*, 9(3):6, 1-15.
- Cowan, N. (2005). Working memory capacity. New York: Psychology.
- Cronin, D.A., & Irwin, D.E. (2018). Visual working memory supports perceptual stability across saccadic eye movements. *Journal of Experimental Psychology: Human Perception and Performance*, 44(11), 1739-1759. <http://dx.doi.org/10.1037/xhp0000567>
- Downing, P. E. (2000). Interactions between visual working memory and selective attention. *Psychological Science*, 11, 467– 473.
- Fougnie, D. & Marois, R. (2007). Executive working memory load induces inattention blindness. *Psychonomic Bulletin, & Review*, 14(1), 142-147.
- Fukuda, K., Awh, E., & Vogel, E.K. (2010). Discrete capacity limits in visual working memory. *Current Opinion in Neurobiology*, 20(2), 177-182.
- Hardman, K. O., Vergauwe, E., & Ricker, T. J. (2017). Categorical working memory representations are used in delayed estimation of continuous colors. *Journal of Experimental Psychology: Human Perception and Performance*, 43, 30– 54. <https://doi.org/10.1037/xhp0000290>
- Hollingworth, A. & Luck, S.J. (2009). The role of visual working memory in the control of gaze during visual search. *Attention, Perception, & Psychophysics*, 71(4), 936-949. doi: 10.3758/APP.71.4.936
- Hollingworth, Matsukura, & Luck, (2013a). Visual working memory modulates rapid eye movements to simple onset targets. *Psychological Science*, 24(5), 790-796.

- Hollingworth, A., Matsukura, M., & Luck, S. J. (2013b). Visual working memory modulates low-level saccade target selection: Evidence from rapidly generated saccades in the global effect paradigm. *Journal of Vision*, 13(13):4, 1-18.
- Hollingworth, A., Richard, A. M., & Luck, S. J. (2008). Understanding the function of visual short-term memory: Transsaccadic memory, object correspondence, and gaze correction. *Journal of Experimental Psychology: General*, 137, 163-181.
- Irwin, D. E. (1992a). Memory for position and identity across eye movements. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 18, 307–317.
- Irwin, D. E. (1992b). Perceiving an integrated visual world. In D. E. Meyer & S. Kornblum (Eds.), *Attention and performance XIV: Synergies in experimental psychology, artificial intelligence, and cognitive neuroscience* (pp. 121–142). Cambridge, MA: MIT Press.
- Kiyonaga, A. & Egner, T. (2013). Working memory as internal attention: Toward an integrative account of internal and external processes. *Psychonomic Bulletin, & Review*, 20(2), 228-242.
<https://doi.org/10.3758/s13423-012-0359-y>
- Luck, S. J., & Vogel, E. K. (1997). The capacity of visual working memory for features and conjunctions. *Nature*, 390, 279– 281. <https://doi.org/10.1038/36846>
- Mack, A. & Rock, I. (1998). *Inattentional Blindness*. Cambridge, MA, US: The MIT Press.
- Miller, G.A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, 63, 81–97.
- Most, S.B., Simons, D.J., Scholl, B.J., Jimenez, R., Clifford, E., et al. (2001). How not to be seen: The contribution of similarity and selective ignoring to sustained inattentional blindness. *Psychological Science*, 12(1), 9-17.
- Makovski, T., Shim, W. M., & Jiang, Y. V. (2006). Interference from filled delays on visual change detection. *Journal of Vision*, 6, 1459–1470. <https://doi.org/10.1167/6.12.11>

Morey, C. C., & Bieler, M. (2013). Visual short-term memory always requires general attention.

Psychonomic Bulletin & Review, 20, 163–170. <https://doi.org/10.3758/s13423-012-0313-z>

Morey, C.C. & Cowan, N. (2004). When visual and verbal memories compete: Evidence of cross-domain

limits in working memory. *Psychonomic Bulletin & Review*, 11(2), 296-301.

<https://doi.org/10.3758/BF03196573>

Neisser, U. (1979). The control of information pickup in selective looking, in *Perception and its*

Development: A Tribute to Eleanor J Gibson. In: Pick A.D., editor. Hillsdale, NJ: Lawrence Erlbaum Associates. pp. 201-219.

Neisser, U. & Becklen, R. (1975). Selective looking: Attending to visually specified events. *Cognitive*

Psychology, 7, 480-494. doi: 10.1016/0010-0285(75)90019-5.

Pashler, H. (1988). Familiarity and visual change detection. *Perception & Psychophysics*, 44, 369 –378.

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for

Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.

Ricker, T. J., Cowan, N., & Morey, C. C. (2010). Visual working memory is disrupted by covert verbal

retrieval. *Psychonomic Bulletin & Review*, 17, 516– 521. <https://doi.org/10.3758/PBR.17.4.516>

Saults, J. S., & Cowan, N. (2007). A central capacity limit to the simultaneous storage of visual and

auditory arrays in working memory. *Journal of Experimental Psychology:*

General, 136, 663– 684. <https://doi.org/10.1037/0096-3445.136.4.663>

Schmidt, B.K., Vogel, E.K., Woodman, G.F., & Luck, S.J. (2002). Voluntary and automatic attentional

control of visual working memory. *Perception & Psychophysics*, 64(5), 754-763.

Simons, D.J. & Chabris, C.F. (1999). Gorillas in our midst: sustained inattention blindness for dynamic

events. *Perception*, 28(9), 1059-1074.

Smith, E.E., Jonides, J., & Koeppe, R.A. (1996). Dissociating verbal and spatial working memory using PET.

Cerebral Cortex, 6(1), 11-20.

- 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. (2006). Seeing the content of the mind: Enhanced awareness through working memory in patients with visual extinction. *Proceedings of the National Academy of Sciences, USA*, 103, 4789–4792.
- Soto, D., & Humphreys, G.W. (2007). Automatic guidance of visual attention from verbal working memory. *Journal of Experimental Psychology: Human Perception and Performance*, 33(3), 730-757. doi: 10.1037/0096-1523.33.3.730
- 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.
- Tas, A. C., Luck, S. J., & Hollingworth, A. (2016). The relationship between visual attention and visual working memory encoding: A dissociation between covert and overt orienting. *Journal of Experimental Psychology: Human Perception and Performance*, 42, 1121-1138.
- Van der Stigchel, S., & Hollingworth, A. (2018). Visuo-spatial working memory as a fundamental component of the eye movement system. *Current Directions in Psychological Science*, 27, 136-143.
- Vergauwe, E., Barrouillet, P., & Camos, V. (2010). Do mental processes share a domain-general resource? *Psychological Science*, 21, 384–390. <https://doi.org/10.1177/0956797610361340>
- Wilken, P. & Ma, W.J. (2004). A detection theory account of change detection. *Journal of Vision*, 4, 1120–1135.