

50TH ANNIVERSARY ARTICLE

How Attention and Working Memory Married and Divorced, With *Journal of Experimental Psychology: Human Perception and Performance* as the Witness

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How do we find stuff that we are looking for? This question has been central to many a study in *Journal of Experimental Psychology: Human Perception and Performance*. We describe how seminal studies in the journal eventually led to the hypothesis that top-down attentional guidance and visual working memory activation might be regarded as one and the same process. However, crucial tests revealed a more complex picture, raising important new questions about potential functional divisions within working memory, and how these should be characterized. This contributed to wider debates within the journal on what is the capacity of top-down attention, how we ignore stuff that is irrelevant, and how we switch between sensory and mnemonic representations—debates that still call for resolution.

Public Significance Statement

How do we find stuff that we are looking for? Over the past 50 years, the *Journal of Experimental Psychology: Human Perception and Performance* has been the home of many seminal studies on how memory and vision interact to find objects of interest.

Keywords: visual attention, visual working memory, visual search, attentional set, attentional template

About 20 years ago, each of our labs almost simultaneously but independently published a study in the *Journal of Experimental Psychology: Human Perception and Performance* (JEP:HPP), addressing the exact same question, using virtually the same paradigm, but with rather opposite findings and conclusions. Naturally, our work was heavily influenced by earlier studies, many of which also appeared in JEP:HPP. What follows here is not a full review, but a rendering of

JEP:HPP's history that inspired our work, and the scientific debates to which the journal contributed so much afterward.

We were interested in how top-down, feature-based attention works. The 1980s and 1990s were characterized by an upsurge of studies on visual search, where observers try to find a relevant target object, defined by a feature (often color, shape, orientation, or a combination thereof), among irrelevant distractors. While important work focused on stimulus characteristics (e.g., Theeuwes & Burger, 1998; Treisman, 1991; Yantis & Jonides, 1984), others wondered how attention is guided toward task-relevant objects. Wolfe et al. (1989) introduced their seminal Guided Search model, which assumed that the brain upregulates target features over nontarget features. Folk et al. (1992, 1994) provided direct evidence for this, showing that attentional orienting depends on a feature match with what one is looking for. Treisman and Sato (1990) had just revised her influential feature integration theory, proposing that target selection is aided by the inhibition of distractor features. While these studies provided clear evidence for feature-based modulations, the question what kind of representation underlies “what one is looking for” remained open.

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One influential answer came from the field of neuroscience, which back then only started to make its way into mainstream human cognition research. A seminal monkey study by Chelazzi et al. (1993) provided the first evidence that visual working memory (VWM) might provide the means by which top-down selection is driven. The monkeys were trained to memorize an object (the cue), and then search for that object in a subsequent display. Importantly, neurons in inferior temporal cortex that were selectively active in response to the cue sustained their activity during the blank delay period between cue and target display. The same neurons then also responded to the target in the search display. This carried a tantalizing promise of a conceptual integration of VWM and top-down attention, where all that is needed to guide attention to a relevant property is to activate that property in VWM, by recruiting the exact same neurons responsible for the percept itself—an idea that later became popular as the sensory recruitment hypothesis (Serences, 2016). Such integration was further supported by capacity estimates of three to four items emerging for both VWM and attention tasks (e.g., Dehaene & Cohen, 1994; Palmer, 1990; Shibuya & Bundesen, 1988; Trick & Pylyshyn, 1993; Vogel et al., 2001; Yantis & Johnson, 1990).

The first evidence that VWM content indeed automatically biases visual attention arrived in the spatial domain, when Awh et al. (1998) observed improved stimulus detection for locations held in VWM. But the same prediction should also hold for feature memory, and this is what each of our labs sought to test (Houtkamp & Roelfsema, 2006; Olivers et al., 2006; Soto et al., 2005; Woodman & Luck, 2007). We all asked our participants to memorize a visual feature or object for a test at the end of the trial. We then asked them to perform a visual search task in between, for which the memory was actually not relevant, but could return as a distractor.¹ If VWM activation indeed automatically drives attention, then memory-matching distractors should interfere more than nonmatching distractors. The results could not have been more equivocal though: Two of the four studies observed clear and robust positive memory-driven attentional biases (Olivers et al., 2006; Soto et al., 2005). The other two clearly did not or even observed less interference from memory (Houtkamp & Roelfsema, 2006; Woodman & Luck, 2007).

This presented a puzzle. How could a VWM representation be sufficient to drive attention in some cases but not others? Some of us teamed up (Olivers et al., 2011) and, inspired by earlier work (Cowan, 2001; Oberauer, 2002), proposed a functional division within VWM, where an active representation is allowed to interact with the sensory input, while activity-silent memories are shielded from that input—with each state having a different capacity. This contributed to an extensive debate—largely conducted in *JEP: HPP* and still not fully resolved—on whether or not people can actively look for more than one thing at a time (Bahle et al., 2018; Beck & Hollingworth, 2017; Grubert & Eimer, 2013, 2016; Hamblin-Frohm & Becker, 2019; Hollingworth & Beck, 2016; Irons et al., 2012; Kerzel & Witzel, 2019; Menneer et al., 2019; Stroud et al., 2011; van Moorselaar et al., 2014; Williams et al., 2022). Furthermore, the paradigm we used required observers to ignore the memorized feature during the search, raising the question whether observers may be able to proactively suppress known distractors. Existence and workings of such suppression are also still subject of a wider debate, with again a major role for *JEP: HPP* (e.g., Arita et al., 2012; Beck & Hollingworth, 2015; Gaspelin & Luck, 2018; Han & Kim, 2009). Some resolution may lie in

evidence that observers are first biased toward announced distractors, followed by a bias away (Klink et al., 2023; Moher & Egeth, 2012), a phenomenon famously coined in *JEP: HPP* as the “attentional white bear” (Tsal & Makovski, 2006). Recent evidence suggests that these two biases act independently (Beck et al., 2018). Whether or not memory-related attentional capture occurs may be thus determined by the specific temporal dynamics of the search, but this remains to be thoroughly investigated. Finally, there is also an important role for overall task coordination that is still not fully understood, in particular mechanisms that allow observers to switch between attention directed to the external sensory world, and attention directed to internal memory (e.g., Verschooren et al., 2019, 2020).

While the integration of feature-based attention and VWM was an attractive idea as such, and the two concepts clearly do share important mechanisms, the evidence suggests a functional division between memories that interact with the sensory input that those that do not. How this functional division exactly works still raises important unresolved questions. What distinguishes these functional states? What allows one memory to find stuff and another memory to ignore things? How is the transition from one functionality to another controlled? We call upon new generations of researchers to help us find the answers.

¹ In some studies also as a target, but for the current purpose we limit treatment to distractors.

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