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Subjective aspects of working memory performance: Memoranda-related imagery

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ABSTRACT

Although it is well accepted that working memory (WM) is intimately related to consciousness, little research has illuminated the liaison between the two phenomena. To investigate this under-explored nexus, we used an *imagery monitoring task* to investigate the subjective aspects of WM performance. Specifically, in two experiments, we examined the effects on consciousness of (a) holding in mind information having a low versus high memory load, and (b) holding memoranda in mind during the presentation of distractors (e.g., visual stimuli associated with a response incompatible with that of the memoranda). Higher rates of rehearsal (conscious imagery) occurred in the high load and distractor conditions than in comparable control conditions. Examination of the temporal properties of the rehearsal-based imagery revealed that, across subjects, imagery events occurred evenly throughout the delay. We hope that future variants of this new imagery monitoring task will reveal additional insights about WM, consciousness, and action control.

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1. Introduction

Perhaps no mental operation is as consistently coupled with conscious processing as is working memory (WM; Baddeley, 2007; LeDoux, 2008). (WM has been defined as a temporary, capacity-limited storage system under attentional control that is used to intentionally hold, and manipulate, information in mind; Baddeley, 1986, 2007.) It is obvious to the scientist and nonscientist alike that when one tries to hold or manipulate information that is not furnished by the external world, one's conscious mind seems to be occupied almost entirely with the task at hand (James, 1890). For instance, when holding a to-be-dialed telephone number in mind (or gargling with mouthwash for 30 s), action-related mental imagery occupies one's conscious mind till the number is dialed (Paivio, 1979). While many sophisticated processes can be carried out unconsciously (see review of unconscious processing in Morsella & Bargh, 2011), WM performance tends to be a conscious phenomenon (but see Hassin, 2005).

Apart from these quotidian observations, and despite that theorists have long noted that WM is intimately related to conscious processing (Baddeley, 2007; Gray, 2004; LeDoux, 2008; Oberauer & Hein, 2012), little empirical research has illuminated the nexus between the two phenomena. To address this gap in the literature, our experimental project—involving

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novel paradigms, predictions, and dependent measures—serves as a first step to investigate the interrelations between these two multifaceted phenomena. Before describing our synthesis of the two areas of research and delineating our experimental project, it is helpful to first survey the challenges and advances associated with the study of the most complicated of the two phenomena: conscious processing.

1.1. The nature of conscious processing

How events in the nervous system give rise to our subjective experiences—the experience of pain, of afterimages, or of actively holding a telephone number in mind—remains one of the greatest puzzles in science (Roach, 2005). Subjective experience, also referred to as 'sentience' (Pinker, 1997), 'phenomenal state' (Tye, 1999), 'qualia' (Gray, 2004), and 'consciousness of the most basic kind' (Chalmers, 1996; Merker, 2007), has perhaps been best defined by the philosopher Thomas Nagel (1974), who proposed that an organism possesses subjective experiences if there is *something it is like* to be that organism—something it is like, for example, to be human and experience pain, love, or breathlessness. Similarly, Block (1995) claimed, '"the phenomenally conscious aspect of a state is what it is like to be in that state"' (p. 227). The scientific enigma of how consciousness stems from brain processes, often referred to as the 'mind–body' problem, the 'explanatory gap' (Levine, 1983), or the 'hard problem' of consciousness (Chalmers, 1995), is more intractable than what the non-specialist may surmise. Regarding this puzzle, not only do researchers not have a clue regarding how subjective experience arises from the nervous system, they do not even possess an inkling about how consciousness could arise from any set of real (or even hypothetical) circumstances (Godwin, Gazzaley, & Morsella, 2013). For this and other reasons (cf., Chalmers, 1996), some of the greatest scientific minds, including Nobel Laureates Leon Cooper, Francis Crick, Gerald Edelman, Eric Kandel, and Charles Sherrington, have concluded that the puzzle of consciousness may be the greatest mystery in science.

Over the last four decades, progress regarding this puzzle has stemmed from attempts to contrast conscious and unconscious processes in terms of their cognitive and neural correlates (e.g., Baars, 1988, 2002; Boly et al., 2011; Crick & Koch, 1995; Damasio, 1989; Dehaene & Naccache, 2001; Di Lollo, Enns, & Rensink, 2000; Doesburg, Green, McDonald, & Ward, 2009; Gray, 2004; Grossberg, 1999; Kinsbourne, 1996; Laureys, 2005; Libet, 2004; Logothetis & Schall, 1989; Merker, 2007; Morsella, 2005; Shallice, 1972; Wegner & Bargh, 1998). (For a review regarding the conclusions of this contrast, see Godwin et al., 2013.) To examine this contrast, researchers have focused primarily on perceptual processing (cf., Crick & Koch, 2003). This research has led to several insights about conscious processing (see review in Koch, 2004), including the differences in the brain between supraliminal stimuli (i.e., stimuli that are consciously-perceptible) and subliminal stimuli (i.e., stimuli that are consciously-imperceptible; Dehaene & Naccache, 2001; Doesburg et al., 2009; Koch, 2004; Logothetis & Schall, 1989; Roser & Gazzaniga, 2004); and the nature of the unconscious processes preceding the subjective experience of a perceptual representation (Di Lollo et al., 2000; Goodhew, Dux, Lipp, & Visser, 2012). Together, this research has revealed how, for example, an unconscious representation may become a conscious one. It has been determined that such a transition is influenced by processes that (a) are 'bottom-up' (e.g., stimulus salience, motion, novelty, incentive and emotional quality, etc.; Gazzaley & D'Esposito, 2007), (b) attentional (cf., Most, Scholl, Clifford, & Simons, 2005), (c) activation-dependent (i.e., how activated a representation is; Kinsbourne, 1996), or (d) associated with future tasks (Morsella, Ben-Zeev, Lanska, & Bargh, 2010).

1.2. Limitation of current approaches

The majority of the paradigms employed to study consciousness (e.g., backward masking and binocular rivalry) involve discrete events (e.g., the presentation of a stimulus) and punctate acts (e.g., pressing a button) that are executed quickly. In such a scenario, minimal demands are made on WM. However, many forms of cognitive control and behavioral control ('control,' for short) in everyday life, such as holding one's breath or the less dramatic example of gargling strong mouthwash for 30 s, are not fleeting, short-lived events, but events that unfold over time and make demands on WM, by requiring one to hold in mind intended action goals (e.g., to not expel the mouthwash before 30 s; Hommel & Elsner, 2009). In everyday life, seldom is control driven wholly by representations activated only by external stimuli. Many controlled behaviors are guided by representations that are generated internally (Miller, Galanter, & Pribram, 1960; Neisser, 1976).

One difference between representations that are activated by external stimuli and representations that are activated internally is that the latter are usually more effortful (Farah, 2000). Accordingly, there is a performance benefit of having external stimuli sustain (or 'scaffold'; Hoover & Richardson, 2008) the activation of internal representations. This notion is consistent with research suggesting that mental control can be influenced by the external stimuli composing one's current environment (Levine, Morsella, & Bargh, 2007; Morsella & Miozzo, 2002). In such a situation, external stimuli can activate action-related *sets* (Levine et al., 2007; Morsella, Larson, Zarolia, & Bargh, 2011) that can help participants hold information in mind, making the world a kind of 'external memory' (O'Regan, 1992), to which some of the burden of mental control can be relegated (Arkin, 1998; Brooks, 1991; Clark & Chalmers, 1998; Hoover & Richardson, 2008). Thus, perceptual stimuli arising from the external world (or from even one's own body) can be used as cues that facilitate mental control and cognitive processing more generally (Ballard, Hayhoe, Pook, & Rao, 1997; Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001; Morsella & Krauss, 2004).

Thus, sustaining the activation of internally generated representations is an effortful process, requiring top-down activation to strengthen some mental contents (e.g., the action goal) over others (e.g., task-irrelevant stimulation). This process is a

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