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# Information Matching the Content of Visual Working Memory Is Prioritized for Conscious Access

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## Abstract

Visual working memory (VWM) is used to retain relevant information for imminent goal-directed behavior. In the experiments reported here, we found that VWM helps to prioritize relevant information that is not yet available for conscious experience. In five experiments, we demonstrated that information matching VWM content reaches visual awareness faster than does information not matching VWM content. Our findings suggest a functional link between VWM and visual awareness: The content of VWM is recruited to funnel down the vast amount of sensory input to that which is relevant for subsequent behavior and therefore requires conscious access.

## Keywords

consciousness, visual awareness, visual working memory, working memory, subliminal processing, behavioral relevance, interocular suppression, visual perception

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Most of the visual information that people use to interact with the physical environment does not give rise to conscious experience. However, when people are confronted with a situation that requires mental effort, such as playing a game of chess or memorizing a telephone number, they seem to be fully aware of the sensory input that is relevant for subsequent behavior (Dehaene, Kerszberg, & Changeux, 1998). This suggests that consciousness is required for handling certain situations. In accordance, a growing number of studies have associated visual awareness with different functional properties, such as decision making (e.g., Van Gaal, Lange, & Cohen, 2012) and planning (e.g., Crick & Koch, 2003). Visual awareness, however, is of limited capacity and is capable of representing only a minute part of the available information at a particular time (e.g., Baars, 1997a, 1997b; Dennett, 1991). As a consequence of this limitation, a selection stage is needed to filter out the vast amount of incoming visual input.

The human brain uses visual working memory (VWM) to actively retain relevant information for imminent goal-directed behavior (for a review, see Baddeley, 2003). Therefore, the content of VWM would be a good

candidate to help in selecting relevant information for conscious access. Two types of findings provide an indication that VWM might well play such a role. First, a stimulus presented below the threshold of awareness exerts a greater influence on behavior when it matches the content of VWM than when it does not (Pan, Cheng, & Luo, 2012). Second, VWM plays a role in selecting relevant stimuli for the attentional system by providing a bias toward stimuli matching VWM content (Hollingworth & Luck, 2009; Hollingworth, Matsukura, & Luck, 2013; Olivers, 2009; Olivers, Meijer, & Theeuwes, 2006). Our aim in the present experiments was to examine whether the content of VWM could act on information that is not yet consciously perceived, so as to prioritize conscious access of matching, and therefore potentially relevant, information.

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A recently developed method called *breaking continuous flash suppression* (b-CFS) provides the means to compare the potency of different visual stimuli to reach conscious access (e.g., Jiang, Costello, & He, 2007; Mudrik, Breska, Lamy, & Deouell, 2011; Sklar et al., 2012; Stein, Hebart, & Sterzer, 2011; Wang, Weng, & He, 2012). In this paradigm, a stimulus presented to one eye is rendered temporarily invisible by presenting a dynamic pattern to the other eye. Consequently, the time it takes for this interocularly suppressed stimulus to break into visual awareness provides a measure of prioritization for conscious access of that stimulus.

In the color-memory conditions of the present experiments, we instructed participants to retain a color in VWM and measured how this VWM content affected suppression durations of colored stimuli. Specifically, we tested whether suppressed targets that match (i.e., are congruent with) a color category held in VWM break through interocular suppression faster than targets of nonmatching (i.e., incongruent) colors.

## Experiment 1

At the start of each trial in Experiment 1, a colored patch was shown, which participants were instructed to either actively memorize for a subsequent recognition task (color-memory condition) or only fixate without memorizing (passive-viewing condition). Next, a target was rendered invisible by continuous flash suppression (CFS): A target, either matching the color category of the memorized stimulus or not, gradually increased in intensity for one eye while a high-contrast dynamic pattern was presented continuously to the other eye. As soon as they detected the target, participants reported its location. In the final phase, which was omitted in the passive-viewing condition, participants reported which of three colored patches had the same specific color as the memorized stimulus.

## Method

**Participants.** Ten participants (age 18 to 27 years) completed Experiment 1. All participants were right-handed and had normal or corrected-to-normal vision. Before taking part in the experiment, they were tested for stereoscopic vision with the TNO test for stereoscopic vision (12th edition; Walraven, 1972). Additionally, each participant's eye dominance was determined off-line by comparing each eye's median detection time for interocularly suppressed stimuli. The presentation that led to the longest suppression durations (i.e., presenting the mask to the left eye and the target to the right eye or vice versa) was used during b-CFS.

**Apparatus and stimuli.** The experiment was conducted using an Apple dual 2-GHz PowerPC G5 equipped with a linearized 22-in. LaCie Electron Blue IV CRT monitor (1,024 × 768 pixels; 100 Hz refresh rate) and an Apple keyboard, which was used for response registration. There were no light sources in the experiment room, except for the computer monitor. Stimulus presentation and response collection were managed using the Psychophysics Toolbox 3 (Brainard, 1997; Pelli, 1997) in MATLAB (Release R2010a; The Mathworks, Natick, MA). A pair of displays was viewed dichoptically through a mirror stereoscope mounted on a chin rest, which kept the effective viewing distance at 57 cm. All stimuli were presented on a uniform gray background with a luminance of 24.5 cd/m<sup>2</sup>. To facilitate binocular fusion of the two complementary images, we surrounded the area presented to each eye with a black frame (< 1 cd/m<sup>2</sup>; > 96% Weber contrast) that subtended 5.8° × 5.8° of visual angle. Instructions were presented in white letters (46.2 cd/m<sup>2</sup>; 86% Weber contrast) in Arial font with a size of 14. All color stimuli were circles with a diameter of 1.2° of visual angle.

All 15 colors (5 red, 5 green, and 5 blue hues) for the memory task were physically matched to the luminance of the blue target stimulus using a PR-650 SpectraScan colorimeter-telephotometer (Photo Research, Chatsworth, CA). The obtained color patches had a mean luminance of 6.06 cd/m<sup>2</sup> (*SD* = 0.17 cd/m<sup>2</sup>) and a 76% Weber contrast with the background.

The colored patches for the suppression task consisted of saturated red, green, or blue. The saturated-blue target stimulus (5.98 cd/m<sup>2</sup>,  $x = 0.149$ ,  $y = 0.073$ ; 76% Weber contrast) was used to obtain perceptual equiluminance of the saturated-red and saturated-green target stimuli for each subject by means of heterochromatic flicker photometry (Kaiser & Comerford, 1975; Wagner & Boynton, 1972). In the suppression task, these patches increased in contrast, reaching full contrast at 1,500 ms. Patches were presented to the participant's nondominant eye. The dominant eye was simultaneously presented with a high-contrast dynamic pattern to evoke CFS. These pattern masks were created by (a) filtering pink (1/*f*) noise using a rotationally symmetric Gaussian low-pass filter ( $\sigma = 3.5$ ) and by (b) making the resulting gray-scale image binary with maximum contrast (> 96% Michelson contrast). On every trial, 200 new masks were generated, which were presented for 10 frames each (10 Hz). Note that the target stimuli in the suppression task were never of the same identical hue as the colors used for the memory task.

**Procedure.** Each trial began with a fixation cross (500 ms), followed by a color stimulus (1,000 ms), which

participants were told to remember for later recall (color-memory condition) or to only fixate without memorizing (passive-viewing condition). After a blank screen (2,000 ms), the suppression task was initiated. Participants were instructed to report as soon as possible whether a stimulus appeared either to the left or to the right of fixation ( $1.8^\circ$  of eccentricity). The color of the target was irrelevant for the suppression task. This task lasted until a response was given or until 20 s elapsed, and it ended with a blank screen (500 ms). In the color-memory condition, participants were then presented with three color patches of the same color category, each with a different hue, one of which was identical to the color presented at the start of the trial. They were instructed to indicate which of these three colors had the exact same color as the memorized stimulus. The stimulus sequence of a congruent trial is depicted in Figure 1.

Participants performed a total of 108 trials. Color patches for the memory task were randomly selected (but counterbalanced) from three basic color categories (red, green, or blue). Within each color category, the specific hue was randomly selected from one of five different color variations. There were 36 congruent trials, in which the target was of the same color category as the memorized stimulus, and 72 incongruent trials, in which target color and memorized color did not match; these two trial types were randomized within blocks. There were 54 color-memory trials and 54 passive-viewing trials, which were blocked. The order in which the blocks were presented was counterbalanced across participants. Both memory conditions (color memory and passive viewing) were preceded by an 8-trial practice session.

**Data analysis.** Only the trials in which the correct target location (left/right) was reported were included in the response-time (RT) analyses of the suppression task (less than 1% of the responses were incorrect). We determined participants' median RT for each memory condition (passive viewing and color memory) and target congruency (congruent and incongruent), and averaged them over participants. In each experiment, a  $2 \times 2$  repeated measures analysis of variance (ANOVA) was conducted with memory condition and target congruency as factors.

## Results

Results are depicted in Figure 2. The content of working memory affected suppression durations such that targets matching VWM content reached visual awareness faster than targets that did not match VWM content. This was revealed by the interaction between memory condition and target congruency,  $F(1, 9) = 19.827$ ,  $p = .002$ . Subsequent paired-samples  $t$  tests showed that in the

color-memory condition, congruent targets broke through suppression faster than did incongruent targets,  $t(9) = 4.559$ ,  $p = .001$ , whereas this congruency effect was not observed in the passive-viewing condition ( $p > .8$ ). The mean size of the congruency effect in the color-memory task was 238 ms ( $SD = 165$  ms, range = 42–600 ms). Finally, accuracy on the memory task was well above the 33% chance level ( $M = 68\%$  correct,  $SD = 10\%$ ).

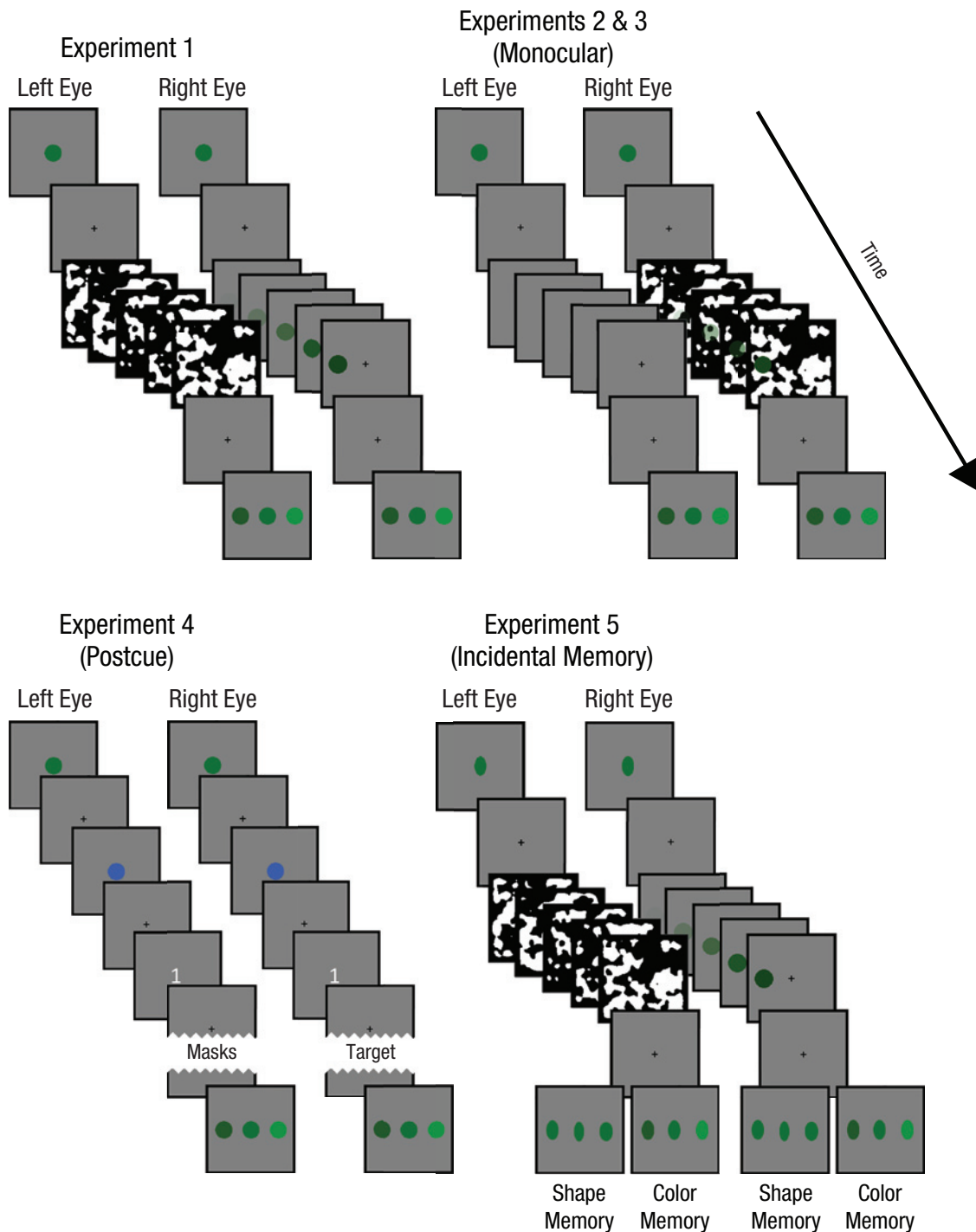
The results of Experiment 1 supported our hypothesis that information matching the content of VWM is prioritized for conscious access relative to nonmatching information. The next experiments were dedicated to tackling possible confounds. Our aim was to ground the claims that we were indeed measuring conscious access (Experiments 2 and 3), manipulating VWM (Experiment 4), and dealing with prioritization (Experiment 4) and that this phenomenon is related to the relevance of the visual information participants were presented with (Experiment 5).

## Experiments 2 and 3

Although differences in detection times under CFS provide a good indication that there are differences in non-conscious processing, these differences could also be accounted for by a difference in response criterion between the passive-viewing condition and the color-memory condition. For instance, a stimulus in VWM could be associated with a more liberal response tendency (i.e., a lower threshold in deciding that a stimulus has been perceived), which would result in faster RTs for matching targets than for nonmatching targets (for a discussion of this issue, see Stein et al., 2011). To ensure that the differences in RTs between congruent and incongruent trials in the color-memory condition reflect faster conscious access rather than a change in response criterion, we conducted two monocular control experiments. In these experiments, both the target and the dynamic pattern were presented to the same eye, as a result of which the target was not rendered invisible by interocular suppression. Hence, if VWM content speeded up responding to targets by other means than prioritization of conscious access, it would result in a larger congruency effect in the color-memory condition than in the passive-viewing condition in these experiments as well. Additionally, in Experiment 3, the time it took for the stimulus to increase full contrast was increased.

## Method

Experiments 2 and 3 were each completed by 10 new participants. Participants ranged in age from 18 to 31 years, were right-handed, had normal or corrected-to-normal vision, and passed the TNO test. Eye dominance



**Fig. 1.** Stimulus sequence of a congruent trial in each of the five experiments, as presented to the left and right eye of participants with left-eye dominance. In the memorization phase of Experiment 1, participants saw a colored circle and were told either to remember or disregard it. In the suppression phase, a mask was presented to one eye while a target ramped up to full contrast in the other eye, and participants had to indicate as soon as possible whether the target appeared to the left or the right of fixation. Targets were either congruent or incongruent with the color of the memorized stimulus. Trials in the color-memory condition (shown here) ended with a recall phase, in which participants were presented with three colored circles of the same color category as the memorized stimulus but with different hues, and they had to identify the circle that was identical in color to the one they had memorized. In the passive-viewing condition, there was no recall phase. Experiments 2 and 3 were the same as Experiment 1, except that the mask and target were presented to the same eye. Additionally, in Experiment 3, the time that the target took to ramp up to full contrast was lengthened. In Experiment 4, participants saw two colored stimuli separated by a blank interval; this was followed by a digit (“1” or “2”) instructing them which stimulus to remember. The suppression phase was then presented as in Experiment 1; however, targets could be congruent with the memorized color, congruent with the color participants saw but were not instructed to memorize, or congruent with a third color not used on that trial. The recall phase was the same as in the previous experiments. Experiment 5 was the same as Experiment 1, except that a shape-memory condition was added; in this condition, participants were told to memorize the shape of the stimulus and, after the suppression phase, to choose which of the three stimuli matched the shape of the memorized stimulus. Additionally, all stimuli in Experiment 5 were horizontal or vertical ellipses instead of circles. In all experiments, the memorization phase, suppression phase, and recall phase were separated by blank intervals.

was determined as in Experiment 1. In Experiment 2, all presentation times and stimuli were identical to those in Experiment 1, the only difference being that the target stimulus was presented to the same eye as the dynamic pattern (Fig. 1). Because targets were not suppressed, the distribution of detection times differed from that of Experiment 1 (for a discussion of this issue, see Stein et al., 2011). Hence, we conducted another monocular experiment (Experiment 3), in which we lengthened the ramp-up of the target, such that it would reach full contrast after 5,000 ms rather than after 1,500 ms. Additionally, we randomly varied the onset of the stimulus between 0 and 1,000 ms after CFS onset, so as to minimize anticipation effects. RTs were measured from target onset.

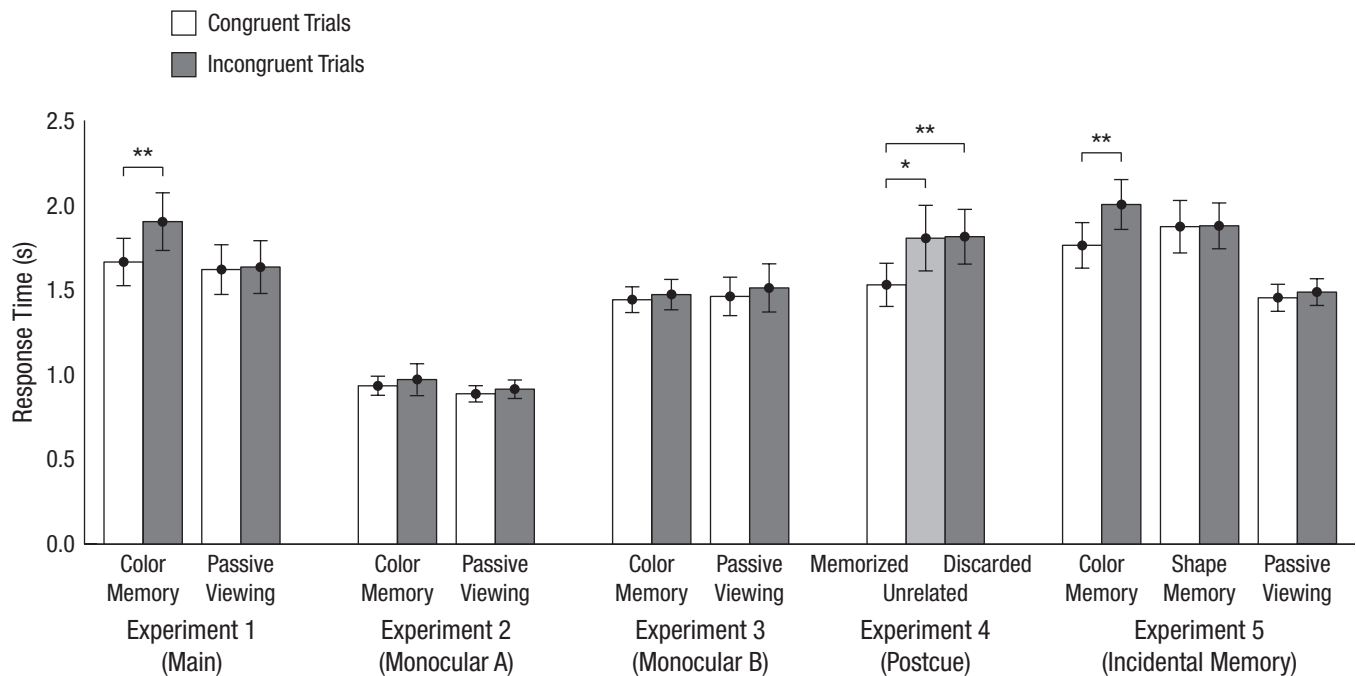
## Results

The results of Experiments 2 and 3 show that detection times for nonsuppressed color patches were not affected by the content of working memory (see Fig. 2). First, RTs on congruent trials did not differ significantly from RTs on incongruent trials either in the color-memory condition (Experiment 2:  $p > .1$ ; Experiment 3:  $p > .4$ ), or in the passive-viewing condition (both experiments:  $p > .2$ ). Second, and more important, this congruency effect did not differ between the color-memory condition and the

passive-viewing condition. This was revealed by the absence of an interaction between memory condition and target congruency in both the physically similar (Experiment 2) and the perceptually similar (Experiment 3) monocular experiments (both  $ps > .7$ ). Mean accuracy on the memory task was 73% correct ( $SD = 8\%$ ) in Experiment 2 and 68% correct ( $SD = 9\%$ ) in Experiment 3. Together, these monocular experiments show that the RT differences in Experiment 1 reflected faster conscious access, rather than a difference in response criterion, in the color-memory condition than in the passive-viewing condition.

## Experiment 4

In Experiment 1, participants knew they had to recall the first stimulus for later report in the color-memory condition and that they would not have to recall it in the passive-viewing condition. Hence, the cued color in the color-memory condition was not only held in working memory, but also it was potentially subject to more extensive initial processing than in the passive-viewing condition. To differentiate between these two accounts, we conducted an experiment designed to keep the initial processing of the color stimuli constant, manipulating only the content of VWM.



**Fig. 2.** Mean response times as a function of experiment and condition. For Experiments 1, 2, 3, and 5, results are shown for congruent and incongruent trials in the color-memory and passive-viewing conditions. For Experiment 5, results are also shown for congruent and incongruent trials in the shape-memory condition. For Experiment 4, results are shown for trials on which the color of the target matched the memorized color (the *memorized* condition), matched the color that participants saw but were not instructed to memorize (the *discarded* condition), and matched the color that had not been presented on that trial (the *unrelated* condition). Asterisks indicate significant differences between conditions ( $*p = .01$ ,  $**p < .001$ ). Error bars show standard errors of the mean.

In addition, Experiment 1 did not allow for direct RT comparisons between the passive-viewing condition and the color-memory condition, because the latter involved a dual-task load, which slowed down target detection (e.g., Pashler, 1994). By keeping the load equal between conditions, we were able in Experiment 4 to compare RTs between memory conditions. This enabled us to distinguish facilitatory effects of congruent trials from inhibitory effects of incongruent trials.

## Method

Fifteen new participants (age 19 to 28 years) completed Experiment 4. Participants were right-handed, had normal or corrected-to-normal vision, and passed the TNO test. Eye dominance was determined as in Experiment 1. In this experiment, participants were presented with two stimuli of different colors (1,000 ms each) separated by a blank interval (1,500 ms). The second stimulus was followed by a blank screen (1,500 ms), after which a post-cue appeared. This cue (the digit "1" or "2") instructed participants to actively retain either the first or the second color stimulus for later recall (Fig. 1). The suppression task and the recall phase in this experiment were identical to those in Experiment 1. Target stimuli were circular and created from the same three hues as in Experiment 1. On a given trial, the target could be from the same color category as the memorized color, from the same color category as the discarded color (i.e., the one participants saw but were not instructed to memorize), or from the unrelated color category (i.e., the one that did not appear on that trial). Because this procedure leads to two levels of congruence (congruent with memorized vs. unrelated vs. discarded stimulus) rather than one (congruent vs. incongruent), we tested more participants in this experiment to obtain comparable statistical power. Participants performed a total of 72 trials (24 per condition) over three blocks. All variables were randomized within blocks. A  $3 \times 2$  repeated measures ANOVA was conducted with the factors condition (memorized, unrelated, discarded) and position (first stimulus is cued, second stimulus is cued).

## Results

Results are depicted in Figure 2. First, the results of Experiment 4 show that VWM content alone affected suppression durations, such that targets matching VWM contents broke through interocular suppression faster than did nonmatching targets. This was revealed by a main effect of memory condition,  $F(2, 28) = 10.456$ ,  $p < .001$ , and the absence of either a main effect of position ( $p > .8$ ) or an interaction between memory condition and position ( $p > .7$ ). Second, the results of this experiment

confirm that information matching VWM content is prioritized rather than nonmatching information being inhibited. Subsequent paired-samples  $t$  tests showed faster breakthrough times for targets matching the memorized color compared with targets matching the unrelated color,  $t(14) = 2.958$ ,  $p = .010$ , as well as compared with targets matching the discarded color,  $t(14) = 4.757$ ,  $p < .001$ . Breakthrough times for targets matching the discarded color did not differ from breakthrough times for targets matching the unrelated color ( $p > .8$ ). Finally, no difference in performance was observed on the memory task between stimuli presented at Position 1 ( $M = 64\%$  correct,  $SD = 8\%$ ) and Position 2 ( $M = 63\%$  correct,  $SD = 10\%$ ), which shows that participants were equally proficient in retaining either one ( $p > .8$ ).

## Experiment 5

Luck and Vogel (1997) demonstrated that objects in VWM are stored as integrated wholes rather than as independent features. As such, an object in VWM contains a relevant stimulus dimension, which is volitionally memorized (as the task requires; e.g., its shape), but also contains incidentally memorized dimensions (which happen to be part of that object; e.g., its color). Experiment 5 was set up to test whether incidental memory for color would also prioritize conscious access of a target matching the memorized color category. This was achieved by having participants retain either the shape (shape-memory condition) or the color (color-memory condition) of a stimulus and assessing the effect of color congruency on suppression durations of a colored target stimulus. Accordingly, color was the relevant stimulus feature in the color-memory condition, whereas it was the irrelevant feature in the shape-memory condition.

## Method

Ten new participants (age 18 to 30 years) completed Experiment 5. Participants were right-handed, had normal or corrected-to-normal vision, and passed the TNO test. Eye dominance was determined as in Experiment 1. The stimuli and procedure of this experiment were similar to those of Experiment 1, with the addition of a condition (two blocks of 54 trials each) in which participants were instructed to retain the shape of the stimulus rather than the color. The stimuli for the memory task were either horizontal or vertical ellipses (two categories) that differed in height and width (five variations per category, ranging respectively in width from  $0.6^\circ$  to  $1.2^\circ$  and in height from  $1.2^\circ$  to  $0.6^\circ$ ). Up to the recall phase of the experiment, stimulus presentation was identical in the color- and shape-memory conditions. These conditions only differed in the instruction to retain one feature or

the other. In the recall phase of the shape-memory condition, three shape variations of the same shape category were presented, with all three stimuli having the same color as the memorized stimulus. Participants had to judge which shape corresponded with the one they had memorized. Conversely, in the color-memory condition, three hue variations of the same color category were presented, with all three stimuli having the same shape as the memorized stimulus (Fig. 1). As in the previous experiments, participants had to judge which color corresponded with the one they had memorized.

## Results

The results of this experiment show that only the relevant feature of a stimulus stored in VWM prioritizes conscious access of a matching target stimulus (see Fig. 2). This was revealed by an interaction between memory condition (color memory, shape memory, passive viewing) and target congruency (congruent, incongruent),  $F(2, 8) = 8.310$ ,  $p = .011$ . Subsequent paired-samples  $t$  tests showed that this interaction was caused by the congruency effect in the color-memory condition: Congruent targets broke through interocular suppression faster than did incongruent targets in the color-memory condition,  $t(9) = 5.308$ ,  $p < .001$ , but not in the shape-memory condition ( $p > .9$ ) or the passive-viewing condition ( $p > .5$ ). No difference in performance was observed on the memory task between shape memory ( $M = 70\%$  correct,  $SD = 16\%$ ) and color memory ( $M = 69\%$  correct,  $SD = 9\%$ ), which shows that both tasks were equally demanding ( $p > .8$ ).

## General Discussion

The literature on VWM is mostly concerned with information that is conscious (e.g., Baars, 2003; Baddeley, 2003; but see Soto, Mäntylä, & Silvanto, 2011). Here, we showed that the content of VWM affects processing of visual information that is not yet available for conscious inspection. Crucially, we demonstrated a direct functional link between VWM and the selection of information for visual awareness: Information that matches VWM content is prioritized by the visual system so that it reaches visual awareness faster than nonmatching information does. The magnitude of this effect (about a 14% RT difference between matching and nonmatching targets) was very consistent (see Fig. 2), even when different stimuli (Experiment 5) or different stimulus sequences (Experiment 4) were used. In addition, prioritization for conscious access was selective for the relevant stimulus dimension of a memorized stimulus.

It is important to ground the claim that the b-CFS method used in the current experiments assesses conscious access. In these experiments, the suppressed target stimuli were identical in all conditions. This is different

from other studies, in which differences in breakthrough times can potentially be accounted for by stimulus differences (as argued by Stein et al., 2011). Hence, if, as in the present case, suppressed stimuli are identical, an experimental manipulation that affects the time it takes for a stimulus to break through suppression reflects differential processing of that stimulus before it broke through suppression. As such, differences in suppression durations reveal differences in unconscious processing caused by the manipulation (for similar conclusions, see Gaillard et al., 2006; Stein et al., 2011). Still, detection times can also be affected by a number of cognitive or perceptual processes that arise after conscious detection of the stimuli, such as differences in response criterion. This alternative explanation was tackled in Experiments 2 and 3, which showed that VWM content did not affect detection times of nonsuppressed targets.

From a neuronal perspective, the influence of VWM content on suppression durations might reflect the competition between inhibition and activation of a stimulus representation in early visual areas. Neuroimaging studies have shown that representations retained in VWM can be decoded from activity in the early visual cortex (e.g., Christophel, Hebart, & Haynes, 2012; Harrison & Tong, 2009; Serences, Ester, Vogel, & Awh, 2009). Early visual areas have also been associated with visual awareness (e.g., Ress & Heeger, 2003; Super, Spekreijse, & Lamme, 2001; Weiskrantz, 1986, 1997) and, more specifically, with interocular suppression, which is partly accounted for by reciprocal inhibition of visual areas that retain eye-selective information (for a review, see Blake, 1989; Tong, 2001; Tong, Meng, & Blake, 2006). This spatial overlap in neuronal substrates for VWM representations and visual awareness provides the grounds for our behavioral results. In addition, this approach might explain why no color congruency effect was obtained when the shape of a colored stimulus was memorized (Experiment 5): Serences et al. (2009) showed that only the intentionally stored feature of a remembered stimulus (i.e., color but not orientation and vice versa) elicited a sustained pattern of activation in early visual areas. Thus, based on the idea of competition for visual awareness, only the intentionally stored feature has the potency to shorten suppression durations.

The present results can be framed within the global workspace model of consciousness (Dehaene et al., 1998; Dehaene & Naccache, 2001), according to which dedicated modular systems in the brain operate nonconsciously. When people face demanding tasks, however, appeals made on these systems are often conflicting, which requires the mediation of a distributed and flexible neural network. This broad neural network, then, reflects the content of consciousness (e.g., Baars, 2005; Dehaene & Naccache, 2001; Lau & Rosenthal, 2011). The implication of this model is that the current state of



consciousness (reflecting strategy, intentions, etc.) affects both conscious and nonconscious processes. In accordance with this, voluntarily retained VWM content is known to affect conscious processes, such as attention allocation (Olivers et al., 2006), and nonconscious processes, such as priming (Pan et al., 2012). The present experiments provide evidence that the current conscious state (i.e., the volitional retention of information) influences visual processing in yet another way: It affects the selection of sensory information in the visual system that is not yet available for conscious report in order for it to breach the threshold of consciousness.

## Conclusion

The present results reveal a functional connection between visual awareness and VWM. Whereas VWM is used to retain relevant visual information for imminent goal-directed behavior, visual awareness is needed to flexibly deal with incoming information to guide future behavior. Considering that people are continuously presented with vast amounts of sensory information, a system is needed to select and prioritize the most relevant information. The results of the present experiments suggest that VWM might well play that role in human consciousness; it funnels down the incoming sensory information to that which is relevant for imminent goal-directed behavior.

## Author Contributions

All authors developed the study concept and contributed to the study design. Programming, testing, and data collection were performed by S. Gayet, who also analyzed and interpreted the data under the supervision of C. L. E. Paffen and S. Van der Stigchel. The manuscript was written by S. Gayet, and critical revisions were provided by C. L. E. Paffen and S. Van der Stigchel. All authors approved the final version of the manuscript for submission.

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## Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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