Consciousness and Cognition 25 (2014) 88–100

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

Subjective aspects of working memory performance: Memoranda-related imagery

Tiffany K. Jantz [a], Jessica J. Tomory [a], Christina Merrick [a], Shanna Cooper [a], Adam Gazzaley [b,c], Ezequiel Morsella [a,c,*]

[a] Department of Psychology, San Francisco State University, United States
[b] Departments of Psychiatry and Physiology, University of California, San Francisco, United States
[c] Department of Neurology, University of California, San Francisco, United States

ARTICLE INFO

Article history:
Received 18 May 2013

Keywords:
Working memory
Consciousness
Mental imagery
Cognitive control
Refreshing

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.

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

* Corresponding author at: Department of Psychology, San Francisco State University (SFSU), 1600 Holloway Avenue, EP 301, San Francisco, CA 94132-4168, United States.
E-mail address: morsella@sfsu.edu (E. Morsella).

http://dx.doi.org/10.1016/j.concog.2014.01.013
1053-8100/

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 special case of 'rehearsing' (Johnson & Johnson, 2009), the executive component process in WM that maintains activation of a just-seen or just-heard representation (Raye, Johnson, Mitchell, Greene, & Johnson, 2007). Specifically, rehearsing is a deliberate, controlled process of thinking of, or foregrounding, the representation of multiple contents (e.g., a telephone number) or percepts repeatedly over a delay (Johnson & Johnson, 2009).

1.3. Working memory-based control

From our standpoint, many everyday cases of control are actually instances of *WM-based control* in which one effortfully holds in mind an action goal (e.g., through rehearsal) while overcoming performance deficits from interference. Specifically, control often includes a *delayed action phase*, in which one keeps an action goal in mind but does not express it, as when rehearsing a telephone number (Curtis & D'Esposito, 2003, 2009). This WM-related phase is then followed by an *action production phase*, in which the action goal is realized motorically (e.g., dialing the telephone number). Regarding the relationship between consciousness and the delayed action phase, recent theoretical developments have revealed that WM during the delay is intimately related to both consciousness and action control (Jordan, 1998, 2009; LeDoux, 2008; Oberauer & Hein, 2012), as is evident in the title of the book *Working Memory, Thought, and Action* (Baddeley, 2007), a synthesis of WM research by one of the pioneers of this area of study.

To our knowledge, Montague, Hillix, Kiess, and Harris (1970) were the first to document participants' subjective experience of covert rehearsal, by instructing participants to press a button every time they were 'thinking' about trigrams held in mind while they completed a distractor task. Participants reported more covert rehearsal when incentivized to complete a task, but rehearsal was not related to overall memory performance. Using the same button-pressing method, Kroll and Kellicut (1972) found that participants report more covert rehearsal while completing easier distractor tasks than while completing demanding distractor tasks. The authors concluded that the button-pressing subjective report of covert rehearsal is a more accurate and sensitive measure of what participants were experiencing compared to indirect methods of altering task difficulty and assuming participants' increase in rehearsal follows suit. While this line of research laid the foundation for the study of the subjective experience of WM processes, little research has since been conducted to document the subjective aspects of WM performance.

1.4. Overview and overarching hypotheses

To begin to address this gap in the literature, we conducted a series of experiments to obtain subjective data regarding the delayed action phase of WM-based control. Specifically, to investigate the nature of action-related mental imagery during the delayed action phase of WM, we employed an *imagery monitoring task*, in which participants press a button whenever they consciously rehearse the memoranda, in combination with interference paradigms.

When examining such subjective aspects of responding, the investigator has little choice but to rely on self-report measures, which bring with them well known shortcomings (see Section 4). Despite these limitations, substantial convergent evidence from non-introspective measures corroborates participants' reports about the occurrence of conscious mental content. For example, various neuroimaging studies have revealed that the occurrence of conscious content is coupled systematically with principled brain activations (Logothetis & Schall, 1989; Mason et al., 2007; McVay & Kane, 2010; Mitchell et al., 2007; Wyland, Kelley, Macrae, Gordon, & Heatherton, 2003).

It is important to note that, because this is among the first projects to investigate imagery during WM-based action control, we entertained only a few overarching hypotheses and focused more on collecting data that would begin to illuminate this uncharted area of research. In addition to documenting the trial-by-trial subjective effects from our imagery monitoring task and interference paradigms (an important corpus of data in its own right), we took the opportunity to examine the hypothesis that, during the delay phase, participants rehearse the memoranda continuously in mind in order to perform the task successfully. We refer to this hypothesis as the *covert rehearsal* hypothesis. By measuring the imagery rates that participants experienced during the delay phase, we examined this hypothesis in Studies 1 and 2. (See Section 4 for treatment of alternative hypotheses.) More generally, we hypothesized that, for both studies, the subjective effects associated with WM are systematic, measurable, reliable, and arise from WM processing in a principled fashion. We believe that the following subjective data from this under-explored area of research can illuminate aspects of WM processing that may not be revealed in traditional dependent measures such as response times or error rates (Etkin, Prater, Hoeft, Menon, & Schatzberg, 2010; Morsella, Gray, Krieger, & Bargh, 2009).

2. Study 1

In Study 1, we investigated the amount of imagery during the delay phase of WM-based control. As mentioned above, 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 during the delayed action phase. In light of this quotidian phenomenon, we employed an imagery monitoring task to assess the frequency of imagery during the delay phase. In a fully within-subjects design (trials per participant = 60), participants were instructed to hold in mind memoranda (a series of numbers to be dialed) for a delay (11 s) and to press a button during the delay whenever they experienced imagery about the memoranda. Based on the covert rehearsal hypothesis, our primary prediction was that, during the delay, participants will rehearse the memoranda continuously to perform the task successfully.

We also took the opportunity to evaluate some secondary predictions. First, we tested whether imagery varies as a function of how much information is held in mind. In the Low Load condition (trials per participant = 30), the series was composed of only two items; in the High Load condition (trials per participant = 30), the series was composed of three times as many items (i.e., 6). (When designing the task, one of our aims was for the task to be somewhat challenging, to avoid ceiling effects in accuracy and floor effects in imagery rates.) Consistent with a *load hypothesis*, we predicted that the High Load condition would be associated with the most imagery, perhaps because of the increased rates of covert rehearsal that such a load demands: Simply put, the more that one has to hold in mind, presumably the more imagery there will be (Baddeley, 2007). We also examined the temporal dynamics (i.e., when the imagery occurs) of the imagery during the delay phase.

As this is among the first attempts to examine the subjective aspects of the delay phase, we also took the opportunity to include an established interference manipulation. Research has shown that being presented with irrelevant information (distractors) while holding information in mind can interfere with WM performance. In the well-established *similarity effect* (Baddeley, 2007), for example, distractors that are similar to memoranda introduce more interference than do dissimilar distractors. This may be because the similarity between the memoranda and distractors renders the two kinds of stimuli more confusable. With this in mind, during the delay in our paradigm, participants were presented via computer screen with the images of distractors that, with respect to the memoranda, were similar (numbers) or dissimilar (letters). Based on this classic effect, the *similarity hypothesis* predicted that there would be the most imagery reported for the Similar condition, due, perhaps, to increased rates of rehearsing in the face of interference. Because of the well-established nature of the similarity effect, this was the strongest directional hypothesis of our project.

2.1. Method

2.1.1. Participants

San Francisco State University undergraduate students ($n = 41$) participated for course credit.

2.1.2. Stimuli and apparatus

All stimuli were presented on an Apple iMac computer monitor (50.8 cm) with a viewing distance of approximately 48 cm. Responses by participants were inputted by keyboard. Stimulus presentation was controlled by PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993). Target stimuli were either 2 or 6 single digits (0–9) that were presented in blue in order to differentiate them from the distractors, which were presented in black. Each to-be-remembered target sequence was comprised of either 2 or 6 blue digits that appeared simultaneously on screen. Each distractor set was comprised of either digits (0–9) or letters (A–H, J) with the letter "I" removed because of its similarity to the number 1. All targets were presented in the center of the screen and occupied less than 3 square cm.

2.1.3. Procedure

Participants were run individually. At the beginning of the session, participants were told that they would be presented with an array of numbers in blue that, after a delay, had to be recalled at the end of each trial. Participants were instructed to indicate whenever they experienced either auditory or visual imagery of the blue target digits during the delay. Participants were given examples of mental imagery and what it means to have visual and auditory imagery. Regarding visual imagery, the onscreen instructions stated, "'*Take a moment to imagine what a tree looks like; Take a moment to imagine what a car looks like. You have just experienced an example of visual mental imagery*.'" Regarding auditory imagery, participants read, "'*Without saying it aloud, take a moment to imagine what the word 'HOUSE' sounds like. Take a moment to imagine what the word 'FLOWER' sounds like. You have just experienced an example of auditory mental imagery*.'" Participants were informed that other digits or letters would appear onscreen during the delay, but to press the button only in response to the occurrence of mental imagery about the blue digits from the beginning of the trial.

Participants completed 4 practice trials before commencing the critical trials ($n = 60$). As illustrated in Fig. 1, during each trial, a fixation (+) would appear (500 ms) in the center of the screen to direct the participant's visual attention. (Participants were instructed to attend to the fixation.) Following the fixation, blue target digits appeared simultaneously, in random locations across the screen. (Trials varied by load: 2 digits for the Low Load, 6 digits for High Load.) We distributed the digits randomly across the screen to minimize the use of 'chunking' strategies for memorizing the digits. The duration of the presentation of the array was proportional to the number of digits in the array, with 1-s of study time per item: For Low Load, the duration was 2 s; for High Load, it was 6 s. After the presentation of the target digits, there was another fixation (500 ms) followed by 14 distractor items that were presented in the center of the screen sequentially, one immediately after the other (each spanning 750 ms). Distractor items were either letters (Dissimilar condition) or digits (Similar condition). During this time, participants indicated by pressing the space bar with their left hand each moment they experienced the memoranda-related imagery. Participants were instructed to, when not pressing the spacebar, rest their fingers on, and maintain contact with, the spacebar. The total delay span was 11 s. Finally, participants were asked to "'*enter all of the blue digits that you remember from the beginning of the trial*'" using the keypad on the right-side of the keyboard. We took care to make sure that the keys that participants pressed to indicate imagery during the delay were different from those pressed to report the memoranda, so that participants would never be confused about which button to press and so that participants would not press

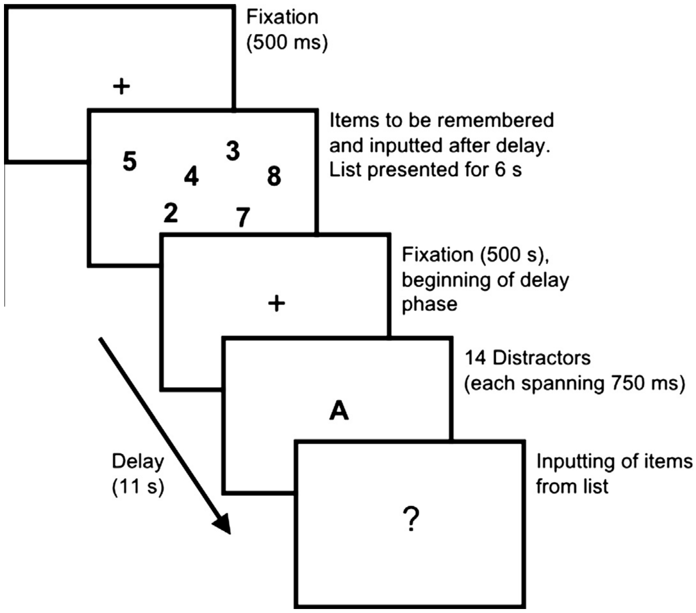

Fig. 1. Schematic illustration of the time course of a sample trial from Study 1. Not drawn to scale.

the button indicating the experience of imagery when reporting the memoranda or vice versa. All 60 trials were presented randomly. Target numbers and target locations were chosen randomly. Distractor items were chosen randomly and presented in random order.

The experimenter, who observed the entire experimental session, checked that this instruction was followed correctly on each trial. To assess participants' knowledge about the hypothesis at hand and verify aspects of their task performance, we had participants fill out a funneled debriefing form (following the procedures detailed in Bargh & Chartrand, 2000) after completing the critical trials. Specifically, participants were asked: (a) *What did you think the purpose of this experiment was?* (b) *What do you think the experiment was trying to study?* (c) *Did you have any goals or strategies used while completing this experiment? If so, please briefly describe them.* (d) *If you reported having any visual or auditory imagery (by pressing the spacebar), please describe what you experienced.* (e) *If you experienced imagery (reported by pressing the spacebar), did you experience the imagery in brief moments or did you experience it in a sustained fashion (for example, experiencing the image UN-interrupted throughout the whole trial)?* (f) *Was there anything that interfered with your performance on the task?* The data from two participants were removed from analysis because the participants did not follow instructions. Of the remaining 39 participants, only one participant did not report experiencing any mental imagery during the delay. On the other hand, 38 of the remaining 39 participants reported experiencing some memoranda-related mental imagery during the delay periods, thus lending support to the rehearsal hypothesis. The proceeding analysis includes only those 38 participants who reported experiencing mental imagery at some point during the study.

2.2. Results

2.2.1. Error rates

Regarding trial-by-trial recall performance, the mean error rate per participant was .08 (*SEM* = .01). As revealed in Table 1, Load had a main effect on error rates, $F(1,37) = 11.22$, $p = .0019$, but Similarity had no effect, $F(1,37) = .20$, $p = .66$; there was no interaction between the two factors, $p > .99$. Similar to the findings of Montague et al. (1970), covert rehearsal rate was not associated with accurate recall, $F(1,5) = 1.63$, $p = .257$.

Table 1
Descriptive statistic for conditions of Study 1.

Condition	Error rates		Imagery rates	
	Mean	SEM	Mean	SEM
Low load, dissimilar (letters)	.04	.01	5.32	1.26
Low load, similar (numbers)	.04	.01	5.66	1.22
High load, dissimilar (letters)	.12	.03	6.79	1.25
High load, similar (numbers)	.12	.02	7.53	1.32

2.2.2. Subjective measure: Imagery rates

The average number of times that participants pressed the spacebar to indicate imagery of the memoranda during the delay phase per trial was 6.35 (*SEM* = 1.23). As revealed in Fig. 2, there was a main effect of Load on imagery, $F(1,37) = 18.18$, $p = .0001$ ($\eta_p^2 = .33$), in which more imagery was reported for High Load than Low Load. In addition, a trend arose where similar distractors led to more covert rehearsal than did dissimilar distractors, $F(1,37) = 3.11$, $p = .0859$ ($\eta_p^2 = .08$). There was no interaction between the Load and Similarity factors, $F(1,37) = 2.19$, $p = .15$. Planned comparisons revealed that all the contrasts between the four cells presented in Fig. 2 are significant (*t*s > 2; *p*s < .05) except for the contrast between the two Low Load cells, that is, between Letters versus Numbers (see Table 1 for descriptive statistics). Our pattern of results may be explained by a trending interaction, in which there is a floor effect for Similarity in the Low Load condition, but a detectable effect of this factor in the High Load condition. Consistent with such an interpretation, for the High Load condition, the effect arose in 26 out of 38 subjects, which would be significant in a sign test, $p = .034$. In addition, the planned comparisons between Similar and Dissimilar for the High Load condition revealed a significant effect. However, for the Low Load condition, the effect arose in 22 out of 38 subjects, which would be nonsignificant in a sign test, $p = .42$. Future research can assess whether the present pattern of results reflects a weak interaction rather than a weak main effect of Similarity. One could argue that, because the direction of the Similarity effect is well established in the literature, a directional test should have been adopted and implemented for this factor. It is worth noting that such a test would have revealed a significant main effect. Because the similarity effect had never been tested in the present paradigm, we believed that such a test would be somewhat unconservative. Nevertheless, the present data should not be interpreted as being at odds with the classic similarity effect.

See Figs. 3A and B for a schematic depiction of the temporal properties of the imagery events across two sample trials. To further investigate these temporal properties, we divided the delay phase into three time spans (Beginning [0–3499 ms], Middle 2 [3500–6999 ms], and End 3 [7000–10,500 ms]) and examined the rate of imagery as a function of segment. An ANOVA including this partitioning of the imagery data and the factors of Load and Similarity revealed no main effect of Span, $F(2,74) = 2.10$, $p = .13$ ($\eta_p^2 = .05$), a main effect of Load, $F(1,37) = 18.14$, $p = .0001$ ($\eta_p^2 = .33$), a trending effect for Similarity, $F(1,37) = 3.13$, $p = .085$, ($\eta_p^2 = .08$), and no interactions among any factors, *F*s < 2.2, *p*s > .14. Importantly, Fig. 4 reveals that the pattern of results from the factors of Load and Similarity are comparable across the three time spans of the delay phase. In a by-subject analysis, there was a significant correlation between imagery in the two Load conditions, $r = .95$, Fisher's *r* to *z*, $p < .0001$. This was the only correlation of note involving imagery rate and the other dependent measures.

Consistent with the imagery rate data, in response to the funneled debriefing question, "'If you experienced imagery (reported by pressing the spacebar), did you experience the imagery in brief moments or did you experience it in a sustained fashion (for example, experiencing the image UN-interrupted throughout the whole trial)?'", a group of 33 of the 38 participants who answered the question reported that they experienced imagery about numbers throughout the delay phase. Examination of the funneled debriefing data also revealed that the vast majority of participants (all but 3 participants) reported that, for each trial, they implemented some kind of intentional, rehearsal strategy in order to perform the task. Examination of the answers to the funneled debriefing questions also revealed that, consistent with the introspections made during WM performance, both in everyday life and in countless laboratory experiments, people consciously rehearse information when holding it in WM. Thus, our hypothesis and findings possess face validity.

2.2.3. Discussion

The data are consistent with the primary prediction that rehearsal occurs throughout the delay phase. In this task, it seems that participants *do not* consolidate the information, experience imageless thought, and then bring conscious memoranda-related contents to mind only when cued to do so, without performing any form of covert rehearsal during the interim between encoding and test. Regarding the secondary, Load prediction, the High Load condition led to more imagery than the Low Load condition, as hypothesized. In addition, consistent with the secondary, Similarity prediction, more imagery

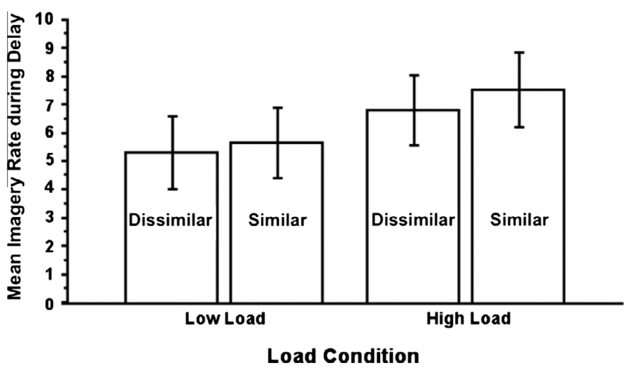

Fig. 2. Imagery rate as a function of Load (2 items versus 6 items) and of the nature of distractors: Similar items (numbers) versus dissimilar items (letters) (Study 1). Error bars indicate *SEM*s.

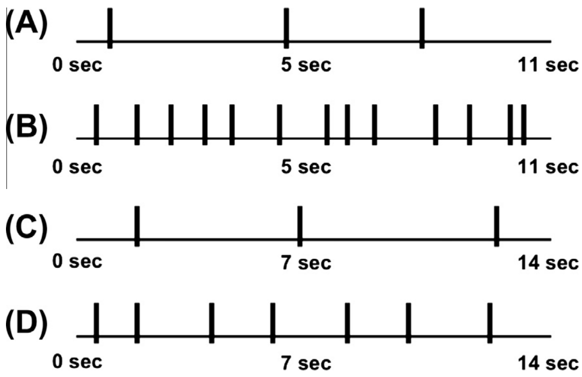

Fig. 3. Schematic representation of the temporal properties of conscious, memoranda-related imagery during four sample trials (A = Low Load condition [Study 1]; B = High Load Condition [Study 1]; C = Neutral condition [Study 2]; D = Response Interference condition [Study 2]). Vertical lines indicate points in time at which participants reported conscious imagery.

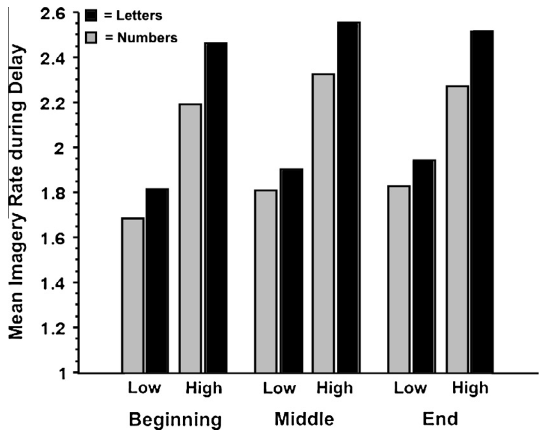

Fig. 4. Imagery rate as a function of memoranda load (low [2 items] versus high [6 items]), the nature of distractors (similar [numbers] versus dissimilar [letters]) and span during the delay (beginning, middle, and end) (Study 1).

tended to occur in the presence of similar distractors than in the presence of dissimilar distractors, which is consistent with what is known regarding the similarity effect in WM (Baddeley, 2007). (We should add that this effect was only a statistical trend, $p = .085$.) In synthesis, support was found for the hypotheses of covert rehearsal, load amount, and, to some extent, similarity.

3. Study 2

In this experiment, we examined whether distractors associated with an incompatible response lead to more covert rehearsal. Such a finding would be consistent with findings showing that, in *response interference* paradigms such as the classic Stroop (Stroop, 1935) and flanker (Eriksen & Eriksen, 1974) tasks, effects on consciousness (e.g., "urges to err") are strongest when visual distractors are not only different in appearance from targets but are associated with an incompatible response. For example, in the flanker task (Eriksen & Eriksen, 1974), one must respond to a visual target and disregard flanking 'distractors.' In one version of the task (Eriksen & Schultz, 1979), during *flanker training*, participants are first trained to press one button with one finger when presented with the letter S or M and to press another button with another finger when presented with the letter P or H. Participants are then instructed to respond to the letter presented in the center of an array and to disregard the flanking letters (the 'distractors'). Interference (e.g., increased response times and trial-by-trial urges to err) is stronger when distractors and targets are associated with different actions (*response interference* [RI]), as in the case of SSPSS, than when distractors and targets look different but are associated with the same response (*perceptual interference*; Eriksen, 1995; Morsella, Gray, et al., 2009; Morsella, Wilson, et al., 2009), as in the case of SSMSS. (To obtain these subjective effects, participants are asked after each trial to introspect and rate on an 8-point scale 'how strong the urge was to make a mistake' [cf., Morsella, Gray, et al., 2009; Morsella, Wilson, et al., 2009]. In this scale, 1 signifies "'no urge'" and 8 signifies "'strong urge.'") (Shortest RTs and decreased urges to err occur in the Identical condition [e.g., SSSSS, target underscored].)

As discussed in Section 3.2.1, that RI is associated with the most perturbations in consciousness is consistent with the hypothesis that incompatible skeletomotor plans must trigger detectable changes in subjective experience (Morsella, 2005). (See quantitative review of the subjective effects from a plethora of interference paradigms in Morsella, Berger, & Krieger, 2011.) More generally, this research on the subjective aspects of performance has revealed insights that may not be learned from behavioral measures alone (Etkin et al., 2010; Molapour, Berger, & Morsella, 2011).

3.1. Method

3.1.1. Participants

San Francisco State University undergraduate students ($n = 39$) participated for course credit.

3.1.2. Stimuli and apparatus

All stimuli were presented on an Apple iMac computer monitor (50.8 cm) with a viewing distance of approximately 48 cm. Stimulus presentation was controlled by PsyScope software (Cohen et al., 1993). The target stimulus was a letter (i.e., S, M, P or H) presented in the center of the screen in 100-point Chicago font. Distractor letters were presented in the center of the screen in 300-point Chicago font. Participants responded by pressing buttons on a PsyScope Response Box (ioLab Systems; UK). The yellow and green buttons for reporting the memoranda were on the top, horizontal plane of the box; the button for reporting imagery during the delay was colored black and on the side of the button box. Thus, the buttons for reporting imagery were different from the buttons for reporting the memoranda.

3.1.3. Procedures

Participants were run individually. During training ($n = 64$ trials), participants learned to press one button on the button box for two target letters (i.e., to press with their right middle finger the green button for letters P and H) and to press another button for two different target letters (i.e., to press with their right index finger the yellow button for letters S and M). Participants were instructed to, when not pressing the buttons, maintain light contact with them. Participants could move onto the next trial only after responding correctly to the target letter (e.g., press yellow button for target letter S). After training, participants performed 8 practice trials that contained a delay after the target letter was presented but before they could respond. Participants were instructed to make a decision as to their intended response while viewing the target letter, but not to act on their response until they were cued at the end of the delay (14 s). During the delay, participants were instructed to press with their left hand a button every time that they experienced mental imagery of the target letter, corresponding response, or any possible connection between the target letter and the response. Participants were given examples of mental imagery and what it means to have visual or auditory imagery. Regarding visual imagery, the onscreen instructions stated: "'*Take a moment to imagine what a tree looks like; Take a moment to imagine what a car looks like. You have just experienced an example of visual mental imagery*'". Regarding auditory imagery, participants read: "'*Without saying it aloud, take a moment to imagine what the word 'HOUSE' sounds like. Take a moment to imagine what the word 'FLOWER' sounds like. You have just experienced an example of auditory mental imagery*'".

Critical trials ($n = 64$) were identical to the aforementioned practice trials except that distractor letters were now presented during the delay period. Each critical trial began with a ready prompt (?) that allowed the participant to initiate the trial by pressing the space bar. Directly after the participant initiated the trial, a fixation (+) would appear (500 ms) in the center of the screen, followed by the target letter (500 ms). Another fixation (+) was presented (500 ms) before the delay period. During the delay, 28 distractor letters were presented sequentially over a period of 14 s, each for a duration of 500 ms. Out of the 28 distractor letters presented in the RI condition, 8 were letters that were associated with a different button-response than the target letter (e.g., letter P [green button] was presented as a distractor letter when the target letter was S [yellow button]). In the Neutral condition, the distractor letters did not have any association with the task (the letter N was discarded due to similarity with M). Participants were instructed to ignore the distractor letters, and to continue responding via button-press every time that they experienced mental imagery of the target letter, corresponding response, or any possible connection between the target letter and the response. After the delay, a cue (■; 1.3×1.3 cm) was presented and remained onscreen until a response was made (i.e., yellow or green button). Participants were instructed to press the imagery button only for the reporting of imagery. The experimenter, who observed the entire experimental session, checked that this instruction was followed correctly on each trial.

At the conclusion of every trial, participants were presented with a question about their mental imagery: *When you experienced imagery, how often did you feel that the imagery was caused automatically?* Participants were instructed to respond via keyboard using a scale from 1–8, in which 1 indicates that the imagery was not at all automatic, and in which 8 indicates that the imagery was completely automatic. In addition, to assess participants' knowledge about the hypotheses at hand and verify aspects of their task performance, we had participants fill out a funneled debriefing form (following the procedures detailed in Bargh & Chartrand, 2000) after completing the critical trials. Specifically, participants were asked: (a) *What did you think the purpose of this experiment was?* (b) *What do you think the experiment was trying to study?* (c) *Did you have any goals or strategies while completing this experiment? If so, please briefly describe them.* (d) *Was there anything that interfered with your performance on the task?* (e) *When you pressed the button to indicate that you experienced imagery, what type(s) of imagery did you experience? Please describe the type(s) of imagery briefly.* (f) *When you experienced task related imagery, did you experience the imagery in brief moments or in a sustained fashion?* The data from 2 participants were excluded from analysis because, first, it was obvious to the experimenter that these participants did not follow instructions, and, second, because these participants yielded excessive error rates: a 50% error rate for one of the participants and a 39% error rate for the other participant. The data from another participant were excluded from analysis because the participant discerned the hypothesis at hand and, on the experimental trials, intentionally responded according to the hypothesis.

3.2. Results

More covert rehearsal occurred in the RI condition ($M = 9.24$, $SEM = 1.61$) than in the Neutral condition ($M = 8.88$, $SEM = 1.53$), $t(35) = 2.33$, $p = .026$. See Figs. 3C and D for a schematic depiction of the temporal properties of the imagery events across two sample trials. Error rates between the Neutral ($M = .07$, $SEM = .01$) and RI ($M = .07$, $SEM = .01$) conditions were comparable, $t(34) = .68$, $p = .50$, as were the response times (excluding response times <200 ms and >2 s) to targets in both conditions ($M_{Neutral} = 755.31$, $SEM_{Neutral} = 40.70$; $M_{RI} = 777.17$, $SEM_{RI} = 40.96$), $t(34) = .87$, $p = .39$. Mean ratings of automaticity, too, were comparable across the conditions ($M_{Neutral} = 5.20$, $SEM_{Neutral} = .29$; $M_{RI} = 5.17$, $SEM_{RI} = .29$), $t(35) = .46$, $p = .65$. Interestingly, these ratings were not toward the lower-end of the range and were significantly different from zero, $ts > 17$, $ps < 0001$.

3.2.1. Discussion

As predicted, more covert rehearsal (and the associated increased entry into consciousness) occurred in the RI condition than in the Neutral condition. One could argue that, in both Studies 1 and 2, the increased imagery rate reflected, not that participants increased rehearsal rates to thwart the influence of distractors, but that the distractors activated the memoranda in a passive manner. For example, it could be that participants did not intentionally rehearse the memoranda but that the distractors 'primed' the memoranda, thereby inducing conscious imagery. We believe that such an account could not account for several empirical observations. First, examination of the funneled debriefing data revealed that the vast majority of participants (e.g., all but 3 participants in Study 1 and all but 4 in Study 2) reported that, for each trial, they implemented some kind of *intentional*, rehearsal strategy for performing the task. Second, data from other studies reveal that conscious rehearsal of the memoranda occurs even when there are no distractors presented during the delay. We found this in a pilot study ($n = 6$), in which, though no distractors were presented during the delay, participants experienced conscious imagery of the memoranda. Specifically, when holding four items in mind, the mean imagery rate was 2.7 per 10-s delay period ($SEM = 2.7$). Moreover, in another study (Jantz, Tomory, Gazzaley, & Morsella, 2013), the average number of times that participants ($n = 23$) pressed the space bar to indicate imagery of the memoranda during the delay phase (7 s) was 3.83 ($SEM = .86$). These data corroborate the idea that our effect cannot have arisen solely from the priming effects of distractors. It seems that covert rehearsal can occur to some extent without such priming effects. The degree to which our effect was caused by endogenous processes is worthy of future investigation.

One framework that is consistent with the present RI finding is the hypothesis that people are most likely to be conscious of mental processes involving competition for control of the skeletal muscle system (Morsella, 2005), as occurs in RI. From this theoretical standpoint, the primary function of consciousness is to integrate such incompatible skeletomotor intentions (see quantitative review of evidence in Morsella et al., 2011). From this standpoint, *conscious conflicts* stem from incompatible skeletomotor intentions, such as when one suppresses a prepotent response, diets, suppresses emotions, holds one's breath while underwater, or inhibits a conflicting or prepotent response in a laboratory interference paradigm such as the Stroop task or flanker task (Morsella, 2005; Morsella, Gray, et al., 2009; Morsella, Wilson, et al., 2009; Morsella et al., 2011). Accordingly, incompatible skeletomotor intentions (e.g., to point right *and* left, to eat *and* not eat, to inhale *and* not inhale) produce strong, systematic changes in consciousness. For example, in a paradigm in which participants are trained to introspect conflict-related aspects of cognition while sustaining compatible intentions and incompatible intentions (e.g., to point left *and* right with the same finger), participants reported stronger systematic changes in subjective experience when sustaining incompatible than compatible skeletomotor intentions, even though participants were always in a motionless state (Gray, Bargh, & Morsella, 2013; Morsella, Gray, et al., 2009). (See examination of the neural correlates of such conflicted states in Gray et al., 2013.) Such subjective effects are also obtained when the conflicting representations are triggered by external stimuli (e.g., as in the flanker task) or, relevant to the current study, when the representations are actively held in mind during a WM task (Hubbard, Rigby, Godwin, Gazzaley, & Morsella, 2013).

4. General discussion

Although theoretical developments and anecdotal evidence strongly suggest that WM is intimately related to consciousness (Allport, 1989; Baddeley, 2007; Hamker, 2003; James, 1890; Jordan, 1998; Jordan, 2009; Morsella, 2005; Oberauer & Hein, 2012), little research has examined the liaisons between the two phenomena. To address this issue, we examined the subjective aspects of WM-based control in a series of studies. Using an imagery monitoring task, we focused on the subjective aspects of the delayed action phase of WM-based control. In Study 1, we examined covert rehearsal as a function of load and the similarity of distractors; in Study 2, we examined whether such rehearsal is influenced by the nature of the responses associated with the distractors. It was anticipated that, as an initial foray into an uncharted area of research, each study would present its own strengths and weaknesses.

Regarding strengths, our paradigm is one of the first to use imagery rate (during a delay) as a dependent measure. The imagery rate data (including the time-course analysis of the imagery) were consistent with the *covert rehearsal* hypothesis, in which one rehearses action-related memoranda (e.g., an unfamiliar, to-be-dialed telephone number) during a delay. Our findings seem inconsistent with a less plausible, alternative hypothesis: the *consolidate-then-recall* hypothesis. This hypothesis proposes that, after being presented with the stimuli to-be-remembered, participants tend to consolidate the information in memory, experience no imagery during the delay (perhaps a form of *imageless thought*; Woodworth, 1915), and then simply recall the information when cued to do so. (For neural evidence suggesting that such a sequence of events may occur under some experimental conditions, see Clapp, Rubens, Karlsson, Zanto, & Gazzaley, 2008.)

Exploration of the temporal dynamics of the imagery revealed that imagery is constant throughout the delay phase and that, importantly, the effects of condition (e.g., Load and Similarity) on imagery is similar across the time spans occurring within the delay phase (Fig. 4). It seems that imagery is experienced as a repetitive, punctate (discrete) event. Just as the mental imagery of the lyrics of a song are experienced one lyric at a time, the memoranda of the action-related information seem to be rehearsed effortfully (Farah, 2000) one bit at a time, but in a reiterative fashion. The discrete nature of the subjective experience of rehearsal is of particular interest in light of recent research indicating that regions associated with working memory processes are continuously active during the delay phase of a WM task (Miller & Cohen, 2001). Future research may more precisely home in on the nature of this dynamic, reiterative process.

In Study 1, we also took the opportunity to examine additional, secondary hypotheses and found that (a) more memoranda-related imagery was associated with the High Load condition than the Low Load condition, and (b) the presence of similar distractors tended to increase the rate of rehearsal, which is consistent with what is known regarding the similarity effect in WM (Baddeley, 2007). In Study 2, imagery rates were higher in the RI condition, in which the distractors were associated with an incompatible response, than in the neutral condition, in which the distractors were of the same category of stimuli (letters) but were not associated with an incompatible response. As mentioned above, this finding is consistent with the hypothesis (Morsella, 2005) that people are most likely to be conscious of mental processes involving competition for control of the skeletal muscle system, as occurs in response interference. The theoretical approach is also consistent with the more general observation that conflicts occurring at perceptual levels of processing (e.g., intersensory conflicts as in ventriloquism) are not as subjectively taxing as those occurring at response selection levels of processing, whether in *approach-avoidance* conflicts (Livnat & Pippenger, 2006; Miller, 1959) or the delay of gratification (Metcalfe & Mischel, 1999; Morsella, 2005). As stated in Morsella, Wilson, et al. (2009), people tend not to experience any subjective, mental strife while observing a ventriloquist, but such is apparently not the case while people perform the flanker task or otherwise exert some form of self-control (Baumeister & Vohs, 2004; Morsella, Wilson, et al., 2009; Preston & Wegner, 2009).

4.1. Limitations and future directions

It was anticipated that, as an initial foray into an uncharted area of research, these new paradigms and experiments would be coupled with several shortcomings. We delineate a handful of the many limitations of our empirical approach. Due to the inherent limitations associated with self-report methodologies, one could question whether participants in either study were actually experiencing conscious mental imagery. Due to the systematic changes in subjective reports as a result of condition, it seems unlikely that participants did not follow directions and rather, for instance, chose to randomly indicate the experience of conscious imagery. This could be clarified by coupling the paradigm with neuroimaging techniques that would allow one to detect neural markers of imagery (see preliminary psychophysiological evidence in Samaha, Morsella, & Geisler, 2012). As mentioned above, extant neuroimaging evidence corroborates that, in other paradigms, participants are in fact accurate about reporting the incidence of conscious mental contents (cf., Logothetis & Schall, 1989; Mason et al., 2007; McVay & Kane, 2010; Mitchell et al., 2007; Wyland et al., 2003).

As in the case of the original flanker task (Eriksen & Eriksen, 1974), which contained only one interference condition (RI), Study 2 contained only one form of interference (RI). Future investigations may include a condition in which distractors look different from targets but are associated with the same response as targets, as in perceptual interference (Eriksen & Schultz, 1979; Morsella, Wilson, et al., 2009), which is weaker and more difficult to detect than RI. Future research may also combine our paradigm with neuroimaging technologies, to assess the neural correlates of these WM-related imagery phenomena, or with eye-tracking technology, to better monitor participants' degree of visual focus on the distractors. Regarding eye-tracking technology, in our paradigm, participants were instructed to always focus on the fixation cross presented at the center of the screen, and the experimenter checked on every single trial that participants were paying attention, following instructions, and not, say, closing their eyes or looking away from the screen. Nevertheless, tighter monitoring of participants' eye movements would be obtained from eye-tracking technology.

Research on both prospective memory (McDaniel & Einstein, 2007) and dual mechanisms of cognitive control (Braver, Gray, & Burgess, 2007) have revealed that different situational conditions (e.g., attentional demands, length of delay, instructions) favor different strategies for retrieving information after a delay. It could be the case that the paradigm used in both studies was calibrated in such a way that it would result in participants relying on the use of a rehearsal strategy rather than, say, a consolidate-then-recall strategy (cf., Clapp et al., 2008). Likewise, the act of reporting mental imagery (or of even simply hearing the instructions about reporting such imagery) may have influenced participants' rehearsal frequency, choice of memory maintenance strategy, or overall performance on our task. These limitations could be addressed in future investigations in which the nature of the instructions and of the method by which participants report imagery are manipulated experimentally.

5. Conclusion

Despite these limitations, we believe that these experiments reveal that the subjective effects associated with WM-based control (including memoranda-related imagery) are systematic, measurable, and arise from processing in a principled fashion. We hope that these initial data and novel paradigms will serve as a foundation for further explorations on the liaison between WM and consciousness, an under-explored nexus whose investigation is likely to reveal many insights about WM, action control, consciousness, and executive processing.

Acknowledgment

This research was supported by the Center for Human Culture and Behavior at San Francisco State University.

References

Allport, D. A. (1989). Visual attention. In M. I. Posner (Ed.), *Foundations of cognitive science*. Cambridge, MA: MIT Press.
Arkin, R. C. (1998). *Behavior-based robotics*. Cambridge, MA: The MIT Press.
Baars, B. J. (1988). *A cognitive theory of consciousness*. Cambridge, England: Cambridge University Press.
Baars, B. J. (2002). The conscious access hypothesis: Origins and recent evidence. *Trends in Cognitive Sciences, 6*, 47–52.
Baddeley, A. D. (1986). *Working memory*. Oxford, England: Oxford University Press.
Baddeley, A. D. (2007). *Working memory, thought, and action*. Oxford, UK: Oxford University Press.
Ballard, D. H., Hayhoe, M. M., Pook, P. K., & Rao, R. P. (1997). Deictic codes for the embodiment of cognition. *Behavioral and Brain Sciences, 20*, 723–767.
Bargh, J. A., & Chartrand, T. L. (2000). The mind in the middle: A practical guide to priming and automaticity research. In H. T. Reis & C. M. Judd (Eds.), *Handbook of research methods in social and personality psychology* (pp. 253–285). Cambridge, England: Cambridge University Press.
Baumeister, R. F., & Vohs, K. D. (2004). *Handbook of self-regulation: Research, theory, and applications*. New York: Guilford.
Block, N. (1995). On a confusion about a function of consciousness. *Behavioral and Brain Sciences, 18*, 227–287.
Boly, M., Garrido, M. I., Gosseries, O., Bruno, M.-A., Boveroux, P., Schnakers, C., et al (2011). Preserved feedforward but impaired top-down processes in the vegetative state. *Science, 332*, 858–862.
Braver, T. S., Gray, J. R., & Burgess, G. C. (2007). Explaining the many varieties of working memory variation: Dual mechanisms of cognitive control. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (Eds.), *Variation in working memory* (pp. 76–106). New York: Oxford University Press.
Brooks, R. A. (1991). Intelligence without representation. *Artificial Intelligence, 47*, 139–159.
Chalmers, D. (1995). Facing up to the problem of consciousness. *Journal of Consciousness Studies, 2*, 200–219.
Chalmers, D. (1996). *The conscious mind: In search of a fundamental theory*. New York: Oxford University Press.
Clapp, W. C., Rubens, M. T., Karlsson, J., Zanto, T. P., & Gazzaley, A. (2008). Variations in task difficulty dissociate activity in prefrontal cortex and medial temporal lobe during working memory encoding. *Poster presentation at the annual meeting of the Society for Human Brain Mapping*, Melbourne, Australia.
Clark, A., & Chalmers, D. J. (1998). The extended mind. *Analysis, 58*, 7–19.
Cohen, J. D., MacWhinney, B., Flatt, M., & Provost, J. (1993). PsyScope: A new graphic interactive environment for designing psychology experiments. *Behavior Research Methods, Instruments, & Computers, 25*, 257–271.
Crick, F., & Koch, C. (1995). Are we aware of neural activity in primary visual cortex? *Nature, 375*, 121–123.
Crick, F., & Koch, C. (2003). A framework for consciousness. *Nature Neuroscience, 6*, 1–8.
Curtis, C. E., & D'Esposito, M. (2003). Success and failure suppressing reflexive behavior. *Journal of Cognitive Neuroscience, 15*, 409–418.
Curtis, C. E., & D'Esposito, M. (2009). The inhibition of unwanted actions. In E. Morsella, J. A. Bargh, & P. M. Gollwitzer (Eds.), *The Oxford handbook of human action* (pp. 72–97). New York: Oxford University Press.
Damasio, A. R. (1989). Time-locked multiregional retroactivation: A systems-level proposal for the neural substrates of recall and recognition. *Cognition, 33*, 25–62.
Dehaene, S., & Naccache, L. (2001). Towards a cognitive neuroscience of consciousness: Basic evidence and a workspace framework. *Cognition, 79*, 1–37.
Di Lollo, V., Enns, J. T., & Rensink, R. A. (2000). Competition for consciousness among visual events: The psychophysics of reentrant visual pathways. *Journal of Experimental Psychology: General, 129*, 481–507.
Doesburg, S. M., Green, J. L., McDonald, J. J., & Ward, L. M. (2009). Rhythms of consciousness: Binocular rivalry reveals large-scale oscillatory network dynamics mediating visual perception. *PLoS, 4*, 1–14.
Eriksen, C. W. (1995). The flankers task and response competition: A useful tool for investigating a variety of cognitive problems. *Visual Cognition, 2*, 101–118.
Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception and Psychophysics, 16*, 143–149.
Eriksen, C. W., & Schultz, D. W. (1979). Information processing in visual search: A continuous flow conception and experimental results. *Perception and Psychophysics, 25*, 249–263.
Etkin, A., Prater, K., Hoeft, F., Menon, V., & Schatzberg, A. (2010). Failure of anterior cingulate activation and connectivity with the amygdala during implicit regulation of emotional processing in generalized anxiety disorder. *American Journal of Psychiatry, 167*, 545–554.
Farah, M. J. (2000). The neural bases of mental imagery. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (2nd ed., pp. 965–974). Cambridge, MA: MIT Press.
Gazzaley, A., & D'Esposito, M. (2007). Unifying prefrontal cortex function: Executive control, neural networks and top-down modulation. In B. Miller & J. Cummings (Eds.), *The human frontal lobes: Functions and disorders* (pp. 187–206). New York: Guilford Press.
Godwin, C. A., Gazzaley, A., & Morsella, E. (2013). Homing in on the brain mechanisms linked to consciousness: Buffer of the perception-and-action interface. In A. Pereira & D. Lehmann's (Eds.), *The unity of mind, brain and world: Current perspectives on a science of consciousness* (pp. 43–76). Cambridge, UK: Cambridge University Press.
Goldin-Meadow, S., Nusbaum, H., Kelly, S. D., & Wagner, S. (2001). Explaining math: Gesture lightens the load. *Psychological Science, 12*, 516–522.
Goodhew, S. C., Dux, P. E., Lipp, O. V., & Visser, T. A. W. (2012). Understanding recovery from object substitution masking. *Cognition, 122*, 405–415.
Gray, J. A. (2004). *Consciousness: Creeping up on the hard problem*. New York: Oxford University Press.
Gray, J. R., Bargh, J. A., & Morsella, E. (2013). Neural correlates of the essence of conscious conflict: fMRI of sustaining incompatible intentions. *Experimental Brain Research, 229*, 453–465.
Grossberg, S. (1999). The link between brain learning, attention, and consciousness. *Consciousness and Cognition, 8*, 1–44.
Hamker, F. H. (2003). The reentry hypothesis: Linking eye movements to visual perception. *Journal of Vision, 11*, 808–816.

Hassin, R. (2005). Unconscious and implicit working memory. In R. Hassin, J. Uleman, & J. A. Bargh (Eds.), *The new unconscious*. New York: Oxford.
Hommel, B., & Elsner, B. (2009). Acquisition, representation, and control of action. In E. Morsella, J. A. Bargh, & P. M. Gollwitzer (Eds.), *Oxford handbook of human action* (pp. 371–398). New York: Oxford University Press.
Hoover, M. A., & Richardson, D. C. (2008). When facts go down the rabbit hole: Contrasting features and objecthood as indexes to memory. *Cognition, 108*, 533–542.
Hubbard, J., Rigby, T., Godwin, C. A., Gazzaley, A., & Morsella, E. (2013). Representations in working memory yield interference effects found with externally-triggered representations. *Acta Psychologica, 142*, 127–135.
James, W. (1890). *The principles of psychology*. New York: Dover.
Jantz, T. K., Tomory, J. J., Gazzaley, A., & Morsella, E. (2013). *Subjective aspects of action control for delayed actions: Action-related imagerys.* Unpublished Manuscript, San Francisco State University.
Johnson, M. R., & Johnson, M. K. (2009). Toward characterizing the neural correlates of component processes of cognition. In F. Roesler, C. Ranganath, B. Roeder, & R. H. Kluwe (Eds.), *Neuroimaging of human memory: Linking cognitive processes to neural systems* (pp. 169–194). New York: Oxford University Press.
Jordan, J. S. (1998). Recasting Dewey's critique of the reflex-arc concept via a theory of anticipatory consciousness: Implications for theories of perception. *New Ideas in Psychology, 16*, 165–187.
Jordan, J. S. (2009). Forward-looking aspects of perception-action coupling as a basis for embodied communication. *Discourse Processes, 46*, 127–144.
Kinsbourne, M. (1996). What qualifies a representation for a role in consciousness? In J. D. Cohen & J. W. Schooler (Eds.), *Scientific approaches to consciousness* (pp. 335–355). Hillsdale, NJ: Erlbaum.
Koch, C. (2004). *The quest for consciousness: A neurobiological approach*. Englewood, CO: Roberts and Company Publishers.
Kroll, N. E. A., & Kellicut, M. H. (1972). Short-term recall as a function of covert rehearsal and of intervening task. *Journal of Verbal Learning and Verbal Behavior, 11*, 196–204.
Laureys, S. (2005). The neural correlate of (un)awareness: Lessons from the vegetative state. *Trends in Cognitive Sciences, 12*, 556–559.
LeDoux, J. E. (2008). Emotional colouration of consciousness: How feelings come about. In L. W. Weiskrantz & M. Davies (Eds.), *Frontiers of consciousness* (pp. 69–130). Oxford, UK: Oxford University Press.
Levine, J. (1983). Materialism and qualia: The explanatory gap. *Pacific Philosophical Quarterly, 64*, 354–361.
Levine, L. R., Morsella, E., & Bargh, J. A. (2007). The perversity of inanimate objects: Stimulus control by incidental musical notation. *Social Cognition, 25*, 265–280.
Libet, B. (2004). *Mind time: The temporal factor in consciousness*. Cambridge, MA: Harvard University Press.
Livnat, A., & Pippenger, N. (2006). An optimal brain can be composed of conflicting agents. *Proceedings of the National Academy of Sciences of the United States of America, 103*, 3198–3202.
Logothetis, N. K., & Schall, J. D. (1989). Neuronal correlates of subjective visual perception. *Science, 245*, 761–762.
Mason, M. F., Norton, M. I., van Horn, J. D., Wegner, D. M., Grafton, S. T., & Macrae, C. N. (2007). Wandering minds: The default network and stimulus-independent thought. *Science, 315*, 345–393.
McDaniel, M. A., & Einstein, G. O. (2007). *Prospective memory: An overview and synthesis of an emerging field*. Thousand Oaks, CA: Sage.
McVay, J. C., & Kane, M. J. (2010). Does mind wandering reflect executive function or executive failure? Comment on Smallwood and Schoolor (2006) and Watkins (2008). *Psychological Bulletin, 136*, 188–207.
Merker, B. (2007). Consciousness without a cerebral cortex: A challenge for neuroscience and medicine. *Behavioral and Brain Sciences, 30*, 63–134.
Metcalfe, J., & Mischel, W. (1999). A hot/cool-system analysis of delay of gratification: Dynamics of willpower. *Psychological Review, 106*, 3–19.
Miller, N. E. (1959). Liberalization of basic S–R concepts: Extensions to conflict behavior, motivation, and social learning. In S. Koch (Ed.). *Psychology: A study of science* (Vol. 2, pp. 196–292). New York: McGraw-Hill.
Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*, 167–202.
Miller, G. A., Galanter, E., & Pribram, K. H. (1960). *Plans and the structure of behavior*. New York: Henry Holt & Co.
Mitchell, J. P., Heatherton, T. F., Kelley, W. M., Wyland, C. L., Wegner, D. M., & Macrae, C. N. (2007). Separating sustained from transient aspects of cognitive control during thought suppression. *Psychological Science, 18*, 292–297.
Molapour, T., Berger, C. C., & Morsella, E. (2011). Did I read or did I name? Diminished awareness of processes yielding identical 'outputs'. *Consciousness and Cognition, 20*, 1776–1780.
Montague, W. E., Hillix, W. A., Kiess, H. O., & Harris, R. (1970). Variation in reports of covert rehearsal and in STM produced by differential payoff. *Journal of Experimental Psychology, 83*, 249–254.
Morsella, E. (2005). The function of phenomenal states: Supramodular interaction theory. *Psychological Review, 112*, 1000–1021.
Morsella, E., & Bargh, J. A. (2011). Unconscious action tendencies: Sources of 'un-integrated' action. In J. T. Cacioppo & J. Decety (Eds.), *The Oxford handbook of social neuroscience* (pp. 335–347). New York: Oxford University Press.
Morsella, E., Ben-Zeev, A., Lanska, M., & Bargh, J. A. (2010). The spontaneous thoughts of the night: How future tasks breed intrusive cognitions. *Social Cognition, 28*, 640–649.
Morsella, E., Berger, C. C., & Krieger, S. C. (2011). Cognitive and neural components of the phenomenology of agency. *Neurocase, 17*, 209–230.
Morsella, E., Gray, J. R., Krieger, S. C., & Bargh, J. A. (2009). The essence of conscious conflict: Subjective effects of sustaining incompatible intentions. *Emotion, 9*, 717–728.
Morsella, E., & Krauss, R. M. (2004). The role of gestures in spatial working memory and speech. *American Journal of Psychology, 117*, 411–424.
Morsella, E., Larson, L. R. L., Zarolia, P., & Bargh, J. A. (2011). Stimulus control: The sought or unsought influence of the objects we tend to. *Psicólogica: International Journal of Methodology and Experimental Psychology, 32*, 145–170.
Morsella, E., & Miozzo, M. (2002). Evidence for a cascade model of lexical access in speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28*, 555–563.
Morsella, E., Wilson, L. E., Berger, C. C., Honhongva, M., Gazzaley, A., & Bargh, J. A. (2009). Subjective aspects of cognitive control at different stages of processing. *Attention, Perception, & Psychophysics, 71*, 1807–1824.
Most, S. B., Scholl, B. J., Clifford, E., & Simons, D. J. (2005). What you see is what you set: Sustained inattentional blindness and the capture of awareness. *Psychological Review, 112*, 217–242.
Nagel, T. (1974). What is it like to be a bat? *Philosophical Review, 83*, 435–450.
Neisser, U. (1976). *Cognition and reality: Principles and implications of cognitive psychology*. San Francisco, CA: W. H. Freeman Publishing.
Oberauer, K., & Hein, L. (2012). Attention to information in working memory. *Current Directions in Psychological Science, 21*(3), 164–169.
O'Regan, J. K. (1992). Solving the 'real' mysteries of visual perception: The world as an outside memory. *Canadian Journal of Psychology, 46*, 461–488.
Paivio, A. (1979). *Imagery and verbal processes*. Hillsdales, New Jersey.: Lawrence Erlbaum Associates, Publishers.
Pinker, S. (1997). *How the mind works*. New York: W. W. Norton & Co.
Preston, J., & Wegner, D. M. (2009). Elbow grease: The experience of effort in action. In E. Morsella, J. A. Bargh, & P. M. Gollwitzer (Eds.), *Oxford handbook of human action* (pp. 469–486). New York: Oxford University Press.
Raye, C. L., Johnson, M. K., Mitchell, K. J., Greene, E. J., & Johnson, M. R. (2007). Refreshing: A minimal executive function. *Cortex, 43*, 135–145.
Roach, J. (2005, June 30). *Journal ranks top 25 unanswered science questions*. National Geographic News. <news.nationalgeographic.com>.
Roser, M., & Gazzaniga, M. S. (2004). Automatic brains – Interpretive minds. *Current Directions in Psychological Science, 13*, 56–59.
Samaha, J. M., Morsella, E., Geisler, M. W. (2012). Motor aspects of auditory imagery: Evidence for a Broca's area network. *Poster presented at the annual convention of the Association for the Scientific Study of Consciousness*, Brighton, UK.
Shallice, T. (1972). Dual functions of consciousness. *Psychological Review, 79*, 383–393.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643–662.
Tye, M. (1999). Phenomenal consciousness: The explanatory gap as cognitive illusion. *Mind, 108*, 705–725.
Wegner, D. M., & Bargh, J. A. (1998). Control and automaticity in social life. In D. T. Gilbert, S. T. Fiske, & G. Lindsey (Eds.), *The handbook of social psychology* (Vol. 1, 4th ed., pp. 446–496). Boston, MA: McGraw-Hill.
Woodworth, R. S. (1915). A revision of imageless thought. *Psychological Review, 22*, 1–27.
Wyland, C. L., Kelley, W. M., Macrae, C. N., Gordon, H. L., & Heatherton, T. F. (2003). Neural correlates of thought suppression. *Neuropsychologia, 41*, 1863–1867.