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Spotlight Commentary

Can working memory be non-conscious?

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Abstract

Working memory (WM) is closely linked to conscious awareness: In most conceptions of WM, the inputs to WM need to be conscious. The findings of some recent studies, however, have been taken to suggest that WM can indeed operate on non-conscious inputs. Here, we argue that these findings can easily be accommodated by conventional conceptions of non-conscious perception and conscious WM. We conclude that these studies do not provide conclusive evidence for non-conscious WM. It is thus too early to dismiss the traditional view of a tight link between WM and conscious awareness.

Key words: working memory; consciousness; conscious awareness; non-conscious perception

Working memory (WM) is a concept widely used in psychology and cognitive neuroscience to describe the short-term storage and transformation of information that is not currently present in the environment. A prime example of WM function is remembering a phone number by continuously rehearsing the digit. WM is thought to be involved in most of our everyday activities, such as preparing one's own contribution to a debate while following the other discussants and incorporating their arguments. Thus, WM corresponds well to our everyday phenomenology of 'keeping in mind' some information over a short period of time. From this phenomenology, it seems clear that WM is intricately interwoven with conscious awareness. It is difficult to imagine a situation in which we are not consciously aware of the stimuli that enter WM. Indeed, prominent conceptions of WM and consciousness propose that all WM operations, from input to recall, are conscious (Baars and Franklin, 2003), and that WM provides the global workspace for conscious awareness (Baddeley, 2003). This notion of a tight mesh between WM and conscious awareness has recently been challenged by a series of studies suggesting that WM can operate on non-conscious input (Bergström and Eriksson, 2014, 2015; Dutta *et al.*, 2014; Soto *et al.*, 2011). As these studies call for a revision of our understanding of both WM and consciousness (Soto and Silvanto, 2014), here we critically revisit and evaluate their approach, methodology, and implications.

The general paradigm used to provide evidence for non-conscious WM is illustrated in Fig. 1: A memory cue, such as an oriented grating or a letter, is presented with low visibility, e.g. through backward masking. Following a delay period (usually between 1.4 and 15 s, sometimes filled with visible distractors), a probe is presented and participants provide both a performance-based, objective response (e.g. indicate orientation of the probe relative to the memory cue) as well as a subjective rating of their awareness of the memory cue (e.g. perceptual awareness scale; Overgaard *et al.*, 2010). Evidence for non-conscious WM has been inferred from a dissociation between the subjective and the objective measure: In those trials in which participants reported no subjective awareness of the memory cue (the subjective, appearance-based measure), they showed above-chance performance in the memory test (the objective, performance-based measure). For example, in a subset of trials in which participants indicated not having seen the memory cue, they were nevertheless better than chance in evaluating whether the probe was tilted clockwise or counterclockwise relative to the memory cue (Soto *et al.*, 2011). This dissociation between the objective and the subjective measure was taken to imply that observers encoded a non-conscious input in WM for later use in the memory test, thereby challenging the notion that inputs to WM need to be conscious (Baars and Franklin, 2003).

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However, such dissociations between objective and subjective measures are common in studies on the perception of low-visibility stimuli and do not need to reflect non-conscious WM. Subjective ratings of stimulus visibility are prone to response biases, such that observers may systematically indicate invisibility of a stimulus that they can at least partially see (Schmidt, 2015). Thus, above-chance performance in the objective measure does not provide evidence for maintenance of non-conscious stimulus information in WM, but could simply reflect residual awareness of the memory cue. Such weakly conscious information of the memory cue could have been maintained in 'conscious WM' over the delay period and then applied in the objective memory test to yield above-chance performance.

Note that even if bias-free measures of subjective awareness (Barrett *et al.*, 2013) were applied in future studies to demonstrate that observers had no subjective awareness of the memory cue, this would not provide evidence for non-conscious WM. Consider the following scenario: If observers have no subjective awareness of the memory cue, they need to guess the task-relevant property of the memory cue (e.g. the grating's orientation, or the letter's identity). If guessing performance were above chance while a bias-free measure of subjective awareness were at chance, this would represent evidence for blindsight-like non-conscious perception (e.g. Kunimoto *et al.*, 2001; but see Peters and Lau, 2015). However, evidence for non-conscious perception does not entail evidence for non-conscious WM. Even with an additional delay period between the memory cue and the memory test, non-conscious perception and conscious WM are sufficient to account for objective-subjective dissociations. Non-conscious perception would result in the conscious representation of a guess, and this guess would be maintained in conscious WM during the delay period, until it would be applied in the objective memory test. Thus, there is no need to invoke an additional process of non-conscious WM to account for dissociations between objective and subjective measures of awareness.

Therefore, to provide evidence for non-conscious WM, above-chance performance in the memory test needs to be accompanied by null sensitivity for the memory cue. Although this situation seems unlikely to occur in practice, two studies indeed claimed to have demonstrated such a dissociation between memory performance and objectively assessed awareness of the memory cue (Dutta *et al.*, 2014; Soto *et al.*, 2011). In these studies, a memory cue was presented in only 50% of the trials. For the critical analyses, only those trials in which participants indicated no subjective awareness of the memory cue were included. The proportion of trials in which the memory cue was present was then compared with the proportion of trials in which the memory cue was absent. The underlying reasoning is that if participants could not discriminate between the presence and the absence of the memory cue, both trial types should similarly often be categorized as yielding no subjective awareness. However, although the metric for comparing these proportions has been labeled 'd'' in these studies, these analyses are not grounded in signal detection theory, where d' is the most commonly used bias-free measure of detection sensitivity. The pseudo-d' computed in these studies on non-conscious WM is not invariant to bias, but varies depending on the observer's response criterion, and tends to underestimate actual sensitivity for conservative observers (Fig. 2; see Online Supplementary Material for detailed analyses). Thus, because the metric used in these studies does not represent a valid measure of bias-free detection sensitivity, evidence for a dissociation between memory performance and objectively assessed awareness of the memory cue is lacking.

In summary, the studies covered in our mini-review do not provide conclusive evidence for non-conscious WM. Findings of above-chance memory test performance in the absence of subjective awareness of the memory cue can be explained by blindsight-like non-conscious perception and the maintenance of a

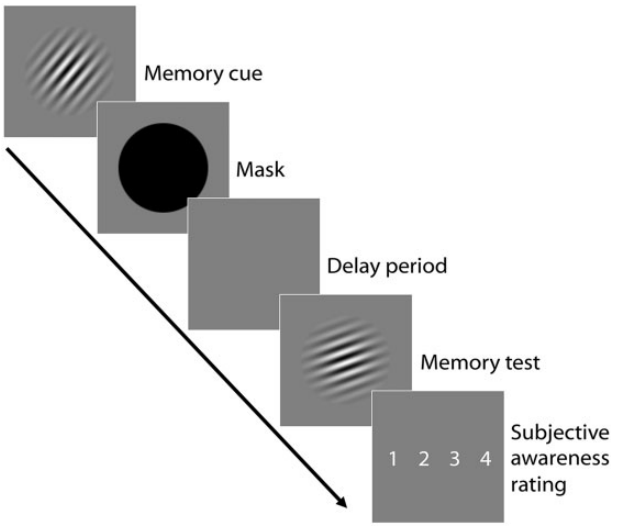

Figure 1. Illustration of an example paradigm used to demonstrate non-conscious WM (cf. Soto *et al.*, 2011, Experiment 1). A memory cue (e.g. an oriented grating) is presented with low visibility, e.g. through backward masking. Following a delay period (usually between 1.4 and 15 s, sometimes filled with visible distractors), participants provide a performance-based, objective response to the visible memory test (e.g. indicate orientation relative to the memory cue) and a subjective rating of their awareness of the memory cue.

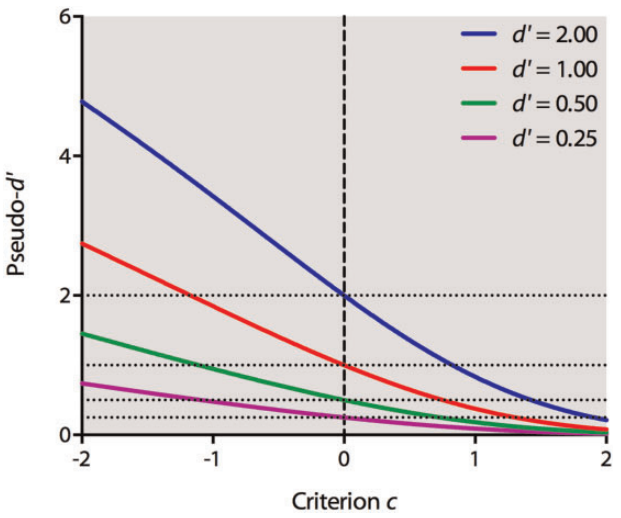

Figure 2. The new index (pseudo-d') used by the two studies on non-conscious WM (Dutta *et al.*, 2014; Soto *et al.*, 2011) to estimate detection sensitivity, plotted for different values of actual d' as a function of response criterion c. The dotted lines represent standard d'. Pseudo-d' varies with the response criterion (see Online Supplementary Material for details). Thus, in contrast to actual d' the new index pseudo-d' does not represent a bias-free measure of detection sensitivity. For relatively conservative observers (positive values of the response criterion c) pseudo-d' underestimates true sensitivity.

guess in conscious WM, without the need to invoke non-conscious WM processes. To provide conclusive evidence for the existence of non-conscious WM processes, null sensitivity for the memory cue needs to be demonstrated with objective, performance-based measures. However, evidence for above-chance memory test performance in the absence of objectively assessed sensitivity for the memory cue is still lacking. Thus, although these recent studies on non-conscious WM opened an exciting new avenue for research on the interplay between consciousness and WM, it would be premature to revise our current understanding of a tight link between WM and conscious awareness.

Supplementary data

Supplementary data are available at *NCONCC Journal* online.

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Conflict of interest statement. None declared.

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