Is there evidence for non-conscious processing in working memory?

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Declaration

I have read and understood The University of Edinburgh guidelines on plagiarism and declare that this dissertation is of my own work, except where I indicate otherwise by proper use of quotes and references; that I have made a substantial contribution in the chapters written as a member of a research group; and that the work has not been submitted for any other degree or professional qualification.

Abstract

Working Memory can be conceived as a mental workspace holding and manipulating a limited amount of recently acquired information for a limited time. Some theories assume that it is tightly coupled with Consciousness (e.g., Baars & Franklin, 2003), commonly defined in experimental studies as the ability to report the content of perception or of memory. Other theories posit that working memory includes cognitive processes of which participants are not conscious (e.g., Soto et al., 2011; Logie, 2016), and can be activated without conscious intention (Hassin et al., 2009).

Here, I describe experimental work designed to investigate the possible implicit activation of working memory without awareness. Importantly, participants were not only unaware of the stimuli that might be held in working memory, but also unaware that such stimuli were being presented at all. They were asked to guess which one of four cards presented on the screen was the winning one; one card was subliminally primed before a retention interval (which could vary between 500, 1000, 2000 and 5000 ms). The winner, on each trial, was chosen from amongst four blue cards, one of which had been primed, without awareness, by a card of a different colour (red or green) using Continuous Flash Suppression or Backward Masking.

Bayesian and classical analyses from nine experiments mostly support the null hypothesis, thus indicating that working memory was not engaged in performing this task. Two conceptual replications and four exact replications of the original study by Soto et al. (2011), also failed in reproducing the original results. In conclusion, this collection of fifteen experiments encompassing different manipulations shows the absence of non-conscious WM retention, questioning the generalisability of previous studies showing non-conscious WM.

Riassunto

La memoria di lavoro (Working Memory) è un sistema di controllo deputato al mantenimento, alla manipolazione ed all'elaborazione delle informazioni utili al conseguimento di uno scopo immediato. I modelli tradizionali considerano i processi e i contenuti della WM strettamente legati alla elaborazione cosciente. Tuttavia, recenti studi mettono in discussione tale assunto, dimostrando che si possono ritenere in memoria di lavoro stimoli di cui non si è consapevoli (Soto et al., 2011) e che la WM può essere attivata in modo implicito (Hassin et al., 2009). Questa tesi indaga la possibilità che la WM possa elaborare l'informazione in maniera indipendente dalla consapevolezza, ovvero possa essere attivata implicitamente da uno stimolo percepito al di sotto della soglia di consapevolezza.

Il paradigma ideato prevede di chiedere ai soggetti di scegliere quale fosse la carta vincente tra quattro carte da gioco. Prima della scelta, in un intervallo di tempo di variabile tra 500, 1000, 2000 e 5000 ms, la carta vincente viene presentata in maniera subliminale, tramite Continuous Flash Suppression o Backward Masking.

I risultati di nove esperimenti basati su diversi stimoli e tecniche di mascheramento, e con classiche analisi della varianza e analisi Bayesiane, non sostengono questa ipotesi. Inoltre, ulteriori sei esperimenti volti a replicare (2 repliche concettuali e 4 repliche esatte) studi presenti in letteratura non dimostrano l'esistenza di WM senza consapevolezza.

Il presente lavoro si inserisce nel dibattito sulla generalizzabilità dei risultati degli studi sulla percezione inconsapevole. L'assenza di effetti affidabili e la mancanza di replicazione di studi dimostranti WM implicita, non ne sostengono l'ipotesi.

Lay Summary

The idea that we can perform actions of which we are not aware or that our behaviour can be influenced by something of which we are not aware has a long history as a source of fascination for the general public. In the last century, thanks to technological advancement, many scientists started exploring this possibility scientifically: does non-conscious cognition exist? According to some of them not only it exists, but it is also deeper than expected. They observed that it is even possible to extract the meaning of sentences or doing arithmetic without being aware of it. These studies, however, are very controversial, as the methodology they use has yet to be refined and their results are seldom replicated. The present work describes fifteen experiments failing to replicate results that have been previously reported in literature, contributing to the debate concerning the reliability of conclusions from non-conscious cognition studies.

The experiments focus on non-conscious Working Memory. We use WM when we keep in mind information for a brief period of time in order to achieve a goal, like remembering a temporary security code or the shopping list. Some authors define it as the place where thinking takes place, and it is commonly associated with conscious experience which means that we can report its content and the operation we perform on it. Recent studies, nonetheless, suggest that processing of subliminal stimuli can be carried out within WM. Also, other studies suggested that WM can be engaged without explicit instructions.

If WM can be disentangled entirely from consciousness- as it can retain stimuli which do not belong to conscious awareness and can also be activated without conscious intention by visible stimuli - then it should get non-consciously activated by subliminal stimuli to be retained in order to perform a task.

With the current work I addressed this possibility, testing whether, to perform an ambiguous task, people can engage WM to retain a subliminal prime without being instructed to do so and without awareness both of the prime and of WM activation. Participants were engaged in a guessing game in which they had to guess which of four playing cards was the winning card. Actually, the location of the winning card was subliminally presented before every selection.

A series of nine experiments, encompassing different masking methods and manipulations, did not find any effect of the subliminal prime on participants' choices. Six attempts to replicate experiments already published also did not confirm the original results.

This work does not confirm the possibility that WM can be non-conscious, and contributes to the debate about non-conscious cognition studies, pointing out that conclusions from these studies should be drawn very carefully.

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Thank you. *Grazie.*

Eat popcorn.

—*James Vicary*

Table of Content

1 GENERAL INTRODUCTION

The idea that we can process information of which we are not aware and that some cognitive processes can take place without us being aware of them has always fascinated researchers and the general public. After behaviourism's denial of the topic as an object of scientific investigation (Dienes & Seth, 2010) the 21st century has been characterised by a multidisciplinary effort in trying to explain the nature and the neural basis of conscious experience, its function and can be done without awareness. Still, even though consciousness is not considered a scientific taboo any longer, it remains a very controversial subject of investigation.

The concept of awareness (or consciousness) is hard to define. Depending on the context, the concept of consciousness can assume diverse meanings. Here, as in most of the experimental literature I will describe, consciousness is defined as the ability to report experiencing the content of perception, whereas a conscious process can be defined as a process claimed by people to be conscious and can be accurately reported and acted upon (McGovern & Baars, 2007).

This definition seems to simplify the operationalization of the subject, by pointing to subjective reports as an indicator of whether something was consciously experienced or not. In reality, however, researchers struggle to find a convincing method of assessment and analysis: subjective reports, in fact, have been shown to be prone to biases as people usually underestimate their ability to discriminate (Eriksen, 1960; Bjorkman, Juslin, & Winman, 1993). In the last years, advancements in technology and the improvements of measurement methods raised expectations regarding the possibility of overcoming this problem and exploring non-conscious cognition in an “objective” way, leading to the development of empirical based and falsifiable theories of consciousness (Block et al., 2014). In fact, there has been an increasing number of studies on non-conscious cognition, and the appearance of specific peer-reviewed journals dedicated to consciousness science.

First, non-conscious cognition studies were related to short-lived, automatic low-level function (e.g. Koch & Crick, 2001), such as priming. The first studies showing a facilitation effect of unseen priming words on the processing of following target words date back to 1983 (Marcel, 1983). These studies encountered strong scepticism and criticisms (Holender, 1986), especially on the methodological ground, but recently this possibility has been newly investigated.

It has been demonstrated, for example, that stimuli of which participants are not aware can bias performance. In a study by Dehaene et al. (1998) participants were asked to rate whether a number was higher or lower than 5. Before the target number they were subliminally primed with a number that could have been either congruent or incongruent with the target number. Strikingly, participants were faster when they were primed with a number congruent with the target (a prime number lower than 5 with a target number lower than 5), and slower when primed with an incongruent number (a prime number lower than 5 with a target number higher than 5).

Since then, researchers have been testing the depth of unconscious processing, and have gone far beyond the processing of simple and briefly presented stimuli. Several studies have investigated the possibility that high-level processes can take place outside of conscious experience, suggesting that it is possible to process the meaning of subliminal words and sentences and do arithmetic unconsciously (Sklar et al., 2012), taking complex decisions (Dijksterhuis, 2008) and keeping subliminal stimuli in memory for up to 15 seconds (Bergström & Eriksson, 2014).

This notwithstanding, the scientific community is divided, and there is debate between those who proclaim the depth of non-conscious cognition and those who recommend caution. In fact, new measurement methods have given rise to new concerns and critiques, and replicability rates and statistical power of non-conscious cognition studies are still very low (Marcus Rothkirch & Hesselmann, 2017; Shanks, 2016; Vadillo, Konstantinidis, & Shanks, 2015). As noted by Shanks (2016, page 2) "*the past half-century of research on unconscious cognition [...] has been characterised by repeated cycles in which new ways of demonstrating unconscious processes have been challenged by later investigations*."

In the following sections, I will describe some of the most influential studies on high-level non-conscious cognition, summarised by the Yes It Can principle (Hassin, 2013), according to which every function can be carried out non-consciously, and their critiques. Then I will focus on one particular high-level function, Working Memory, and the possibility that this high-level function, usually considered to be strongly coupled with awareness can be active unconsciously.

1.1 The exploration of high-level unconscious processing

High-level cognitive processes can be defined as functions requiring complex computations and cognitive control (Hassin, 2013), like problem-solving, planning, abstract thinking and so on. They have usually been associated with consciousness, but some researchers have recently started challenging this view, dominated by a “conscious-centric” bias (Bargh & Morsella, 2008). This new light on non-conscious processing is based on the findings that some complex elaboration seems to take place also outside of conscious awareness.

In a series of studies, Sklar et al. (2012) demonstrated that participants were able to process the meaning of subliminal sentences and could solve arithmetic operations unconsciously. They presented participants with subliminal sentences that could be either semantically coherent or incoherent (e.g. I ironed clothes vs I ironed the coffee, respectively). Sentences were rendered subliminal by presenting them to one eye while the other eye was presented with a dynamic and colourful pattern, a technique based on binocular rivalry and known as Continuous Flash Suppression (Tsuchiya & Koch, 2005). I describe this method more extensively in the next chapters). Participants were asked to indicate whether the sentence appeared above or below the fixation cross. Sklar et al.'s (2012) found that participants' responses were faster in the incongruent condition, indicating that participants were sensitive to the semantic incongruence despite the fact that it was unconscious. The same effect was found with affective sentences, where negative sentences broke the suppression faster than positive ones. A series of control experiments, where sentences were presented supraliminally, ruled out the possibility that such effects were due to a faster decision rather than a faster breakthrough.

Moreover, in a further series of experiments, Sklar et al. (2012) found that participants' reaction times were also facilitated when asked to name a number matching the result of a subliminally primed mathematical three single-digit subtraction. This demonstrated that abstract operations like reading and doing arithmetic can be carried out unconsciously (but see the next section for a description of failed replications).

This is one of the bases of the "Yes It Can" principle (Hassin, 2013), according to which every function that can be carried out consciously can also be performed unconsciously. More support comes from studies demonstrating that several other high-level functions- like conflict management, decision making and goal pursuit- usually associated with consciousness, can be carried out unconsciously or be influenced by subliminal stimuli (Bargh, 1990; Bijleveld, Custers, & Aarts, 2011; Ap Dijksterhuis, 2006; for a review see Hassin, 2013)

Priming participants with subliminally presented flags, for instance, seems to influence political attitude and voting intentions (Hassin, Ferguson, Shidlovski, & Gross, 2007). Besides, according to some social psychology experiments, consciousness can even be counterintuitively disadvantageous when making complex decisions: Dijksterhuis, Bos, Nordgren, & van Baaren (2006) found that participants chose the best options among the ones given when in the time between the options presentation and the choice they were engaged in a distracting task rather than evaluating the options. According to the authors, preventing conscious evaluation of the choices allows 'unconscious thought' to deliberate free from conscious constraints (Dijksterhuis et al., 2006). On the basis of several experiments yielding this conclusion, Dijksterhuis (2008) proposed the Unconscious Thought Theory, according to which better decisions on complex problems are taken following a period of distraction rather than of conscious deliberation. This claim is based on the supposition that unconscious, differently from conscious thought, would have no capacity restraints, so that it can take into account broader information (Dijksterhuis, 2008).

The enthusiasm about this idea got to the point of suggesting physicians rely on their unconscious deliberation when taking complex decisions (e.g. Manigault, Handley, & Whillock, 2015) which basically means not thinking about the best solution to an issue.

It is important to note that there is still some difference between conscious and unconscious functions according to the YIC principle: the two processes may have different outcomes and require different conditions to emerge. Hassin (2013) compares non-conscious abilities to the sprint runners: they can run 100ms in less than 10s, but they do it only when required. Similarly, according to the YIC principle, every function can be potentially carried out unconsciously but it does not necessarily happen all the time. The possibility of non-conscious processing increases with practice, motivation and ability in performing such operations.

So, according to the YIC principle, if a function is tested in a way that allows it to occur unconsciously, metaphorically putting a sprint runner in a match, then every function that is known to work consciously will also be found to work outside of conscious awareness.

1.1.1 Critiques and controversies related to unconscious processing studies

As mentioned above, studies on consciousness, and especially on non-conscious processes, are still very controversial. Doubts have been raised against Hassin's YIC principle. Critiques mainly concern two aspects: experimental methodology and lack of replication.

With regard to experimental methodology, the primary problem lies in finding a reliable way to assess awareness, or better, its absence. As explained above, consciousness is by definition a subjective state, thus assessing it in an objective way is a big experimental challenge. A common practice consists of collecting subjective and objective measures of awareness. Subjective measures of awareness rely on merely asking participants to rate how well they saw the stimulus, usually on a specific 4 points Perceptual Awareness Scale (Ramsøy & Overgaard, 2004), or asking how confident they are about their response (Sterzer, Stein, Ludwig, Rothkirch, & Hesselmann, 2014). Usually, only trials in which participants report being unaware of the stimulus are analysed. These methods are susceptible to response bias, i.e. the inclination to prefer one response over others (McMillan & Creelman, 1990; Eriksen, 1960). Responses, in fact, are not only influenced by sensitivity, i.e. the ability to distinguish signal from noise, but also by participants' criterion for deciding one option over the others when the sensory information is not strong enough to determine a clear choice (Stanislaw & Todorov, 1999). When asked to state if a stimulus was seen or not, participants tend to use a conservative criterion, which means they would claim no awareness even if they partially saw the stimulus (Bjorkman, Juslin, & Winman, 1993). This is why subjective reports are usually accompanied by the calculation of d' prime (Kunimoto, Miller, & Pashler, 2001), a bias-free index of participants' sensitivity, derived from signal detection theory (Green & Swets, 1966).

On the other hand, objective measures consist of testing participants on their ability to detect a particular feature of the stimuli in an awareness test or control experiment. Participants scoring significantly above chance on this awareness test are excluded from data analysis.

Objective measures have two problems: in first place they may be over-conservative (e.g. Hesselmann, 2013; Sterzer et al., 2014), leading to the exclusion of observations which are due to genuine subliminal priming rather than to conscious experience of the stimulus. However, the most worrying issue concerning these measurement methods, recently pointed out by Shanks (2016), is regression to the mean. This refers to the mathematical necessity that when cases are measured on two variables and have an extreme score on one of the variables, they will have a high probability to obtain a score closer to the mean on the other variable (Cohen, Cohen, West & Aiken, 2003). Thus, selecting only observations that indicate no awareness (extremely low scores on the awareness measure) is unlikely to also give extremely low scores in the other task just for a statistical reason. Concerns about post-hoc data selection have been nicely illustrated by Schmidt (2015) with an effective metaphor: the selection of some data based on a specific criterion is like carrying out a drug study by selecting only patients who did not die from it.

Both subjective and objective methods also have another problem: they are based on the failure to reject the null hypothesis. When analysing the d' scores, for example, a d' of zero means that participants are not able to distinguish signal from noise, i.e. they are likely to be unaware of the signal. So, the hypothesis tested is whether the mean d' is significantly different from 0, and failing to reject the null hypothesis is taken as acceptance of the null hypothesis, a conclusion which is theoretically incorrect (e.g., Vadillo et al., 2015, Persuh, 2018) and should not be drawn based on the classical statistic (null hypothesis test). Bayesian analyses, on the other hand, would lead to more convincing deductions by actually testing the likelihood of the null hypothesis to be true compared to the alternative (Vadillo et al., 2015; Sterzer et al., 2014; Dienes, 2014). Still, so far few studies in this field have reported Bayesian analyses (Vadillo et al., 2015).

The same problem arises when claiming that performance in a control task is not different from chance, which is based again on failure to reject the null hypothesis.

The second critique of the YIC principle (Hassin, 2013) is the lack of replications, and especially independent replications (Shanks, 2016). As noted by Hesselmann & Moors (2015) in their "definitely maybe" reply to Hassin, not only is the YIC principle based on a partial literature review but, since its publication, many replication attempts of high-level unconscious processing experiments have failed to obtain the original results.
Rabagliati, Robertson, & Carmel (2018), for example, carried out a series of experiments trying to replicate the unconscious reading effect found by Sklar et al. (2012) and described above. Strikingly, they could not find any evidence of unconscious reading or semantic comprehension, not even related to a single word. By running a series of simulations, Rabagliati et al. demonstrated that this discrepancy may be due to the fact that the results of Sklar et al. (2012) could be an artefact due to common outliers exclusions practices; such practices increase the probability of entirely spurious false positives (Rabagliati et al., 2018).

Similarly, by re-analysing data of the unconscious arithmetic experiment (Sklar et al. 2012), Shanks (2016) demonstrated that participants with high awareness score were actually showing a smaller priming effect than the participants with low awareness score, thus data apparently reflect a regression to the mean rather than unconscious processing. A further re-analysis of the same data (Moors & Hesselmann, 2018) reproduced the effect only partially, showing that it is much weaker than expected. From their set of results, it appears clear that more evidence is required for claiming the existence of unconscious arithmetic (Moors & Hesselmann, 2018), finding that is already having a significant impact on theories of unconscious processing.

The need for further evidence of unconscious arithmetic also emerges from the fact that the only successful replication attempt to date (Karpinski, Yale, & Briggs, 2016) was retracted following the discovery of a calculation error which, once corrected, changed the results showing very weak evidence for unconscious arithmetic (Karpinski, Yale, Briggs, Prislin, & Vivian, 2017).

Issues with replicability also come from social psychology. One famous case is a study by Bargh, Chen, & Burrows (1996) demonstrating that priming participants with ageing-related words made them walk slower when leaving the laboratory. When substituting the experimenters 'stopwatch with automated timing methods to measure the time it took participants to exit the lab, this effect disappeared in a failed independent replication (Doyen, Klein, Pichon, & Cleeremans, 2012).

Many critiques, objections and failed replications had also defied the unconscious thought theory (Dijksterhuis, 2008). A meta-analysis carried out on Dijksterhuis experiments, along with a large scale replication attempt, led Nieuwenstein et al. (2015) to conclude that unconscious advantage effects found by Dijksterhuis were due to underpowered experiments and that there is no reliable support for such a theory. This is particularly worrying considering that physicians have been advised to act according to their gut instinct, without additional thought (see above, Manigault et al., 2015)! Vadillo, Kostopoulou, & Shanks (2015), also published a meta-analysis of the unconscious thought effect in clinical decisions, supported by Bayesian analyses. They could not find any evidence of such an effect and recommend that physicians should not base their decisions on the idea of unconscious thought, at least until more supporting evidence is gathered.

It has to be noted that such critiques do not rule out the possibility of non-conscious processing, but taking them into account is mandatory in planning studies on this topic and interpreting their results.

1.2 Working Memory and Consciousness

Working Memory is one of the high-level functions usually associated with consciousness to the point of even being identified with it by some theories (e.g. Baars & Franklin, 2003).

According to various theories, Working Memory is a volatile information store and control system concerning maintenance and online elaboration of information to pursue current behavioural goals (e.g. Baddeley, 2012; Logie & Cowan, 2015). It can be conceived as a mental workspace holding and manipulating a limited amount of recently acquired bits of information for a limited time. Baars and Franklin (2003) describe it as the workspace where thinking and cognition take place.

Although each theory of WM suggests a slightly different definition of the concept (Cowan, 2016), the prevailing idea is that WM and consciousness are coupled in a close relationship, and sometimes they even overlap (e.g. Baars & Franklin, 2003; Kintsch, Healy, Hegarty, Pennington, & Salthouse, 1999). Nevertheless, this idea has been mostly assumed implicitly (Velichkovsky, 2017), hence there is little direct evidence for it (Logie, 2009), while a growing number of experiments is testing the possibility that WM, or at least some of its aspects (Logie & Cowan, 2015; Pylyshyn, 1973) can operate outside of consciousness. (Bona & Silvanto, 2014; Hassin, 2013; Soto & Silvanto, 2016; Trübutschek, Marti, Ojeda, & King, 2017)

Therefore, at the moment the nature of such a relationship between WM and awareness is still not clearly understood (Eriksson, Vogel, Lansner, Bergstrom, & Nyberg, 2015). The main perspectives on the issue have been described by Jacobs & Silvanto (2015, see figure 1.1): the classical viewpoint suggests that WM functions are necessarily conscious; the second view allows the possibility that there may be WM contents of which we are not aware; and the third viewpoint regards WM and consciousness as two entirely distinct mechanisms, suggesting that memory trace not directly accessible to consciousness and introspection.

Below, I review studies demonstrating that the content of WM can be constituted of stimuli of which we are not aware, and that WM can be engaged without conscious intention.

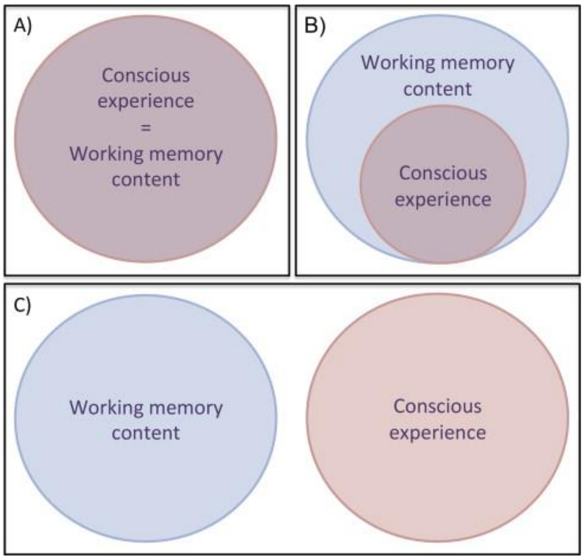


Figure 1.1 Different views of the relationship between WM and consciousness (Jacobs & Silvanto, 2016). The blue circle represents WM and the red circle illustrates the current conscious representation. A) the classical view, according to which all WM functions are conscious. B) Only a subset of the WM is experienced consciously and other operations can take place outside of it. C) WM content is completely separate from conscious experience.

1.2.1 Evidence for WM processing of subliminal stimuli

A classical assumption about WM is that its content is necessarily conscious or easily accessible by consciousness (e.g. Baars & Franklin, 2003). Nevertheless, an increasing number of studies seems to demonstrate that stimuli of which a person is not aware can be retained in WM. One of the first demonstrations supporting this account was the observation of a patient claiming an inability to experience any kind of visual mental experience who nonetheless could engage in visual working memory processes: Botez, Olivier, Vézina, Botez, & Kaufman (1985) reported a case of a patient with a congenital visual imagery deficit. He was unable to imaging people, places and objects, but nevertheless could identify unfamiliar patterns seen a few moments earlier, thus demonstrating that visual and spatial working memory may be dissociated from perceptual awareness of visual information (Logie, 2009).

More recently, Soto, Mäntylä, & Silvanto (2011) using backward masking showed that WM can operate on non-conscious stimuli on healthy participants. In this study participants were briefly presented with a Gabor patch, a sinusoidal grating seen through a Gaussian window, followed by a mask. Participants were instructed to attend to the Gabor even if they could not consciously perceive it, in order to perform an eventual discrimination task. After a delay period during which a subjective rating of cue visibility was required, to rule out the possibility that the cue was consciously perceived, participants were presented with a visible Gabor target and asked to judge whether the target was oriented clockwise or counter-clockwise relative to the cue. Results showed above chance performance, thus suggesting that the cue had been processed and maintained in memory though it was not consciously perceived. Notably, cue-target orientation discrimination was still significantly above chance even if visible distracter Gabors were presented during the retention interval.

The same authors confirmed a similar pattern of results in a subsequent study (Dutta, Shah, Silvanto, & Soto, 2014), accompanied by fMRI scans and tDCS stimulation of prefrontal areas. They demonstrated that prefrontal cortex, usually associated with high-level function and memory (Curtis & D'Esposito, 2003), was engaged during the maintenance of unseen stimuli.

Along the same lines, Bergström & Eriksson (2015) showed that it is possible to retain subliminally presented faces in memory for 15 seconds, in order to perform a delayed match to sample task. In this kind of task, participants are asked to state whether a target stimulus is the same as the prime stimulus or not. The priming stimulus in Bergstrom and Erikkson (2015) was rendered subliminal by CFS, and participants were performing above chance despite the fact that they claimed they were unaware of the to-be-remembered stimulus.

The authors got similar above-chance performance when asking to discriminate the similarity of the subliminal prime and the targets on both location and identity. In this second experiment, stimuli consisted of pictures of tools and the delay was shorter (consisting of 5s). These results confirmed those of Bergstrom and Erikkson's previous paper (Bergström & Eriksson, 2014) using attentional blink to render priming stimuli invisible and scanning participants with fMRI during the task. Attentional blink refers to the phenomenon whereby participants fail to detect a target if it is presented in rapid succession with another one (Raymond, Shapiro, & Arnell, 1992). Undetected stimuli still affected participants' performance after 15 seconds, accompanied by a BOLD signal change in the lateral prefrontal cortex (Bergstrom and Erikkson, 2014), thus confirming results by Dutta et al. (2014), who also observed prefrontal activation during the maintenance of unseen stimuli.

The same activation related to memory recognition of subliminal stimuli has also been found in a subsequent fMRI study by the same authors (Bergström & Eriksson, 2018).

Further evidence of long retention of subliminal stimuli is reported by Trübutschek et al. (2017), who found that participants can correctly locate an invisible target appearing in 1 out of 20 possible locations even after a 4s delay and despite the presence of distractors and memory load, thus confirming the results of Soto et al. (2011).

1.2.1.1 Critiques and open questions

Despite the evidence for non-conscious WM reviewed in the previous section, there are some interesting critiques to consider about the interpretation of the non-conscious WM studies. Stein, Kaiser, & Hesselmann (2016), for instance, point out that studies on WM maintenance of subliminal stimuli do not necessarily demonstrate the existence of unconscious WM. According to the conscious maintenance hypothesis (Stein et al., 2016), the above chance performance could be due to the conscious maintenance in WM of a guess performed following non-conscious priming. So, even if the choice is due to subliminal priming, it could be consciously retained into conscious WM until the response.

Trübutschek et al. (2017) tried to address this issue by comparing neural signals on seen and unseen trials through magnetoencephalography. Along with the behavioural results described above, they found desynchronization in brain activity in the frontal areas only in the 'seen' trials, while in the unseen trials, no matter whether they were correct or not, brain activity was similar to target-absent trials (control condition). According to the authors, this rules out the possibility that behavioural results were due to miscategorisation of unseen trials (i.e., some trials were labelled as "not seen" by mistake and would have influenced the performance). They conclude that their findings rule out conscious maintenance, as neural signatures in the unseen trials were not comparable to those of conscious trials, so it unlikely that any conscious process was taking place. However, the authors acknowledge that more evidence is required to draw definitive conclusions, especially considering that the sample size and the number of unseen trials in their study are relatively small to detect subtle effects.

Another weakness of non-conscious WM studies to date concerns the way in which awareness is assessed, as the measures used appear to be prone to bias. Stein et al. (2016), for instance, demonstrated that the way Soto et al. (2011) and Dutta et al. (2014) calculated the perceptual sensitivity index of the subliminal cue is susceptible to subjective bias, so it is not comparable with a classical d' formula, a bias-free index based on signal detection theory.

Furthermore, these studies are subject to the same critiques generally raised with regard to unconscious processing studies (e.g., Vadillo et al., 2015; Shanks, 2016) as described in the section 1.1.1, about the procedures used to assess awareness, mostly based on subjective reports, acceptance of the null hypothesis and post-hoc data selection.

1.2.2 Evidence for implicit WM activation

Another aspect of the relationship between WM and awareness that has been challenged is implicit WM activation. Hassin, Bargh, Engell, & Mcculloch (2009) demonstrated that WM operations, linked to recall of long-term memory representations, can be engaged unintentionally.

In this study, observers were asked to judge as quickly as possible whether a dot appearing on the screen was filled or empty. Each dot's position in a sequence of such presentations could follow a familiar pattern (for example zigzag), be random, or follow a broken pattern. Participants' behavioural performance was, crucially, facilitated when the sequence followed a familiar pattern. Moreover, participants reported being unaware of having extracted the sequence information. As constructing the pattern requires the maintenance of the previous dots' positions and the updating of visual information, the authors concluded that an implicit activation of WM was involved.

Soto & Silvanto (2014) suggest a possible autonomous activation of those WM functions hardwired by experience, which can occur in the case of semantic retrieval. This idea is supported by evidence from a large number of studies that WM performance within an individual's areas of expertise can be boosted by knowledge and learned strategies belonging to long-term memory (De Groot, 1965; Ericcson, Chase, & Faloon, 1980; Ericsson & Polson, 1988; for a review see Logie, 2016).

Silvanto & Soto (2012), moreover, demonstrated that subliminal distractors can impact WM accuracy even if participants are not instructed to attend to them. They confirmed this results in a subsequent study (Bona, Cattaneo, Vecchi, Soto, & Silvanto, 2013), where the impact of subliminal distractors was found to affect not only objective performance but also the subjective experience of memory-representation vividness.

These findings suggest the existence of implicit WM activation and maintenance of visual details (Velichkovsky, 2017).

1.2.2.1 Critiques and open questions

The notion of implicit WM is particularly problematic: not only is there very little supporting evidence, but the interpretation of relevant findings is also controversial due to the difficulty of disentangling this notion from the more general one of automated processing (Velichkovsky, 2017).

Automated processes, by definition, take place without the need for conscious control (Norman & Shallice, 1986), and it is not clear whether operations of data storage within such processes actually require a WM activation; the effect attributed to an implicit WM activation might be due to other automatic mechanisms (Velichkovsky, 2017). For example, an alternative interpretation of results by Hassin et al. (2009), might be that exposure to familiar patterns activated a perceptual-motor scheme (Norman and Shallice, 1986), leading to rapid automated responses not necessarily linked to WM (Velichkovsky, 2017).

Another interesting example comes from Della Sala, van der Meulen, Bestelmeyer, & Logie (2010), who demonstrated that implicit processing of semantic material from long-term memory can take place independently from WM activation. They asked brain-damaged British patients with left-sided unilateral spatial neglect to listen to and read lists of four proverbs. The proverbs could be familiar (British) or unfamiliar (foreign). While reading and listening, participants were shown with a picture depicting one of the proverbs. Patients' recognition of the proverb matching the picture was above chance, even if the key objects of the proverbs were depicted on the left neglected side of their visual field. Crucially, this was true only for familiar, but not unfamiliar proverbs. The same results were obtained with healthy participants, using subliminal presentation of one half of each picture. As facilitation from the subliminal features of the pictures was only obtained for familiar proverbs, the authors interpreted the results as indicating direct activation of semantic memory from perception, without intermediate stages of processing in working memory.

Thus, it could be the case that the results of Hassin et al. (2009) might have been due to similar long-term memory retrieval rather than WM activation, or that the results by Della Sala et al. (2010) were due to implicit WM activation limited to material stored in the semantic system. Such material would be easier to process subliminally than new semantic material, whose acquisition can be beyond the abilities of subliminal processing.

It is clear that further exploration of the issue is needed. For example, finding evidence of implicit WM activation driven by stimuli not belonging to LTM or perceptual-motor representations would provide a significant contribution to the debate.

1.3 The Research Question

The brief review above makes it clear that there is the need for further investigation on the relationship between WM and consciousness. In particular, if WM can retain subliminal stimuli (e.g., Soto et al., 2011) and can be implicitly activated (Hassin et al., 2009), then finding evidence of implicit WM activation by subliminal stimuli would support the idea that WM can be completely dissociated from consciousness.

The experimental procedure proposed here allows for the assessment of the possibility of implicit WM activation by objects that were perceived recently and non-consciously. Something to take into account is that the conditions for implicit WM activation are not clear. In fact, it also has to be clarified whether implicit activation of WM can take place with objects that are not represented in long-term memory, similarly to the study mentioned above by Della Sala et al. (2010). It is also not clear whether WM operations on non-conscious items can be activated without explicit intention and motivation (Soto and Silvanto, 2014), especially when dealing with newly acquired stimuli. In their review on WM without consciousness, Soto and Silvanto (2014) suggest that some motivation is required to hold subliminal stimuli in WM, and that implicit WM activation can be triggered by functions that are hardwired by experience.

This claim, though, not only bolsters the idea that 'implicit WM' effects might actually be due to more general automatic processing (Velichkovsky, 2017 see section 1.2.2.1), but also seems to contradict their findings (Silvanto and Soto, 2012) of subliminal distractors influencing WM performance even when participants are not instructed to attend to them. This contradiction can be accounted for by the contingent involuntary orienting hypothesis (Folk, Remington, & Wright, 1994) according to which under conditions of spatial uncertainty, stimuli with features critical to the performance trigger involuntary attentional capture (Gayet, Van der Stigchel, & Paffen, 2014).

Therefore, if WM can be implicitly activated, then a relevant stimulus in a condition of uncertainty, where no instructions are given about the best choice) should be able to trigger such activation even if it is not represented in LTM. Thus, implicit WM activation may be unrelated to motor activation (Velichkovsky, 2017), nor to long-term memory retrieval bypassing WM (Della Sala & al., 2010).

Based on the premises that (a) subliminal stimuli can be retained in WM and (b) WM can be implicitly activated, I designed a paradigm in which participants are not aware that they are engaged in a memory task, but the only way to perform the task successfully is to keep a subliminally presented stimulus in memory.

In this sense, WM is here operationalised as the short term storage of information in order to perform an ongoing task (Baddeley, 1986).

Finding above chance performance would not only confirm previous evidence of maintenance of subliminal stimuli and implicit WM activation but would also mean that the storage of stimuli in WM can be dissociated from consciousness. This would be in line with the suggestion that WM could be composed of multiple processes non necessarily available to consciousness (Logie and Cowan, 2015).

1.3.1 Methodology

The paradigm used in the current experiments can be considered as a modified version of free-choice priming paradigms.

In free-choice tasks, participants are required to choose between a set of alternative responses without any predetermined criterion, i.e. none of the options is more "correct" than the others (Bordener & Mulij, 2009). It has been demonstrated that the participants' choices can be biased toward one of the options following a prime, even if the prime is subliminally presented (Klapp & Haas, 2005; Kiesel, Wagener, Kunder, Hoffman, Fallgatter & Stocker, 2006, Mattler & Palmer, 2012). In two experiments by Kiesel et al (2006), for example, participants were instructed to press the left or right button of the keyboard following a visible cue. Sometimes a neutral cue was given, and in that case participants were free to choose whether to press the left or the right key. Strikingly, when a subliminal cue indicating left or right was presented before the neutral visible cue, participants' choices were significantly biased towards the direction of the subliminal cue. Thus, the authors demonstrated that unperceived stimuli can bias free choices.

In my paradigm, the participants were instructed to perform a guessing game, so they are free to choose an option as in the free choice paradigm. In the game, four playing cards are presented in back-view, in a cross formation. Participants are told that in each round one of the cards is the winning card, and asked to choose the one they think it is by using the arrow keys of the keyboard (e.g., the up-arrow for the top card). As in the free-choice paradigms, these were non speeded responses.

Participants are warned to avoid using any spatial strategy and not to pick up the same card all the time, because the winning card is randomly assigned, so they have to rely on their instinct. They are informed that the number of “winning” choices will be provided at the end of the game.

Crucially, a cue highlighting one of the cards is subliminally presented before each choice. In the following chapters, subliminal presentation was accomplished by using CFS in the first series of experiments and backward masking in the second series. The winning card is marked by being of a different colour compared to the others (e.g. a red card among blue ones). A pilot experiment, described in the next chapter, established the effectiveness of this type of cue when it is seen consciously. No card is highlighted in 20% of the trials, as a control baseline condition for reaction times and subjective reports.

Another variable – retention interval – is manipulated by using various durations between the subliminal presentation of the winning card and the participants’ choice, in order to detect memory engagement. Following van der Ham, Strien, Oleksiak, Wezel, & Postma (2010), I selected delays of 500ms, 2000ms and 5000ms, plus an additional delay of 1000ms. Using different delays is important, because the literature contains different suggestions about the time required for a sensory input to be transformed into a WM representation (for a review see Ricker, Newistein, Bayliss & Barouillet, 2018). This process is termed "WM consolidation", and results in an increased memory performance once a certain duration from stimulus presentation has passed. This effect has been described even with masked stimuli (Nieuwenstein & Wyble, 2014; De Schrijver & Barrouillet, 2017; Ricker & Hardman, 2017).

In terms of classic memory models (Atkinson & Shiffrin, 1968), WM consolidation would be the transfer of content from iconic memory into Short Term Memory or WM.

Usually, 500ms is considered the threshold for iconic memory, a pre-categorical and rapidly-decaying memory store whose contents are encoded according to the stimulus' projection on the retina (Öğmen & Herzog, 2016). In his review on iconic memory research, however, Dick (1974) suggests that the threshold between iconic memory and WM should be placed at 1000ms.

The delays of 2000ms and 5000ms have been widely used to investigate WM retention, particularly in previous work on unconscious WM (e.g., Soto et al, 2011; Bergstrom et al. 2015). According to van der Ham et al. (2010) at these delays it is possible to observe slow wave activity related to WM consolidation (e.g., McEvoy et al., 1998; Awh et al., 1998; Ruchkin et al., 1997), as well as detect possible patterns of decay (Postma, Huntjens, Meuwissen & Laeng, 2006). Testing performance after these four different delays – 500, 1000, 2000 and 5000 ms – can therefore provide an important insight into the memory processes involved.

The nature of the present task, i.e. the fact that participants were not told about the subliminal cue, did not allow the collection of trial by trial visibility ratings, but after the main experiment participants performed a perceptual control task. Stimuli in this task were the same as in the main experiment (Stein & Sterzer, 2014), but participants were informed about the presence of a masked red card and asked to locate its position. Objective performance was measured, and subjective ratings of visibility were collected trial-by-trial on a 4-point PAS, thus obtaining both objective and subjective measures of awareness (Yang, Brascamp, Kang, & Blake, 2014). Participants whose performance on the control task indicates awareness of the subliminal stimulus are removed from the main experimental analyses.

Assessing unawareness with this method falls into the post-hoc data selection category of methods criticised by Shanks (2016) for being prone to regression to the mean. Positive results, if any, are therefore subjected to further analyses as suggested by the author (Shanks, 2016). Furthermore, Bayesian analyses will accompany classic statistical analyses, especially when acceptance of the null hypothesis is a condition for claiming the absence of awareness. (Dienes, 2015; Shanks, 2016; Sterzer, Stein, Ludwig, Rothkirch, & Hesselmann, 2014; Vadillo et al., 2015).

The proposed methodology takes into accounts the criticism of the conscious maintenance hypothesis (Stein et al., 2016) in two ways: in first place, subliminal cues without explicit instructions to remember them make it unlikely that guesses were consciously retained; moreover, by using different delays, it is possible to evaluate whether the supposed facilitation is effectively due to implicit WM activation or to a passive-priming mechanism.

1.4 Overview of the empirical chapters (spoiler alert)

Based on the premises outlined above, the first experimental chapter (CH. 2) addresses the research question through a series of experiments using CFS, leading to conflicting and inconclusive results.

With the work described in the Chapter 3, I explore possible reasons behind the puzzling inconsistency of findings. In a first experiment I used a different masking technique, Backward Masking, in a second experiment I provided feedbacks on performance after each trial in order to boost motivation, in the last experiment of the chapter I used semantic relevant material as stimuli. None of these experiments showed evidence for non-conscious working memory.

Finally, in light of my failure to find consistent evidence for non-conscious WM activation, in Chapter 4 I went back to the original background of the research question, conducting an exact replication of a previous influential study (Soto et al., 2011).

My thesis turned out to be the nightmare of every PhD student, with a collection of null results and frustrating attempts to perform exact replications, which failed to produce the original results.

Despite all of this, I stand by my results: I dedicated a significant effort to address possible weaknesses of the paradigm I designed, and to trying to find the reason behind the discrepancies between my results and previous literature.

Hopefully, the large number of ‘no’ answers to my research question may make a constructive contribution to the debate on the possibility of non-conscious WM, which I am now convinced does not exist.

2 CONTINUOUS FLASH SUPPRESSION

2.1 Introduction

Working Memory is considered a volatile information store and control system concerning maintenance and online elaboration of information in order to pursue current behavioural goals (e.g. Baddeley, 2007). It can be conceived as a mental workspace holding and manipulating a limited number of recently acquired information for a limited time. There are different theories of WM and even if each of them suggests a slightly different definition (Cowan, 2016), there is a broad consensus that there is an overlap between some functions of working memory and conscious awareness (e.g. Baars & Franklin, 2003; Block, 1995; Dudai, 2004; Kintsch et al., 1999), commonly defined in experimental studies as the ability to report the content of perception. However, a growing number of studies and theoretical discussions suggests the possible existence of unconscious storage and processing in working memory (e.g. Della Sala et al., 2010; Hassin et al., 2009; Logie, 2016; Soto & Silvanto, 2014)

The study by Soto et al. (2011) demonstrated that WM can process stimuli of which the participant is not aware. In this study participants were briefly presented with a Gabor patch followed by a mask. Participants were instructed to try to attend the cue even if they could not see it, in order to perform an eventual discrimination task. After two seconds, participants were presented with a visible Gabor target and asked to judge whether the target was clockwise or counter-clockwise oriented with respect to the cue. Subjective ratings of cue visibility were collected in order to discard the possibility that the cue was consciously perceived. Results showed an above chance performance on trials where participants claimed to be unaware of the cue, thus suggesting that the patch had been elaborated and maintained in memory even if non-consciously perceived.

Moreover, Hassin and colleagues (2009) demonstrated that WM operations, linked to long-term memory representation recall, can be engaged unintentionally. In their study, observers were asked to judge as quickly as possible whether a dot appearing on the screen was filled or empty. The dot's position of appearance could follow a familiar pattern (for example a zigzag), be random or a broken pattern. Participants' behavioural performance was facilitated when the sequence followed a familiar pattern. Participants reported being unaware of having extracted the sequence information. As constructing the pattern requires the maintenance of the previous dot position and the updating of the visual information, the authors concluded that an implicit activation of WM process was involved.

If objects of which we are not aware can be retained in WM, and WM can be activated without conscious intention in order to perform a task, then a legitimate question is whether WM can be engaged without explicit intention by perceiving subliminal material.

The experimental procedure proposed here allows assessing the possibility of an implicit WM activation with newly acquired subliminal objects, thus assessing whether WM can be independent of consciousness.

2.2 General methods

The experimental paradigm used a technique called Continuous Flash Suppression (CFS). This method is based on binocular rivalry, a visual phenomenon whereby if each eye is presented with a different picture, the conscious percept will alternate from one picture to the other, but only one at a time will be perceived. In CFS, one of the two images is more salient than the other, because it is a dynamic and colourful image (most commonly of a type known as a 'mondrian mask'), whereas the other eye is typically shown a static image with lower contrast. When this is done, the more salient image will be prioritised as a conscious percept. CFS can thus be used to suppress a low contrast stimulus displayed to one eye (Tsuchiya & Koch, 2005). In behavioural experiments, the most common way to elicit binocular rivalry or CFS is by using ~~a~~ system of mirrors called mirror stereoscope (see figure 2.1), which presents each eye with different images that seem to appear at the same location.

In the current paradigm, one eye is presented with the image of three blue cards and one of a different colour, representing the cue, while the other eye is presented with the Mondrian mask. The four cards are arranged in a cross formation. In 20% of the trials the cue is absent and all the cards are blue. After a variable retention interval, participants are supraliminally presented with an array of cards, all blue and in the same cross formation, and asked to guess which one is the winning card by selecting it through arrow keys of the keyboard.

Following van der Ham et al. (2010), I selected delays of 500ms, 2000ms and 5000ms, plus a delay of 1000ms in order to detect a possible fast decay. The task is based on the free choice paradigm, which means that participants are free to choose between the options. Hence, crucially, participants are not aware of performing a memory task; rather, they believe they are playing a guessing game, thus allowing us to assess the presence of implicit activation of WM.

After the experimental session, participants were asked to perform a perceptual control experiment in order to check whether and to what extent they perceived the prime. The control experiment provided measures of awareness, allowing exclusion from the analysis participants who showed a possible breakthrough suppression. This procedure, based on post hoc data selection and frequently employed in consciousness studies, has been recently criticised because it is prone to regression to the mean (Shanks, 2016). This refers to the mathematical necessity that when cases are measured on two variables and have a high score on one of the variables, they will have a high probability to obtain a score closer to the mean on the other variable (Cohen et al., 2003). In the present case, participants might have low scores on the perceptual control experiment and high scores on the primary task, due to this statistical effect. So, any interpretation of possible significant results obtained by using such post-hoc data selection needs to be carefully drawn and accompanied by further analyses and controls as suggested by Shanks (2016).

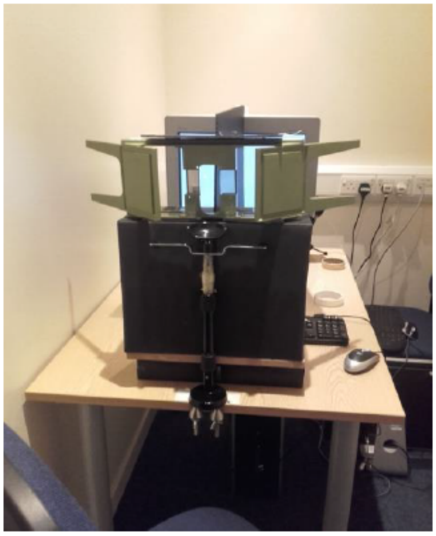
A facilitation effect at longer retention intervals would strongly demonstrate that WM may be effectively engaged outside of awareness and through subliminal stimuli. If such facilitation does not arise, it would mean that even if WM may process non-conscious stimuli, this takes place only under conscious and voluntary activation and that further investigations should be carried out about implicit WM engagement. Hence, finding no facilitation effect in a study with a subliminal cue in delayed choice tasks would mean that WM needs at least some awareness hence posing new questions concerning its implicit activation.

2.2.1 Apparatus

The experiments were run on a DELL Latitude E6430 running Windows 7 Professional with a Nvidia GeForce GT 610 graphic device and a 17.1'' Mitsubishi colour display (1024 x 1280) at 85 Hz refresh rate.

The screen was divided into a left and right half, each half displaying the stimulus over a 6.17°x 5.73° visual angle square, surrounded on the left and right sides by black and white bars to facilitate binocular fusion.

Participants viewed the two halves of the screen through a stereoscope whose mirrors were adjusted for each participant at the beginning of the experimental session, in order to obtain stable binocular vision. Participants' head was stabilised by a chin-rest placed at a viewing distance of 57 cm. (see Figure 2.1)

a) 

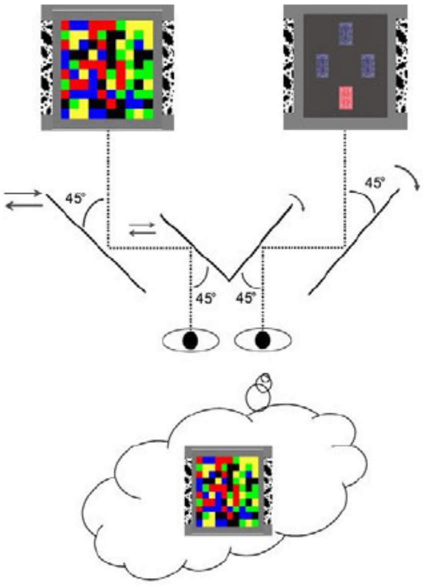
b) 

Figure 2.1. A mirror stereoscope apparatus. a) Actual experimental set-up. b) Schematic representation of how the stereoscope works. A system of mirror reflects one half of the screen to each eye; if the two halves project different images, the observer will consciously perceive only one at time alternating in the middle of the visual field. If one of them is more dynamic and high contrast than the other, it will be perceived for a relatively long time, hiding the other one from conscious perception.

All stimuli were generated using Photoshop and presented on E-prime. Classical analyses were run on R, while JASP was employed for the Bayesian analyses.

2.2.2 Analyses

Control experiment data are analysed and described first. In order to make sure that the results were related to the subliminal processing of the stimuli, I checked if any of the participants were able to locate the masked cue significantly better than chance when explicitly asked to do so, and how good they could evaluate their ability in performing this task. So a binomial analysis was carried out on individual performance to compare it against chance (25%).

Participants showing a significantly above chance performance were excluded from further analyses.

On the remaining participants mean confidence was calculated. Mean confidence of 1 indicates that the participants' judgment on cue visibility was low (I have seen nothing). Mean confidence on correct and incorrect trials was compared by a t-test to assess if participants were able to track their performance. A significant difference between these ratings, with higher confidence on correct than incorrect trials would indicate that participants may have some awareness about their performance, thus being not utterly unconscious about the cue.

Finally, a Bayesian binomial analysis with a flat uninformative prior is run to test the strength of the evidence for the null hypothesis: the likelihood that participants were performing at chance, by guessing, compared to the probability that they were performing above chance, so correctly locating the cue. Bayesian analyses are crucial in this case, where the assumption that participants were actually unaware of the prime is based on the acceptance of the null hypothesis (Shanks, 2016), and classical frequentist statistics do not test how much the null hypothesis is supported by evidence. To determine the Bayes factor, I used an uninformative flat prior, as there was no prior specific assumption about the data.

Analyses on the main experiment were run by excluding the participants performing above chance in the control experiment and by cleaning RTs following a cut-off of 200 ms and 2500 ms (Whelan, 2008). Performance is analysed through a one-way ANOVA with delay as a within-subject factor on the mean accuracy. Classical and Bayesian (flat prior) binomial analyses sorted by delays are performed on the percentage of correct answers to compare the probability that accuracy was at chance (25%) or above chance. Considering four comparisons, Bonferroni adjusted significance threshold would be of $\alpha = 0.012$.

The effect of the cue is also assessed through RTs, with a 4x2 repeated measures ANOVA with delay (500, 1000, 2000, 5000 ms) and cue (present on correct trials vs absent) as within-subjects factor.

2.3 Supraliminal Pilot

The first pilot aimed at checking whether a red card is a valid cue to influence participants’ choice in the absence of explicit instruction.

To this aim, an experiment with supraliminal prime was performed. The CFS apparatus was used even though there was no subliminal presentation of stimuli. If the participants' choices were biased towards the position of the red cue, it would mean that such a cue is effective and can be used in the subliminal experimental paradigm.

2.3.1 Stimuli

The stimulus set consisted of 5 images (6.17°x 5.73°) representing four playing cards in cross formation and back view. In the control (uncued condition) and response stimulus all the cards were blue (luminance: 5.56 cd/m^2) on a grey background (0.70 cd/m^2), in the other images (cued condition) one of the cards was red coloured (22.21 cd/m^2) and represented the prime (Figure 2.2).

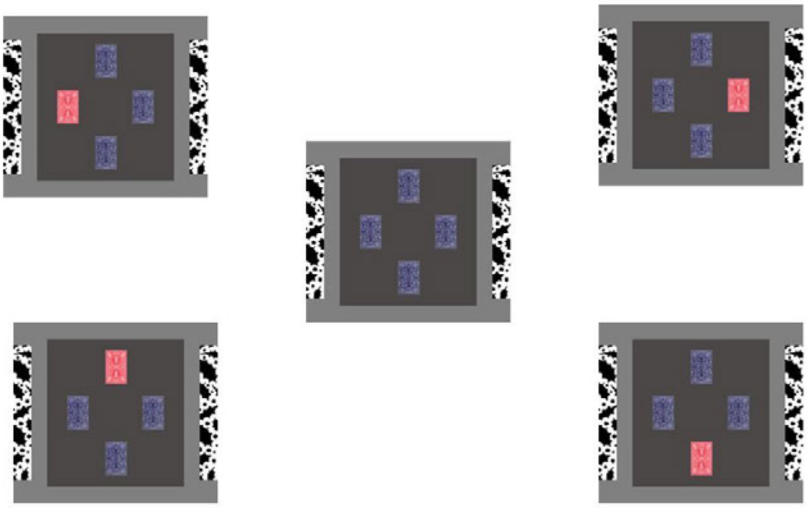


Figure 2.2. Stimulus set. In the middle there is the uncued condition (20% of the trials). In the four cue condition, the red card represents the prime

2.3.2 Participants and procedure

Fourteen healthy participants (3 males, mean age= 19.7), recruited among the first year undergraduate students of the University of Edinburgh, took part in the study for course credits. They all had normal or corrected to normal vision and signed the consent form.

Participants sat with their head on the chin–rest and the stereoscope's mirrors were adjusted to reach binocular vision stabilisation, so that participants' perception of the two halves of the screen was collapsed into one. After that, they were presented with the instructions. They were instructed to perform a

guessing game: they were going to see four cards, a fixation cross and four cards again. They were informed that there was a winning card every round, and asked to pick the card they felt to be the winning one, by using the arrow keys of the keyboard. At the end of the experiment they would be told how many good choices they made, but no feedback was given on individual trials.
The experiment started after eight practice trials. Choices and reaction times were collected.

Each trial started with a 500ms fixation cross, then the prime was presented for 500ms both on the right and left sides of the screen. The prime was followed by a variable delay period of 500, 1000, 2000 or 5000 milliseconds, during which just a fixation cross was displayed. Then the response-stimulus, representing the four blue cards, was presented until the subjects' response. Each stimulus was presented 15 times at the four different delays, for a total of 300 trials. Participants were given a break after 150 trials. Presentation order of trials was randomised.

2.3.3 Results

A chi-square test of independence was performed to examine the relation between cue location and response. The relation between these variables was significant, X2 (12, N= 4088)= 4723.22, $p < .001$, thus demonstrating, along with the descriptive statistics described in table 2.1, that participants' responses are biased toward the card of a different colour.

stimulus * response Crosstabulation

		Response			
		DOWN	LEFT	RIGHT	UP
Stimulus	control	19.5%	20.7%	21.2%	18.6%
	down	62.8%	5.4%	5.1%	7.8%
	left	5.3%	61.9%	6.7%	6.9%
	right	5.0%	6.8%	61.8%	6.3%
	top	7.4%	5.3%	5.2%	60.4%

Table 2.1. Percentage of response for each stimulus

2.4 Perceptual Pilot

The second pilot was planned in order to check whether stimuli luminance was appropriate to undergo CFS. In this case, participants were asked to indicate the position of the red card and how well they saw it. A successful suppression would be reflected in a mean confidence rating close to 1 (I have seen nothing) and no difference between mean ratings on correct and incorrect trials, which means that participants are not able to assess their performance and were actually guessing.

2.4.1 Stimuli

Masks were created as 20 Hz refresh rating GIF consisting of squares in five palette colours (yellow, green, blue, black and red) covering a visual angle of 7.93°.

Stimulus set was the same as the supraliminal pilot.

2.4.2 Participants and procedure

Six participants were recruited among the students (2 males, mean age= 19.17) of the University of Edinburgh. They took part in the experiment in exchange of course credit. They all had normal or corrected to normal vision and signed the consent form.

The participants were seated with their head on the chin – rest and, after the binocular vision stabilisation, were presented with instructions. They were told they were going to see a pattern of colours, a fixation cross, and four cards, and that sometimes a red card was hidden "behind" the colours. They were asked to indicate through the arrow keys in which of the four positions they think the red card appeared. Then they had to rate, on a scale ranging from 1 to 4, how well they saw the red card.

Each trial began with a 500ms fixation cross, followed by the presentation of the cue to the right eye together with the mask to the left eye, for 500ms. Then, both eyes were presented with a 500ms fixation cross, followed by the response stimulus. After the response, participants were asked to provide a rating on the Perceptual Awareness Scale (Ramsøy & Overgaard, 2004): both eyes were presented with a rating grid ranging from 1 to 4 and the question "how well did you see the red card?". The rating 1 was labelled as "nothing", the 2 as "a glimpse", the 3 as "something, but not sure", the 4 as "clearly seen". The ratings were given with the left hand on the keyboard.

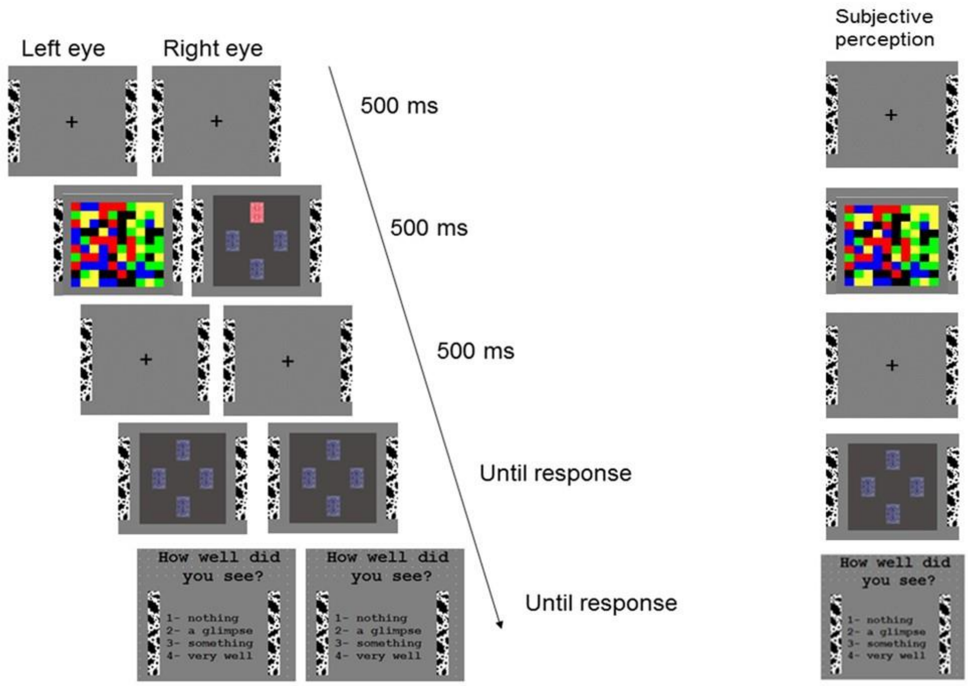


Figure 2.3. Example of a trial sequence: images were presented to the left and right eye separately using a stereoscope. The final percept is shown on the right of the picture. Each trial begins with a 500 ms fixation cross; then the subliminal cue appeared to the right eye while the mask was presented to the left eye for 500ms. After a delay of 500ms in which the fixation cross appeared participants were presented with four playing cards and asked to pick the red card by pressing the correspondent arrow key. After the choice, they were asked to rate how well they saw the red card on a scale from 1 to 4.

2.4.3 Results

Mean confidence ratings were higher than expected (M=2.87, sd= 1.01), with higher confidence on cue-congruent (M= 3.03, sd= .98) than cue-incongruent (M= 2.41, sd= 1.03) trials [t (5) = 2.551, p= .05], with 70% of cue-congruent answers when visibility rating was 4. These results indicate that the stimuli used broke the CFS mask and were consciously perceived.

From the results of the second pilot, the need to modify stimuli luminance emerged. Stimuli luminance was lowered through Photoshop and tested through a further pilot.

2.5 Perceptual pilot 2

This pilot was similar to the previous one, but with the modified version of the stimuli

2.5.1 Stimuli

Stimulus set was the same as the previous pilot, with the exception that luminance was reduced to 0.77 cd/m^2 for the blue cards, and to 1.39 cd/m^2 for the red card.

2.5.2 Participants and procedure

Six healthy participants (2 males, mean age = 23.4) were recruited from among the students of the University of Edinburgh. They took part in the experiment for £7. They all had normal or corrected to normal vision and signed the consent form.

The procedure was the same as the previous perceptual pilot.

2.5.3 Results

Mean confidence rating was calculated (M=1.52, sd= 0.88). No difference was found between confidence ratings on cue-congruent (M= 1.5, sd= 0.8) and cue-incongruent (M= 1.54, sd= 0.9) trials [t (5) = - .707, p= .51], with 23% of cue-congruent answers when visibility rating was 4 and an overall accuracy of 27%, not significantly different from chance [t (5) = 1.34, p= .23].

Results from pilot 3 indicated that the modified stimuli were successfully suppressed from awareness using CFS.

Through three pilots, I ensured that a red card among blue ones would bias participants' choice, and found a reasonable level of luminance to allow stimuli suppression under CFS. At this point, a first version of the main experiment was run to analyse preliminary data and fix possible detailed problems with the stimuli or procedure.

2.6 Experiment 1 – Red card and red in the mask

After assessing the validity of the stimuli through three pilot experiments, demonstrating that a red card biases participants' choices and that stimulus luminosity was appropriate to be suppressed, I programmed the first experiment. The working hypothesis was that WM can be activated without conscious effort by a subliminal cue helping to solve an ambiguous task. Such hypothesis would be supported by finding that performance is above chance level (25% in this 4-choices case) after a retention interval higher than 500ms.

Also, facilitation of the cue (vs uncued trials) on RTs would support the maintenance of a memory trace of the cue.

2.6.1 Stimuli

Stimulus set was the same as the perceptual pilot 2.

2.6.2 Participants and procedure

Twenty healthy participants (2 males, mean age= 19.7 years) were recruited from the University of Edinburgh students. They had normal or corrected to normal vision, and were offered course credits or an honorarium of £7 for taking part in the experiment.

Participants were seated with their head on the chin – rest and, after the binocular vision stabilisation, were presented with instructions. They were told to engage in a guessing game and informed that they were going to see a pattern of colours, a fixation cross and four cards. They were told that there was a winning card every round, and asked to pick the card they felt to be the winning one, by using the arrow keys of the keyboard. At the end of the experiment, they were presented with feedback about how many good choices they had made. The experiment proper began after eight practice trials.

Each trial started with a 500ms fixation cross; then the prime was presented for 500ms to the right eye, at the same time with the mask appearing on the left side. The prime was followed by a variable delay period of 500, 1000, 2000 or 5000 milliseconds, during which just a fixation cross was displayed. Then the response-stimulus, showing the four blue cards, was presented until the participants' response (Figure 2.4). Each stimulus was presented 15 times at the 4 different delays, for a total of 300 trials (in random order), a break was given after 150 trials.

Choices and reaction times were collected.

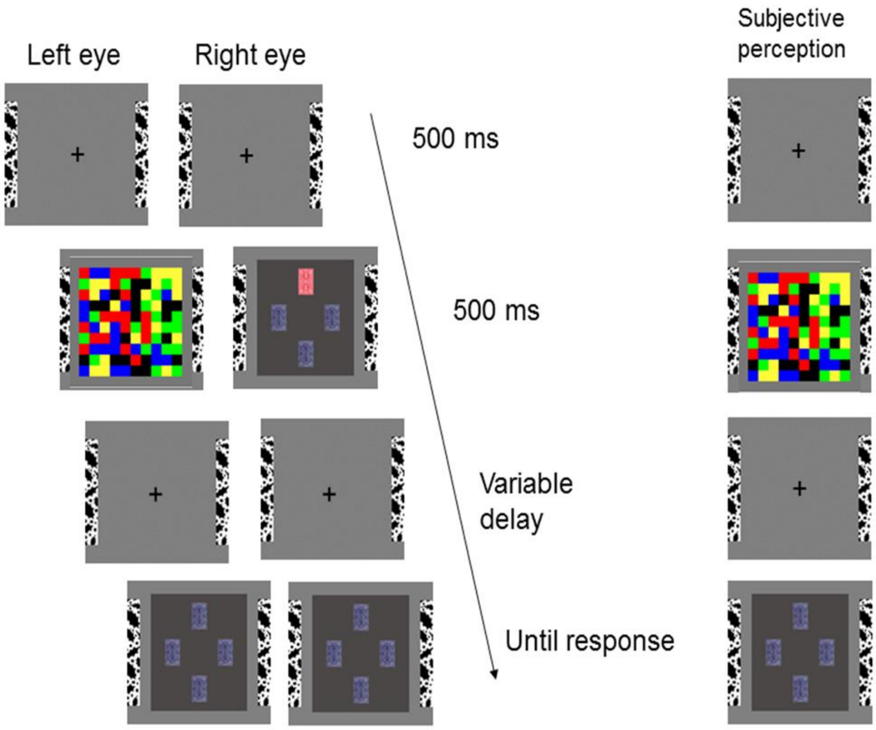


Figure 2.4. Example of a typical trial sequence: images were presented to the left and right eye separately using a stereoscope. The final percept is shown on the right of the picture. Each trial began with a 500 ms fixation cross; then the subliminal cue appeared to the right eye while the mask was presented to the left eye for 500ms. After a delay of either 500, 1000, 2000, or 5000 ms in which the fixation cross appeared in the middle of the screen, participants were presented with four playing cards and asked to pick the winning card by pressing the correspondent arrow key.

2.6.3 Control Experiment

After the main experiment, every participant performed a control experiment to make sure the cue did not break CFS. Participants showing a weak suppression, indicated by an above chance ability to localise the cue and a mean confidence rating bigger than 1 and higher in the cue-congruent than cue-incongruent answers, were excluded from the experiment data analyses. The control experiment was built with the same stimuli of the main experiment and procedure was identical to the procedure of the perceptual pilots.

2.6.4 Results

Two participants were excluded from data analysis due to a failure in stabilising binocular vision. Control experiment data were analysed first, in order to exclude from the main experimental analysis participants showing a break of CFS.

- *Control experiment*

In order to make sure that results were related to the subliminal processing of the stimuli, I had to check if any of the participants were able to locate the masked cue significantly better than chance when explicitly asked to do so, and how good they could evaluate their ability in performing this task. A binomial analysis was then performed to compare individual performance with chance (25%). Seven participants showing a significantly above chance performance were excluded from the experimental analysis.

Mean confidence on cue-congruent (M= 1.38, sd= 0.13) and cue-incongruent trials (M= 1.36, sd= 0.09) were then compared by a t-test showing no significant difference [t (10) =.60, p = .56], with an overall mean confidence rating of 1.37 (sd= 0.31). This is an index that participants were unable to successfully track their performance, so stimuli were properly suppressed from awareness.

A Bayesian binomial analysis was performed in order to statistically test the likelihood that remaining participants' performance was at chance, compared to the probability that it was above chance. Bayes binomial on the frequency of choices showed strong evidence for the null hypothesis over the alternative (BF01 = 13.585). Thus demonstrating that for 11 participants the stimuli were properly suppressed from awareness.

- *Main experiment*

Seven participants were excluded from the data analysis after analysing the control experiment data. Trials with reaction time higher than 2500ms and lower than 200ms (Whelan, 2008) were excluded from analyses (6% of trials; mean per participant = 19.08, sd = 20.7, median = 11 [range 1, 60]).

A one way ANOVA with delay as within subject factor performed on the mean accuracy showed no significant effect [$F(3, 33) = .750$, $p = .530$ $\eta^2 = .064$].

A binomial analysis was performed to estimate whether the performance was significantly different from chance. Binomial analysis on performance sorted by delays showed that performance was at chance at each delay (Figure 2.5).

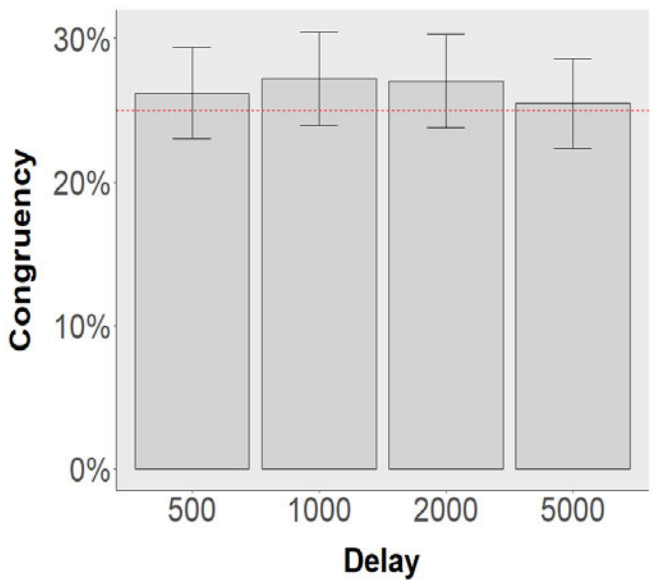


Figure 2.5. Percentage of cue-congruent answers for each delay. The red dotted line represents chance level (25%). Bars are SEM.

A Bayesian binomial test sorted by delays with a flat uninformative prior was run to compare the probability that the frequency of choices was at chance (0.25) with the probability that it was above chance. Results showed that data provide evidence in support of the null hypothesis over the alternative at each delay [500ms (BF01 = 16.474); 1000ms (BF01= 7.149); 2000ms (BF01= 6.151) 5000ms (BF01= 19.080)], which confirms that participants' performance was at chance, and responses were not biased towards the cued card at any of the delays.

Reaction times on cued cue-congruent responses vs responses in uncued trials were analysed through a repeated measures 4 x 2 ANOVA with delay (500, 1000, 2000, 5000 ms) and cue (present, absent) as within subjects factors. Results showed no significant main effect of the delay [$F(3, 33) = .854$, $p=.475$,

η^2 = .072] or of the cue [F (1, 11) = .628, p = .445, η^2 = .054] as well as the interaction between cue and delay [F (3, 33) =.501, p = .684, η^2 = .044].

Data from the main experiment do not confirm the experimental hypothesis. Still, there exists the possibility that the presence of the red colour included both in the mask and in the cue created an interference. It is well known in working memory literature that if the items of a to-be-remembered list are phonologically similar to each other, the memory performance is poorer than when they are phonologically different (Conrad, 1964). Visually similar items in an array also result in poorer memory performance than when items are visually distinct (e.g. Logie, Saito, Morita, Varma, & Norris, 2016). In a paradigm closer that used in the current experiments, Blalock (2013) found a disruption of VWM consolidation in a colour change detection task when the mask was made of the same colours as the array to be remembered.

To rule out that results of Experiment 1 were due to interference caused by the presence of the red colour in the mask and as a prime, I ran a second experiment with a new mask in which the colour red was substituted by other colours.

2.7 Experiment 2 – red card with a mask without red

In order to minimise the interference of the colour red, which in the previous experiment was included both in the mask and the cue, and avoid any similarity effect (Baddeley, 2007) an experiment with a different mask has been performed.

2.7.1 Stimuli

Masks were created as 20 Hz refresh rating GIF consisting of squares in five palette colours (yellow, green, blue, black and dark grey) covering a visual angle of 7.93°. Stimulus set was the same as the previous experiment.

2.7.2 Participants and procedure

23 healthy participants (6 males, average age= 18.6) were recruited among the first year students of the University of Edinburgh, they had normal or corrected to normal vision. All participants took part in the experiment in exchange of course credits. The procedure was the same as the previous experiment.

2.7.3 Results

Control experiment data were analysed in first place, in order to exclude from the main experiment's analysis participants showing a break of CFS.

Control experiment

A binomial analysis was then performed to compare individual performance with chance (25%). Nine participants showing a significantly above chance performance were excluded from the experimental analysis.

For the remaining 14 participants, mean confidence on cue-congruent (M= 1.31, sd= 0.48, 25%) and cue-incongruent trials (M= 1.27, sd= 0.47, 75%) were compared by a t-test still showing a significant difference [t (13) = 2.889, p= .012]. The overall mean confidence rating of 1.28 (sd= .47) was reasonably close to 1 (I have seen nothing), but the possibility that there was some awareness about the choices needs to be taken into account in making any interpretation. Again, we run a Bayesian binomial analysis with a flat prior to test the strength of the null hypothesis, i.e. that participants' performance was at chance and they were guessing. I found a very strong evidence for H0 (BF01 = 72.522), thus supporting the idea that stimuli were still properly suppressed from awareness.

- *Main experiment*

Nine participants were excluded from data analyses after analysing the control experiment data. Trials with reaction time higher than 2500 ms and lower than 200ms were discarded from analyses (4.5% of trials; mean per participant = 13.8, sd = 14.7, median = 10 [range 2, 56]).

A one way ANOVA with delay as within-subject factor performed on the mean congruency showed an effect of the delay approaching the commonly assumed level of significance (95%) [$F(3, 39) = 2.617$, $p = 0.06$ $\eta^2 = .168$], with an higher congruency at 2000ms delay than at others delay ($p < .05$)

Binomial analysis sorted by delays showed that performance was significantly above chance at 2000ms (31%, $p < .001$), while at chance for the other delays (Figure 2.6).

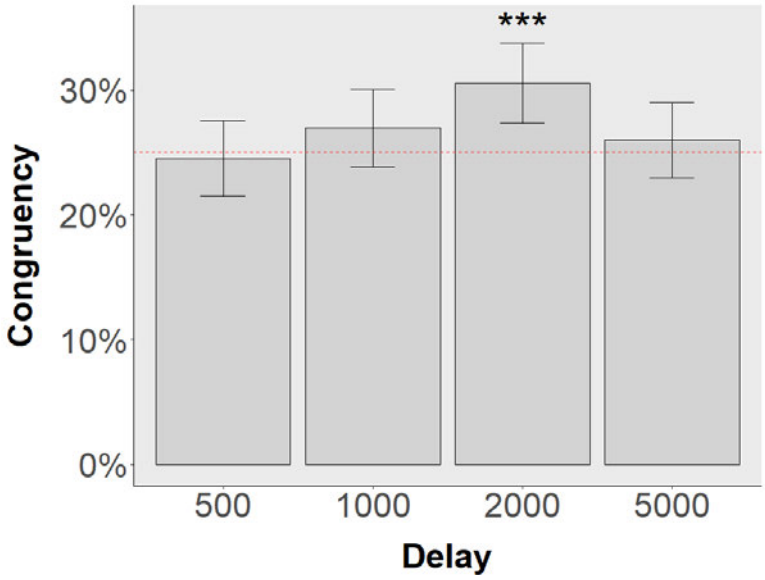


Figure 2.6. Percentage of cue-congruent answers for each delay, the red dotted line represents the chance level. The performance was significantly above chance after a retention interval of 2000ms (31%). Bars are SEM.

A Bayesian binomial sorted by delays with a flat uninformative prior was run to compare further the probability that the accuracy was at chance with the probability that it was above chance (0.25). Results confirmed support for the hypothesis that performance was above chance at 2000ms delay (BF01= 0.035; BF10= 28.189). At the other delays, instead, data were in support of the null hypothesis [500ms (BF01 = 48.647); 1000ms (BF01= 9.617); 5000ms (BF01= 53.379)].

Reaction times on cue-congruent responses vs responses in uncued trials were analysed through a repeated measures 4 x 2 ANOVA with delay (500, 1000, 2000, 5000 ms) and cue (present, absent) as within subjects factors. Results showed a main effect of delay [$F (3, 39) = 11.840$, $p = .001$, $\eta^2 = .477$, Figure 2.7]. Post hoc comparison showed that RTs were significantly longer at 500 ms (M=

855.8, sd= 270.8) compared to 1000ms (M= 721.3, sd= 189.35, p = .001), 2000ms (M= 704.8, sd= 200.8, p=. 001) and 5000ms (M= 678.95, sd= 209.65, p= .001). Cue effect was not significant [F (1, 13) = 1.033, p = .328, η^2 = .074], as well as the interaction between cue and delay [F (3, 39) = 2.201, p = .103, η^2 = .145]

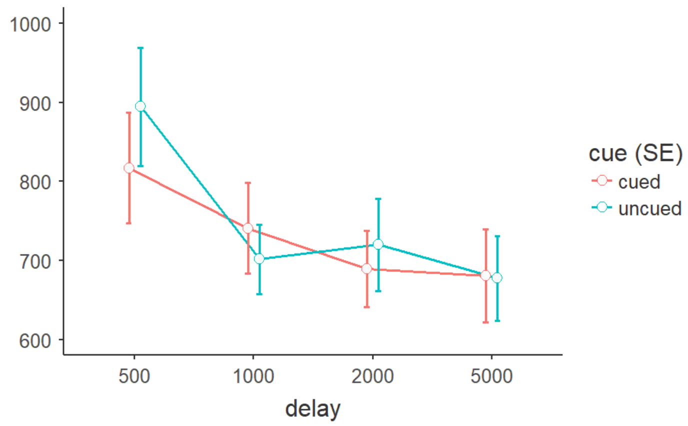


Figure 2.7. Mean RTs across conditions on cue-congruent responses vs uncued trials. Only a main effect of the delay emerged, with responses being slower after 500 ms retention interval. Bars are standard errors.

Results from this experiment seem to support the hypothesis that WM can be engaged unintentionally to retain subliminal stimuli. The absence of a priming effect at 500 ms excludes the possibility that the results are due to iconic memory, while the decrement of the performance at 5000ms seems to indicate a decay of the memory trace.

Even if this pattern of results seems promising, considering that participants showed an ability to discriminate correct and incorrect answers in the control experiment (significant t-test between mean confidence on correct and incorrect trials), these results need to be interpreted carefully. Thus, I decided to replicate them before making any strong conclusion, by running another experiment with a cue of a different colour.

2.8 Experiment 3 - green card

In the previous experiment participants seemed to unconsciously retain a subliminal cue after 2000 ms retention interval, showing an above chance performance in a delayed choice. In order to assess whether these results would persist, we ran the same experiment with a little variation: in the following experiment the red card was replaced by a green card.

2.8.1 Stimuli

Masks were created as 20 Hz refresh rating GIF consisting of squares in five palette colours (yellow, pink, blue, black and red), and then converted to AVI files, covering a visual angle of 7.93°.

Stimulus set consisted of 5 images (6.17°x 5.73°) representing four playing cards in cross formation and back view. In the control (uncued condition) and response stimuli all the cards were blue coloured (0.77 cd/m^2) on a grey background (0.70 cd/m^2), in the other images (cued condition) one of the cards was green coloured (1.317 cd/m^2) and represented the prime.

2.8.2 Participants and procedure

22 healthy participants (7 males, mean age= 21.3) were recruited from the University of Edinburgh students. They had normal or corrected to normal vision, signed a consent form and took part in the experiment in exchange of course credits.

The procedure was the same as the previous experiment.

2.8.3 Results

- *Control experiment*

A binomial analysis was performed to compare individual performance with chance (25%). Five participants showing a significantly above chance performance were excluded from the experimental analyses.

Mean confidence ratings on cue-congruent (M= 1.32, sd= .49) and cue-incongruent trials (M= 1.35, sd= .57) were then compared by a t-test and showed no significant difference [$t(16) = -1.217$, $p= .241$], with an overall mean confidence rating of 1.34 (sd= .55). This demonstrated that the remaining 17 participants were unable to track their performance successfully, so their correct answers were likely to be a guess. A Bayesian binomial analysis with a flat prior confirmed in fact that participants' performance was at chance. We found very strong evidence for H0 (BF01 = 45.461), thus supporting the assumption that stimuli were properly suppressed from awareness

- *Main experiment*

Five participants were excluded from data analyses after analysing the control experiment data. Trials with reaction time higher than 2500 ms and lower than 200ms (Whelan, 2008) were excluded from analyses (6.4% of trials; mean per participant = 19.2, sd = 26.4, median = 8 [range 3, 103]).

A one way ANOVA with delay as a within-subject factor performed on the mean accuracy showed no effect of the delay [$F(3, 48) = 1.688$, $p = .182$ $\eta^2 = .095$]. Binomial analysis sorted by delays showed that at 5000 ms, performance was above chance (p=.01, 28%), while it was firmly at chance for the other delays (Figure 2.8).

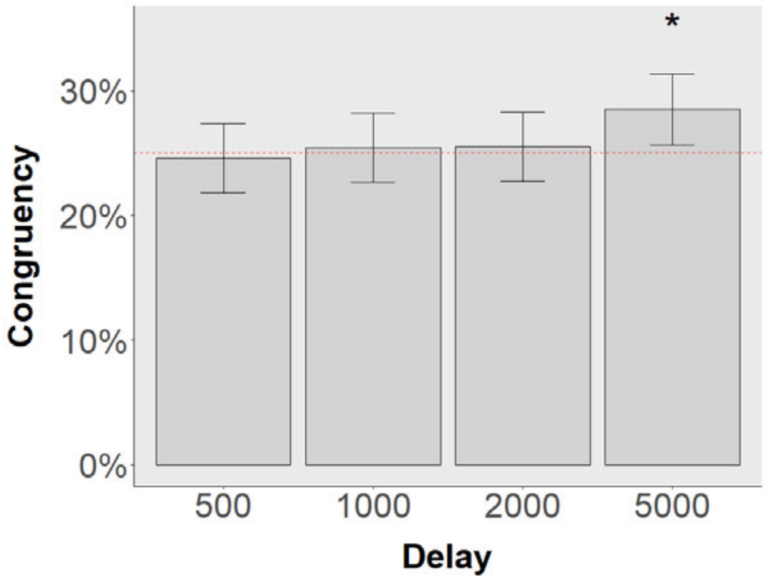


Figure 2.8. Percentage of cue-congruent answers for each delay. The red dotted line represents the chance level (25%). Bars are SEM.

A Bayesian binomial sorted by delays was run with a flat uninformative prior to compare the probability that the accuracy was at chance with the probability that it was higher than chance (0.25). Results supported null hypothesis over the alternative [500ms (BF01 = 45.870); 1000ms (BF01= 40.857); 2000ms (BF01= 33.839);5000ms (BF01= 1.862)]. Hence, according to Bayesian analyses, evidence from this experiment mostly support the hypothesis that performance was at chance. It has to be noted that, differently from the strong support for the null hypothesis at earlier delays, at 5000ms retention interval such support was just anecdotal, partially confirming the pattern of the classical analyses.

Reaction times on cue-congruent responses vs responses in uncued trials were analysed through a repeated measures 4 x 2 ANOVA with delay (500, 1000, 2000, 5000 ms) and cue (present, absent) as within subjects factors. Results showed a main effects of delay [F (3, 45) = 4.498, p = .008, η^2 = .231]. Post hoc comparisons (Bonferroni corrected) showed that RTs at 500 ms (M= 897.05, sd= 287.6) were significantly longer than 2000ms (M= 796.9, sd= 303.9, p= .03) and to 5000ms (M= 775.15, sd= 279.15, p= .009). The cue effect was not significant [F (1, 15) = .066, p = .801, η^2 = .004], neither was the interaction between cue and delay [F (3, 45) = 1.370, p = .264, η^2 = .084, Figure 2.9]

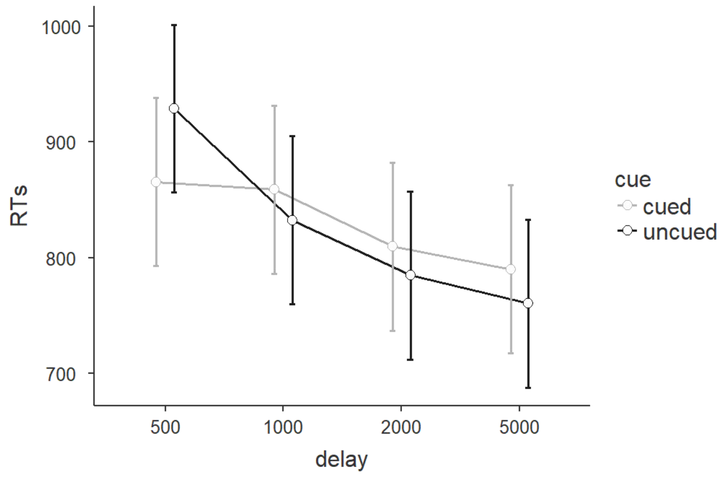


Figure 2.9. Mean RTs across delays on cue-congruent vs uncued trials. Bars are SEM.

Results from this study do not replicate the effect of the experiment with the red cue, where performance was facilitated after 2000ms retention. Still, there is still some small evidence for implicit retention of subliminal stimuli, as an increase in performance was found after 5000ms. This result was not strong enough to reach statistical significance on a Bayesian analysis, but cannot be ignored. The difference with the previous experiment might, in fact, be explained in terms of saliency, as the red colour has been demonstrated to be a salient stimulus processed earlier than other contrast-matched stimuli in primary visual cortex (Emmanouil, Avigan, Persuh, & Ro, 2013).

Thus, a new experiment with both green and red primes needs to be performed in order to clarify previous results, as replicating both the patterns would confirm that there is a retention of the subliminal cue, and its course is influenced by stimulus features.

2.9 Experiment 4 - red and green cards intermixed across trials

To understand whether the difference found in the previous experiments was due to physical characteristics of the stimuli, I ran another experiment by using both the green and the red card as primes, intermixing them randomly across trials.

2.9.1 Stimuli

Masks and stimuli were the same as the experiments 2 and 3. Stimuli in the green condition were always associated with the mask without green, vice versa for the red condition (yellow, pink, blue, black and red - as mask for the green cue; yellow, green, blue, black and dark grey -to use with the red cue).

2.9.2 Participants and procedure

Twenty-two healthy participants (9 males, average age= 18.7) were recruited from the University of Edinburgh students. They had normal or corrected to normal vision, and took part in the experiment for course credits or £7/hour. Colour vision was assessed through Dvorine Colour Plates (4/4 correct).

The procedure was the same as in the previous experiments, with the exception that each stimulus was presented 12 times at the 4 different delays and two different colours, for a total of 480 trials. Two breaks were given (every 150 trials). Trial presentation order was randomized. Choices and reaction times were collected.

After the main experiment, every participant performed a control experiment with the same stimuli as the main experiment. Participants were informed that the pattern of colours was hiding either a red or a green card, and were asked to say in which of the four positions they think that card was, and then to rate from 1 (nothing) to 4 (very well) how well they saw it. The procedure was the same as all the previously described control experiments.

Each stimulus was presented 16 times in the two different colours -with the corresponding mask- for a total of 160 trials.

2.9.3 Results

Green and red trials were analysed separately both in the control and in the main experiment.

- *Control experiment*

A binomial analysis sorted by subjects and prime colour was performed. Four participants showing significantly above chance performance with the green cue were excluded from the experimental analysis of the green cue trials. Similarly, four participants – two of them being the same in both colour conditions - performing above chance with the red cue in the control experiments were excluded from the analysis of the red cue trials of the main experiment.

For the green cue trials, mean confidence on cue-congruent (M= 1.27, sd= .36) and cue-incongruent responses (M= 1.26, sd= .36) were then compared by a t-test showing no significant difference [t (17) = 1.28, p= .21], with an overall mean confidence rating of 1.26 (sd= .36).

The same analysis was run for the red trials, with mean confidence on cue-congruent (M= 1.28, sd= .35) and cue-incongruent responses (M= 1.26, sd= .34) showing no significant difference [t (17) = 0.97, p= .34], and an overall mean confidence of 1.27 (sd= .34).

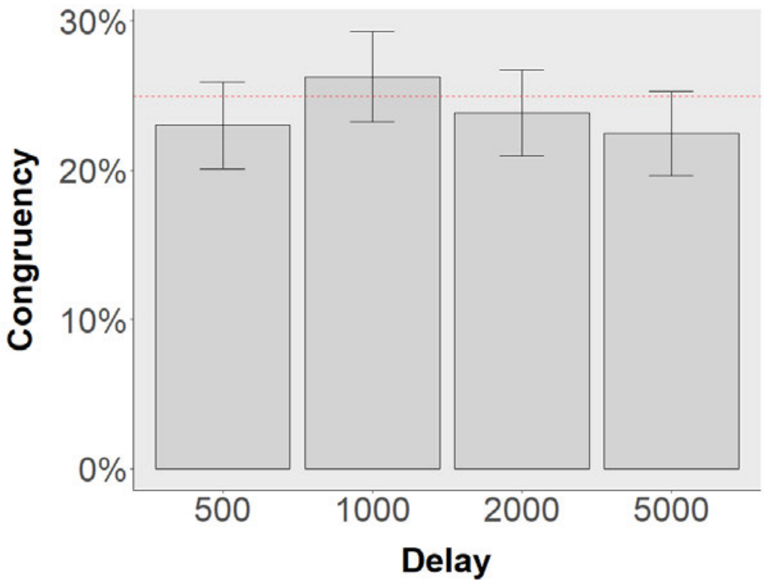
As in the previous experiments, I ran a Bayesian binomial analysis with a flat prior on JASP to test the strength of our assumption about the null hypothesis, to confirm whether participants' performance was at chance. There was strong evidence for the null hypothesis both in green cue trials (BF01 = 40.541) and in red (BF01 = 800.528) cue trials.

- *Main experiment*

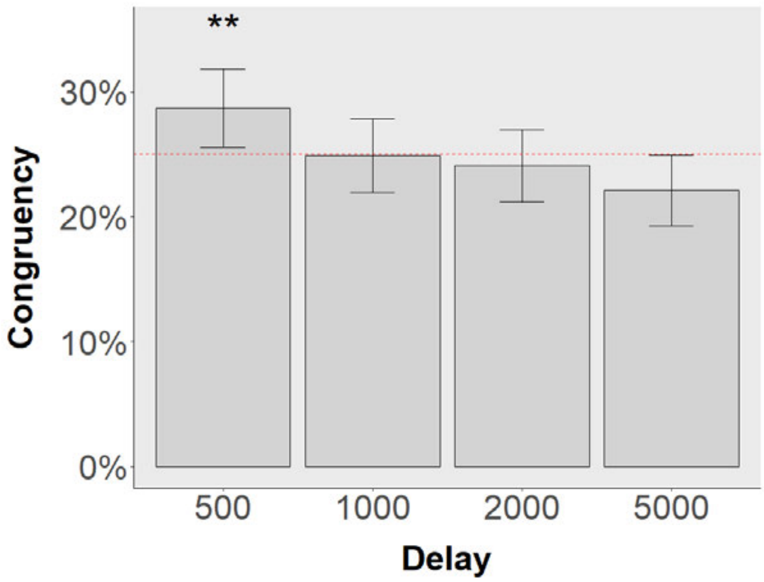
Trials with reaction times higher than 2500ms and lower than 200ms were excluded from analysis (4.42% of trials. Green: 4.12%; mean per participant = 9.9, sd = 10.2, median = 7 [range 1, 40]; Red: 4.93%; mean per participant = 11.9, sd = 14.9, median = 7 [range 0, 61]).

A repeated measures ANOVA on mean accuracy with delay as within-subject factor showed no effect of the delay on the green [F (3, 51) = 1.673, p = .184, η^2 = .090], but this effect was significant with the red card trials [F (3, 51) = 4.399, p = .008, η^2 = .206]. Post-hoc comparison with Bonferroni correction showed that there was a significant difference between accuracy at 500 ms (M= .28, sd=.07) and 5000 ms (M=.22, sd=.05, p=.012)

Binomial analysis sorted by delays and colour showed that performance was not significantly different from chance at each delay for the green trials (Figure 2.10a). For the red trials performance was at chance at each delay, with the exception of 500ms, where probability to have 28% of success was significantly different from chance (p= .009, Figure 2.10b).



a)



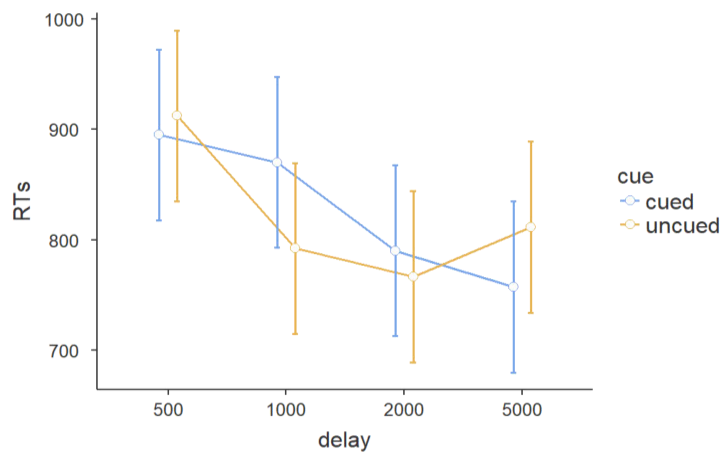
b)

Figure 2.10. Percentage of cue-congruent answers at each delay, with the green cue (a) and the red cue (b). The red dotted line represents the chance level (25%). Performance is at chance at each delay, with the exception of 500ms delay in the red cue condition (b), with 28% of cue-congruent answers (p=.009).Bars are SEM.

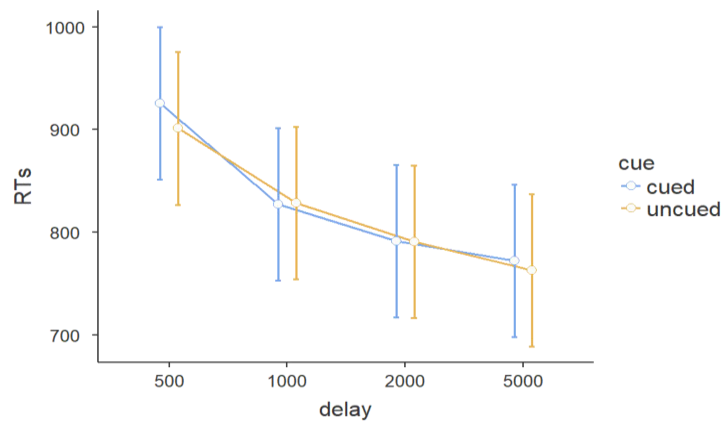
A Bayesian binomial sorted by delays was run with a flat uninformative prior to compare the probability that the accuracy was at chance (null hypothesis- H0) with the probability that it was above chance (alternative hypothesis- H1). Results with the green cue showed support for the null hypothesis over the alternative at [500ms (BF01 = 66.792);1000ms (BF01= 8.297); 2000ms (BF01= 63.739) 5000ms (BF01= 102.845)]. Also results with the red cue showed evidence for the null hypothesis over the alternative at [500ms (BF01 = 6.430); 1000ms (BF01= 43.820);2000ms (BF01= 66.792) 5000ms (BF01= 106.300)]. Hence, the Bayesian test does not confirm that performance at 500ms in the red cue trials was different enough from chance to disconfirm the null hypothesis.

On trials with the green cue, reaction times on cue-congruent responses vs responses in uncued trials were analysed through a repeated measures 4 x 2 ANOVA with delay (500, 1000, 2000, 5000 ms) and cue (present, absent) as within subjects factors. Results showed a main effect of delay [$F(3, 51) = 6.237$, $p = .001$, $\eta^2 = .268$]. Post hoc comparison (Bonferroni corrected) showed that RTs were significantly longer at 500 ms (M= 903.7, sd= 357.05) compared to 2000ms (M= 778.5, sd= 320.45, p= .002) and to 5000ms (M= 784.6, sd= 307.45, p= .004). The effect of the cue was not significant [$F(1, 17) = .141$, $p = .712$, $\eta^2 = .008$] as well as the interaction between cue and delay [$F(3, 51) = 1.901$, $p = .141$, $\eta^2 = .101$, Figure 2.11a].

The same analysis on the red cued trials similarly showed a main effect of delay [F (3, 51) = 6.970, p=.000, η^2 = .291], with significantly longer RTs at 500 ms (M= 913.45, sd= 375.7) compared to 2000ms (Mean= 791, sd= 312.75, p= .004) and to 5000ms (M= 767.75, sd= 268.65, p=.000). The effect of the cue was not significant [F (1, 17) = 6.970, p = .659, η^2 = .012], as well as the interaction between cue and delay [F (3, 51) = .082, p = .969, η^2 = .005, Figure 2.11b].



a)



b)

Figure 2.11 Mean RTs across conditions on cue-congruent vs uncued trials in the green block (a) and the red block (b). In both analyses, only a main effect of the delay emerged, with responses being slower after 500ms retention interval. Bars are standard errors

Results and patterns from this experiment do not replicate any of the previous findings, with no significant above chance performance apart from 500ms delay with the red cue, not confirmed by Bayesian test and not resembling the previous results or patterns. This made the interpretation somewhat puzzling. One possible explanation is that constant subliminal exposure to the same stimulus can differentially affect the processing of such stimulus compared to an intermixed presentation. To address this possibility, I carried out another experiment where the green and the red prime were presented in two different blocks, whose order was counterbalanced across participants.

2.10 Experiment 5 - red and green card in blocks

To further explore the possibility that WM can be implicitly activated by a subliminal stimulus in order to perform a task, I ran four experiments with different results. In the first experiment the absence of any effect of the cue could be attributed to an interference of the red colour in the mask on the processing of the red cue. When this issue was addressed by modifying the mask in the second experiment, a significant effect of the cue on performance emerged after 2000 ms delay. This was not the case in the 3rd experiment, where the cue was green, and there was a trend to perform above chance after 5000 ms delay. The lack of replication of these results in the 4th experiment might be due to the intermixed presentation of the two different cues across trials.

For these reasons, I performed another experiment in which the red cue and the green cue were presented to every participant in separate blocks. In this way I tried to replicate the two different effects found in the Experiments 2 and 3, making sure that the alternate presentation of the colours does not create any interference.

2.10.1 Stimuli

Stimuli were the same as in the previous experiment.

2.10.2 Participants and procedure

Nineteen healthy participants (6 males, average age= 19.6) were recruited from among the University of Edinburgh students. They had normal or corrected to normal vision, and took part in the experiment for course credits or £7/hour. Colour vision was assessed through Dvorine colour plates (4/4 correct).

The procedure was the same as for the previous experiments, with the exception that each of the 5 stimuli was presented 15 times in two different colours at 4 delays (500, 1000, 2000, 5000 ms), for a total of 600 trials. Breaks were given after each block of 150 trials. Red cues and green cues were presented in different blocks, whose presentation order was counterbalanced across participants (R-G-R-G/G-R-G-R/ R-R-G-G/G-G-R-R). Choices and reaction times were collected.

After the main experiment, each participant performed a control experiment with the same stimuli as the main experiment. Participants were informed that the pattern of colours was hiding a red card (for the red block) or a green card (for the green block) and were asked to indicate in which of the four positions they think the differently coloured card was presented, and then to rate from 1 to 4 how well they saw it. Presentation order was counterbalanced across participants. The procedure was the same as the previous control experiment, each stimulus was presented 15 times in two different colour and one delay (500ms), for a total of 150 trials.

2.10.3 Results

- *Control experiment*

A binomial analysis sorted by cue colour was performed on individual performance. Ten participants showing a significantly above chance performance in the green cue blocks were excluded from the experimental analysis of the green cue. Eight participants performing above chance in the red cue blocks of the control experiments were excluded from the analysis of the red cue blocks of the main experiment. Six of them were excluded from both conditions.

For the green trials, mean confidence on cue-congruent (M= 1.40, sd= .55) and cue-incongruent responses (M= 1.34, sd= .52) were then compared by a t-test showing a difference approaching the commonly assumed significance level of 95% [t (8) = 2.09, p= .06], although the overall mean confidence rating of 1.36 (sd= .53) was reasonably close to 1 (I have seen nothing). The possibility that there was some awareness about the choices needs to be taken into account in making any interpretation of any possible results with the green cue.

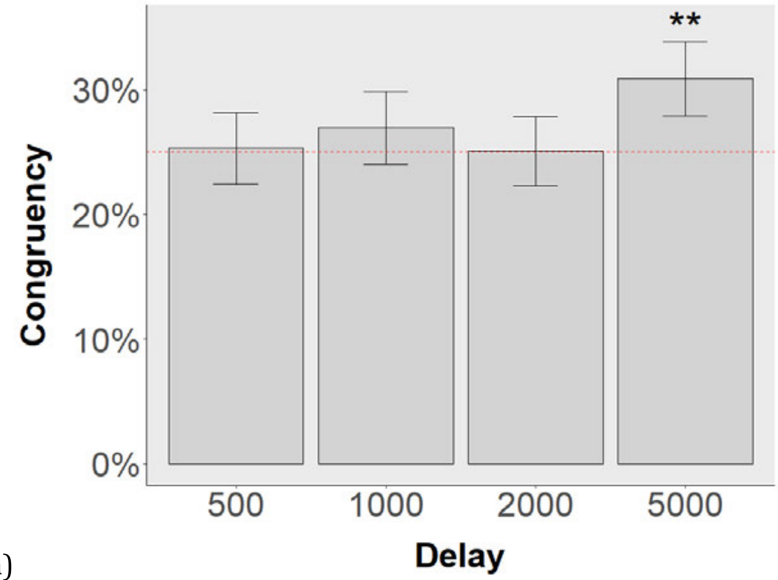
For the red cue trials, mean confidence on cue-congruent (M= 1.34, sd= .27) and cue-incongruent trials (M= 1.31, sd= .27) were also compared by a t-test showing no significant difference [t (9) = 1.37, p= .20], with an overall mean confidence rating of 1.32 (sd= .27). As in the previous experiments, I ran a Bayesian binomial analysis with a flat prior to test the strength of the null hypothesis (performance is at chance) for both prime colours. I found anecdotal evidence for the alternative hypothesis (BF01 = 0.571) in the green block, and moderate evidence for the null hypothesis over the alternative for the red block (BF01= 4.224). The weaker suppression compared to the previous experiments can be due to the long exposure to the stimuli, which has been shown to reduce the effectiveness of suppression (Carmel, 2016), so the results of the main analyses have to be interpreted carefully.

Main experiment

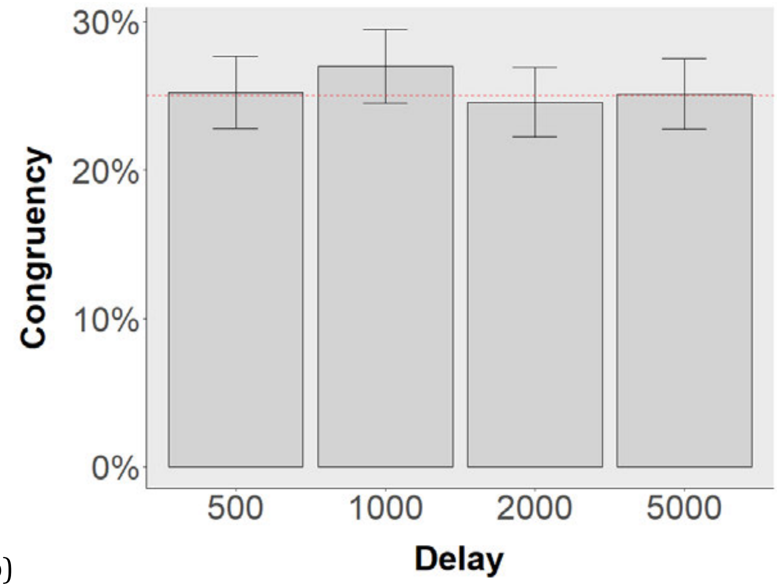
Trials with reaction time higher than 2500ms and lower than 200ms were excluded from analysis (5.46% of the total trials. Green: 5.7%; mean per participant = 17, sd = 17.2, median = 12 [range 2, 54]; Red: 5.12%; mean per participant = 15.4, sd = 16.3, median = 12 [range 1, 58]).

A repeated measures ANOVA on mean accuracy with delay as within-subject factor showed no effect of the delay on the green [F (3, 24) = 1.069, p = .381, η^2 = .118] and red card trials [F (3, 30) = 0.314, p = .815, η^2 = .030]

Binomial analysis sorted by delays and colour showed that performance with the green prime was significantly above chance at a delay of 5000ms ($p = .002$), while at chance for the other delays (Figure 2.12a). The performance with the red prime was at chance at each delay (Figure 2.12b).



a)



b)

Figure 2.12. Percentage of cue-congruent answers at each delay, with the green cue (a) and the red cue (b). The red dotted line represents the chance level (25%). Performance is at chance at each delay, with the exception of 5000ms delay in the green cue condition (a), with 30% of the cue-congruent answers ($p=.002$)

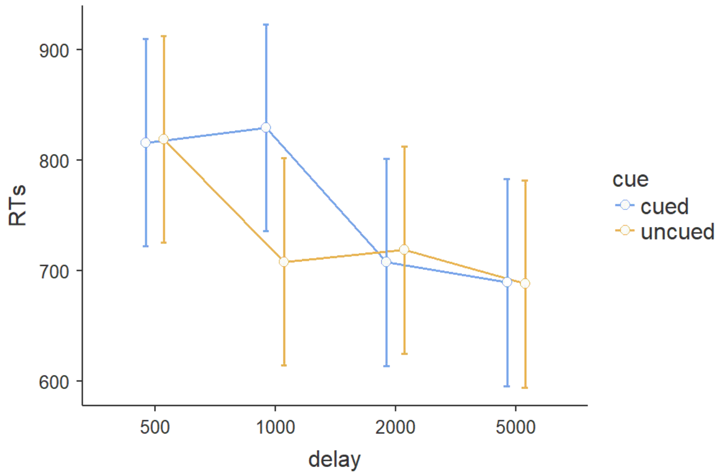
Again, I ran a Bayesian binomial sorted by delays with a flat uninformative prior to compare the probability that the accuracy was at chance (null hypothesis) with the probability that it was higher than chance, to confirm or discard the results of classical analysis. Results for the green block showed more evidence for the null hypothesis over the alternative at every delay [500ms (BF01 = 12.941); 1000ms (BF01= 3.341); 2000ms (BF01= 17.656)] but 5000ms, where there is moderate evidence for the alternative hypothesis over the null (BF01= 0.272, BF10= 3.680).

Results from the red block showed a very strong evidence for the null hypothesis over the alternative at every delay [500ms (BF01 = 32.145); 1000ms (BF01= 11.979); 2000ms (BF01= 41.458); 5000ms (BF01= 38.381)].

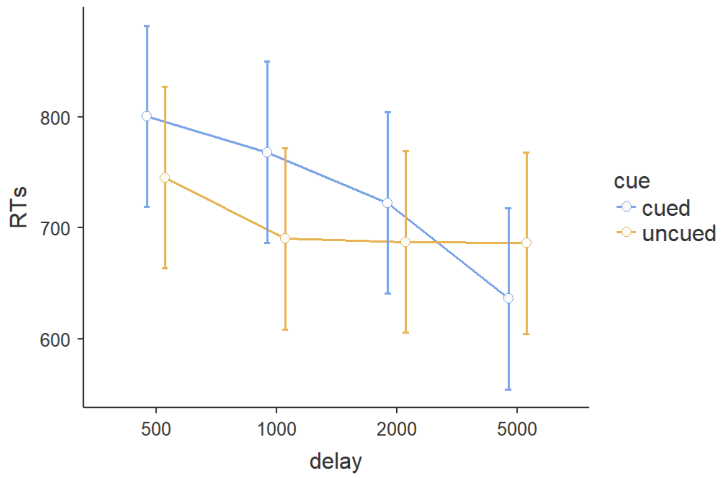
On green trials, reaction times on cue-congruent responses vs responses in uncued trials were analysed through a repeated measures 4 x 2 ANOVA with delay (500, 1000, 2000, 5000 ms) and cue (present, absent) as within subjects factors. Results showed a main effect of delay [$F (3, 24) = 4.499$, $p = .01$, $\eta^2 = .360$]. Post hoc comparison with Bonferroni correction showed longer RTs at 500ms (Mean= 817.35, sd= 260.2) compared to 5000ms (Mean= 688.7, sd= 275.3, $p =.01$). The effect of the cue was not significant [$F (1, 8) = 1.08$, $p=.328$, $\eta^2 = .119$], as well as the interaction between cue and delay [$F (3, 24) = 2.60$, $p=.075$, $\eta^2 = .245$, Figure 2.13a].

Similarly, the same analysis conducted on the red trials showed a main effect of delay [$F (3, 30) = 3.007$, $p = .046$, $\eta^2 = .231$], with significantly longer RTs at

500ms (Mean= 777.6, sd= 266.25) compared to 5000ms (Mean= 661.3, sd= 248.3, p= .03). The effect of the cue was not significant [$F(1, 10) = 1.93$, $p=.195$, $\eta^2 = .162$], while the interaction was only close to the commonly assumed significance level threshold [$F(3, 30) = 2.71$, $p=.06$, $\eta^2 = .213$, Figure 2.13b].



a)



b)

Figure 2.13. Mean RTs across conditions on cue-congruent vs uncued trials in the green block (a) and the red block (b). In both analyses, only a main effect of the delay emerged, with responses being slower after 500ms retention interval. Bars are standard errors.

Results from this experiment seem to show a facilitation effect again with the green card after 5000ms, but the weakness of suppression emerged from the analysis on the control experiment with the green cue makes challenging to exclude that such a result was due to partial awareness. Also, the lack of any effect with the red card does not replicate the effects found with the red cue in Experiment 2.

2.11 Experiment 6 – Replication of Experiment 2

Considering that the Experiment 2, with the red cue and the mask without the red, was the only one showing a strong effect among all the other experiments, running an exact replication of that experiment could help to clarify the ambiguous results presented in the chapter. Results from the Experiment 2 showed that performance was above chance after 2000ms retention, which would have indicated that encoding into WM required time to achieve. However, this effect was not replicated with small experimental variations through 3 further experiments.

If running an exact replication confirms the result, then the ambiguity of the results from the other experiments might be considered and investigated as perceptual effects arising from the experimental variations. As CFS is a relatively new technique, many of its perceptual aspects and how these affect experimental outcomes are still under investigation. On the other side, a lack of replication would undermine the interpretation of the results from Experiment 2, suggesting that they might have arisen by chance, as also suggested by the small support from the BF value. In order to verify this possibility, I repeated the procedure for Experiment 2.

2.11.1 Stimuli

All stimuli were the same as in Experiment 2

2.11.2 Participants and procedure

Eleven healthy participants (2 males, average age= 18.01) were recruited among the first year students of the University of Edinburgh, they had normal or corrected to normal vision. Colour vision was assessed through Dvorine Colour Plates (4/4). All participants took part in the experiment in exchange of course credits. The procedure was the same as in Experiment 2.

2.11.3 Results

- *Control experiment*

A binomial analysis was run on individual performance. Five participants showing a significantly above chance performance were excluded from the experimental analysis. This is a high exclusion rate, so a possible lack of power (0.06 of power in detecting an accuracy of 31% as in the Experiment 2) has to be considered before drawing any conclusion from this data. Still, this experiment only is only a further replication aimed to give an indication about the lack of effects in the previous two experiments with the same red cue. Analyses from the entire sample are also reported in the supplemental material (0.07).

Mean confidence on cue-congruent (M= 1.39, sd= 0.69) and cue-incongruent trials (M= 1.42, sd= 0.82) were compared by a t-test showing no significant difference [$t(5) = -0.62$, $p = .55$]. The overall mean confidence rating was of 1.41 (sd= .79).

Again, I ran a Bayesian binomial analysis with a flat prior on accuracy to test the strength of my prediction about the null hypothesis, assuming that participants' performance was at chance. There was extreme evidence for H0 (BF_{01} = 623.002), thus confirming that stimuli were adequately suppressed from awareness.

Main experiment

Five participants were excluded from the data analysis after analysing the control experiment data. Trials with reaction time higher than 2500 ms and lower than 200ms were discarded from analyses (5.4% of trials; mean per participant = 16.3, sd = 13.4, median = 14 [range 0, 36]).

A one way ANOVA with delay as within-subject factor performed on the mean accuracy showed no effect of the delay [$F(3, 15) = 0.016$, $p = .997$ $\eta^2 = .003$].

Binomial analysis sorted by delays showed that performance was not significantly different from chance at any delay ($p > .1$, Figure 2.14)

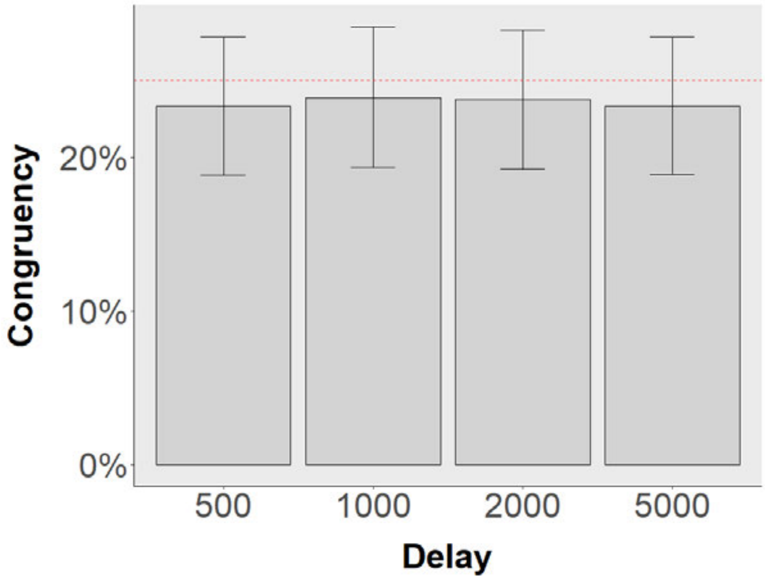


Figure 2.14. Percentage of cue-congruent answers for each delay. The red dotted line represents the chance level (25%)

A Bayesian binomial sorted by delays with a flat uninformative prior showed very strong evidence for the null hypothesis (performance was at chance) over the alternative (performance was higher than chance) at every delay [500ms (BF01 = 40.690); 1000ms (BF01= 34.687); 2000ms (BF01= 36.195; 5000ms (BF01= 40.832)]

Reaction times on cue-congruent responses vs responses in uncued trials were analysed through a repeated measures 4 x 2 ANOVA with delay (500, 1000, 2000, 5000 ms) and cue (present, absent) as within subjects factors. Results showed no significant effect of delay [$F (3, 15) = .702$, $p = .566$, $\eta^2 = .123$], no significant effect of the cue [$F (1, 5) = .136$, $p = .727$, $\eta^2 = .027$], and no significant interaction [$F (3, 15) = .153$, $p = .926$, $\eta^2 = .030$, Figure 2.15a]. The absence of any significant effect of the delay on RTs, consistently encountered across the previous experiments, might be due to the very high variability of the data due to the small sample (see Figure 2.15).

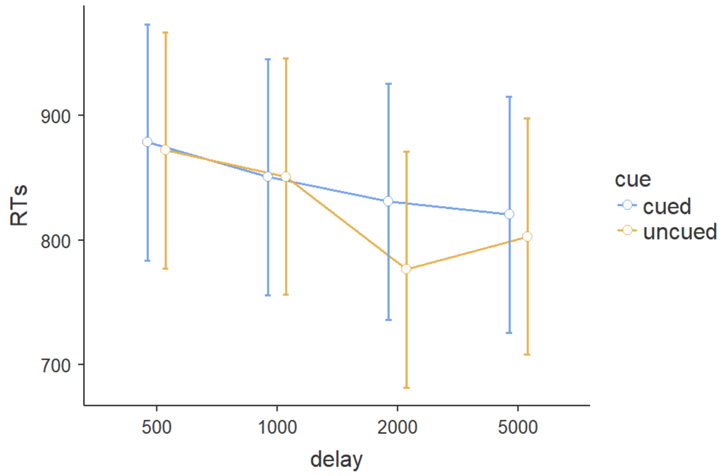


Figure 2.15. Mean RTs across conditions on cue-congruent vs uncued trials. No main effect or interaction was present. Bars are standard errors.

Results from this experiment do not replicate the significant outcome that emerged in a previous identical experiment, thus indicating that those results were not reliable and the lack of replication in the following experiments was not due solely to experimental manipulation.

Experiment	delay	%correct	pvalue	BF01
Red cue and	500	27%	.230	16.474
red in the mask	1000	27%	.08	7.149

	2000	27%	.07	6.151
	5000	26%	.267	19.080
Red cue and mask without red	500	24%	.642	48.647
	1000	27%	.111	9.617
	2000	31%	.000	0.035
	5000	26%	.265	53.379
Green cue	500	25%	.541	45.870
	1000	25%	.483	40.857
	2000	25%	.398	33.839
	5000	28%	.014	1.862
Green and Red cues intermixed (green)	500	23%	.196	66.792
	1000	26%	.418	8.297
	2000	24%	.450	63.739
	5000	23%	.09	102.845
Green and Red cues intermixed (red)	500	28%	.009	6.430
	1000	25%	.545	43.820
	2000	24%	.743	66.792
	5000	32%	.975	106.3
Green and Red cues in blocks (green)	500	26%	.209	12.941
	1000	28%	.04	3.341
	2000	27%	.287	17.656
	5000	31%	.002	0.272
Green and Red cues in blocks (red)	500	26%	.459	32.145
	1000	27%	.138	11.979
	2000	25%	.614	41.458
	5000	25%	.488	38.381

Red cue replication	500	25%	.487	40.690
	1000	27%	.113	34.687
	2000	25%	.423	36.195
	5000	25%	.397	40.832

Table 2.1. Summary of the main experimental results.

2.12 Discussion

The aim of the experiments reported here was to investigate if WM could be implicitly activated by a subliminal cue, thus questioning the depth of the relationship between WM and awareness. Previous studies suggested that subliminal processing could be carried out within WM (e.g., Soto et al., 2011) and that WM could be engaged without explicit instructions and awareness (Hassin et al., 2009). In the current study we addressed the issue of whether, in order to perform an ambiguous task, people can engage WM to retain a subliminal prime without being instructed to do so and without awareness of both the prime and the memory activation. Differently from previous experiments on implicit WM activation using stimuli available as long-term memory representations (Hassin et al., 2009), in the present study no semantic processing was implied, it was a simple but pure Visual task. With the present paradigm, we also tried to address some criticisms raised against previous studies of WM without awareness (Stein et al., 2016). I controlled for the possibility of conscious maintenance of a guess due to the subliminal perception by using different delays and performing a perceptual experiment as a control after each main experiment.

Experiment 1 (red both in the mask and in the prime) was inconclusive. However, it raised the interesting question of whether a colour in the Mondrian mask could affect the colour processing of a suppressed stimulus. This indicates how important it is to pay considerable attention to the method chosen to suppress stimuli from awareness.

In the subsequent study (Experiment 2) I observed a performance significantly above chance after the 2000ms delay. This result would indicate that participants were implicitly engaging their WM with subliminal stimuli after a consolidation period and fast decay. This finding did not replicate (Experiment 3), however performance significantly above chance emerged after 5000ms. To ascertain whether the difference between these two outcomes was due to the physical characteristics of the colours (red vs green) or to a statistical fluke we performed a further experiment (Experiment 4) by intermixing red and green trials whereby the target was the red card with trials whereby the target was the green card, with the respective masks. The outcome was at odds with the previous findings: no significant effect for the green card and a weak significance with the red card after 500ms. In a further study (Experiment 5) the green and the red cues were presented in blocks, in counterbalanced order, with the respective Mondrian masks. This experiment showed a partial replication of the effect with the green prime (above chance performance after 5000ms delay), but chance performance with the red prime. The attempt to replicate the results of Experiment 2 was unsuccessful in Experiment 6, with no significant above chance performance.

In conclusion, results from seven experiments failed to demonstrate the implicit activation of WM with unconscious, non-semantic visual stimuli. The apparently significant results found in experiments 2, 3 and 4 are inconsistent and do not replicate. Thus they seem to be due to random statistical variation, as also supported by the Bayesian analyses.

The poor statistical power of these experiments, due to the high exclusion rate of participants after analyses of the control experiments, will be addressed by an overall analysis in supplemental material, pooling all the experiments together (b). Results from each experiment including the entire participants' sample will also be provided in supplemental material (a). Both analyses will be in support of the absence of any effect.

It is clear that further investigation is needed in order to draw firm conclusions. In first place, there is the need to verify a possible influence of the masking method. As CFS is becoming widely used in unconscious processing literature, some studies comparing this method to other masking techniques as backward masking and metacontrast masking revealed significant differences in the perceptual effects of the different methods. In particular weak or absent perceptual priming is often found under CFS compared to other masking techniques (Faivre, Berthet, & Kouider, 2014; Izatt, Dubois, Faivre, & Koch, 2014; Peremen & Lamy, 2014, Moors, Hesselmann, Wagemans, & van Ee, 2017).

For this reason, it is advisable to take into account these differences when running studies on subliminal perception (Izatt et al., 2014).

On this basis I adapted the paradigm to perform it with Backward Masking, which is the masking method used in the study by Soto et al. (2011), first demonstrating the maintenance of subliminal stimuli in WM.

3 BACKWARD MASKING

3.1 Introduction

In the previous chapter, I described a series of experiments aimed at assessing if WM could be implicitly activated by stimuli suppressed from awareness by CFS, in order to perform a task. The outcome from 6 experiments did not support this hypothesis. However, to support a negative finding more robust evidence is needed. One concern is related to the method used to suppress the stimuli from awareness, as it is possible that CFS might not be the best technique for the purpose. Different suppression methods, in fact, have been shown to differently affect stimulus processing (Marcus Rothkirch & Hesselmann, 2017).

CFS is based on the presentation of a stimulus to one eye while the other eye is presented with a dynamic pattern which, due to binocular rivalry, will suppress the stimulus from consciousness for several seconds (Tsuchiya & Koch, 2005). This suppression technique is relatively recent, but produced promising results (Hassin, 2013, Sklar et al., 2012). It has been employed in many experiments showing high-level elaboration taking place outside of conscious awareness, like reading small sentences and performing arithmetic (Sklar et al.2012), processing words meaning (Costello, Jiang, Baartman, McGlennen, & He, 2009) and detecting scene congruency (Mudrik, Breska, Lamy, & Deouell, 2011).

Bergström & Eriksson, (2015) found that participants could retain in WM stimuli suppressed from awareness through CFS for up to 15 seconds.

However, some recent attempted replications of these studies did not reach the same conclusions: Rabagliati et al., (2018), for instance, failed to replicate Sklar's et al. (2012) results on unconscious reading, recommending particular attention to false positives in this kind of study. Similar conclusions were drawn by Moors, Boelens, van Overwalle, & Wagemans, (2016) after they conducted a Bayesian reanalysis of the study by Mudrik et al. (2011).

Hesselman and Moors (2015) pointed out that the high expectations about the possibility to study unconscious high level cognition using CFS seem in contrast with decades of studies exploring the effects of binocular rivalry, on which CFS is based, and mostly demonstrating limited cognitive processing under this manipulation (for a review see Sterzer, Stein, Ludwig, Rothkirch, Hesselmann, et al., 2014). Also, the activity of the early visual cortex seems to be dramatically reduced by CFS masks (Yuval-Greenberg & Heeger, 2013), and it has been suggested that this could leave only some basic features of the suppressed object available for processing (Hesselmann & Moors, 2015; Moors et al., 2017).

It could be the case, then, that CFS not only suppressed the present stimuli from conscious processing but also disrupted the unconscious representation of their key features.

An alternative to CFS to render stimuli subliminal is Backward Masking (BM), which involves a very brief presentation of the stimulus (shorter than 50 ms) immediately followed by a mask (Faivre, Berthet, & Kouider, 2012).

BM and CFS seem to affect visual processing in a different way. A common idea of visual processing in the brain considers a division between two visual streams (Goodale & Milner, 1992): the ventral stream has been generally associated with the processing of visual shapes and objects, while the dorsal pathway seems to be involved in reaching and grasping behaviour. Fang & He (2005), in a fMRI study, found that stimuli made invisible by interocular suppression produced activation in the dorsal cortical area, suggesting that CFS may selectively affect the ventral visual pathways, leaving intact the features processed by the dorsal stream (Lin & He, 2009). This idea was confirmed by Almeida, Mahon, Nakayama, & Caramazza (2008), who found priming effects under BM with several stimulus categories (e.g., tools or animals), while priming under CFS was only restricted to tools and manipulable objects. The latter category is, in fact, considered to be processed in the dorsal visual pathway (Fang & He, 2005).

This theory is debated, and the results are not conclusive (Hebart & Hesselmann, 2012; Sterzer, Stein, Ludwig, Rothkirch, Hesselmann, et al., 2014; Rothkirch & Hesselmann, 2018), but still the possibility that different masking methods affect the visual processing in different ways cannot be ignored.

Therefore, I ran a further series of experiments following a procedure similar to the one described in the previous chapter, but using BM instead of CFS.

Over and above the use of a different masking method, other methodological variations have been introduced in the experiments reported in this chapter. One of these consisted of providing feedback after each trial, in order to rule out the possibility that the lack of reinforcement might have lead participants to neglect the cue (Ansorge, Kiss, & Eimer, 2009). It has been demonstrated, in fact, that top-down attribution of cue relevance and the presence of explicit feedback do have a significant impact on accuracy in subliminal priming and implicit learning experiments (e.g. Mealor & Dienes, 2013). This motivational factor could have played an essential role in modulating the present results, so the second experiment of this chapter aims to establish whether this was the case.

In a further experiment, I used stimuli selected to activate semantic representations, to address the possibility that implicit WM activation only concerns semantic and long-term memory retrieval. The influence of knowledge and long-term memories on WM performance has been widely acknowledged (see Logie, 2016). Della Sala et al. (2010), for example, found an implicit WM activation for familiar but not unfamiliar stimuli in brain-damaged patients. Also, following Hassin's (2009) demonstration of implicit WM activation with familiar geometrical patterns, Soto and Silvanto (2014) suggested that WM functions hardwired by experience might lead such an activation.

Although playing cards can be considered objects belonging to semantic knowledge, this is not the case for the spatial configuration of a red card among three blue cards, which was the actual feature to remember in my own experiments. If the only way to engage WM outside awareness is by activating semantic representation, then the meaningless location of an item could not trigger it, whereas meaningful stimuli like the sun or a heart to be associated with their typical colour, should.

In sum, the experiments reported in the present chapter address the question of implicit WM activation with subliminal stimuli along with some methodological issues: first, would BM experiments confirm the results obtained with CFS? Second, does feedback following the cue play any role? Third, could implicit WM activation be related only to semantic information retrieval? To answer these questions, I adapted the experimental paradigm described in the previous chapters to a backward masking setting (to answer the questions 1 & 2), and a new set of stimuli was created to address the possibility of implicit semantic activation.

Finding above chance performance or facilitation of the cued condition compared to the uncued condition on reaction times at longer retention intervals would mean that WM can be activated without the intention to process subliminal objects. Also, it would mean that such an effect is modulated by different factors, like masking methods, reinforcement and type of to-be-remembered stimuli.

3.2 General methods

All the experiments were based on BM as a method to suppress stimuli from awareness. This consists of presenting a stimulus binocularly and very briefly, immediately followed by a mask.

In the present paradigm, the image of three blue cards and one of a different colour was presented in the middle of the screen for 24 ms, followed by a colourful mask. No card was highlighted in 20% of the trials. After a variable retention interval, participants were presented with 4 blue cards in the same cross formation. Crucially, participants were not aware of the presence of a to-remember cue, thus allowing us to investigate implicit WM activation. They were instructed to perform a guessing game, trying to pick the winning card in each trial. They were instructed to follow their instinct in picking the card, and avoid any sequential strategy or picking the same card all the time.

After the experimental session, participants were asked to perform a perceptual control experiment in order to check whether and to what extent they perceived the cue. The control experiment provided measures of awareness, allowing exclusion from the analysis subjects who showed an unsuccessful suppression. As in the previous chapter, to account for the criticisms recently raised against this post hoc data selection (Shanks, 2016), in case of significant results, additional analyses including the performance from all the participants have been reported as supplemental materials.

3.2.1 Apparatus

Backward Masking experiments were run on a DELL Latitude P991 laptop running Windows 7 Professional with a Nvidia GeForce GT 610 graphics device and an 18'' Mitsubishi colour display (1280 x 960) at 85 Hz refresh rate.

Participants' head was stabilised by a chin-rest placed at a viewing distance of 57 cm. The experiment was implemented in PsychoPy2 since for brief presentation of visual stimuli better control of timing was required than is possible with Eprime (Garaizar, Vadillo, & Lo, 2014).

3.3 Experiment 7 - Guessing game with BM

In the previous chapter, I described 6 studies whereby I employed CFS to hide a memory cue from consciousness and assess if participants still maintain such a cue in WM to perform a delayed choice. Results did not support such a possibility: some significant results emerged, but they were weak and did not replicate.

If this inconsistency was due to CFS being inadequate to allow the subliminal processing of the present stimuli's features, then running the same experiment by using BM should give a clearer insight: finding above chance performance after long delays would indicate that the lack of consistent results in the previous experiments was due to an excessive disruption of stimulus feature processing under CFS; finding no above chance performance or facilitation of the cue also with BM would suggest that weakness in the previous results was likely to be due to the absence of the phenomena under investigation, although there would be more methodological questions to face before reaching this conclusion, such as the nature of the stimuli or motivational factors as explained above.

3.3.1 Stimuli

The stimulus set consisted of 5 images (6.17°x 5.73°) representing four playing cards arranged in a cross formation and viewed from the back (Figure 3.1). In the control (uncued condition) and response stimulus all the cards were blue coloured (5.56 cd/m^2 luminance) on a grey background (0.70 cd/m^2). In the other images (cued condition) one of the cards was red coloured (1.39 cd/m^2) and served as a cue.

Masks consisted of a 20 fps AVI files showing flickering squares in five palette colours (yellow, green, blue, black and dark grey), covering a visual angle of 7.93°.

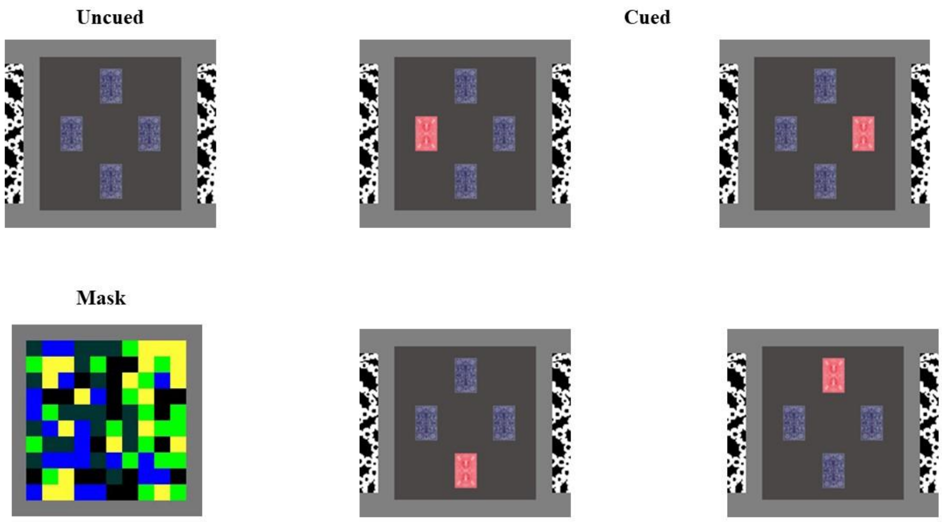


Figure 3.1. Stimulus set: images represent stimuli in the uncued condition, the four cued condition, and a screenshot of the mask. For illustration purposes, contrast is increased compared to the actual stimuli.

3.3.2 Participants and procedure

15 healthy participants (3 males, mean age= 20 years) were recruited among students of the University of Edinburgh. They had normal or corrected to normal vision, and took part in the experiment for course credits or £7. Colour

vision was assessed through the Dvorine Colour Plates (4/4 correct). One participant failed to complete the task and was excluded from data analysis.

Participants sat with the head on the chin – rest and were presented with instructions. They were asked to complete a guessing game and informed that they were going to see a pattern of colours, a fixation cross and four cards. In each trial, one of these cards was a winning card, and they had to guess which one it was by pressing the arrow keys on the keyboard. At the end of the experiment, they were presented with feedback about how many good guesses were made. The experiment started after eight practice trials.

Each trial started with a 500ms fixation cross; then the prime was presented for 2 frames (24ms) in the centre of the screen, then the mask appeared for 8 frames (100ms). The mask offset was followed by a variable delay period of 500, 1000, 2000 or 5000 milliseconds, during which just a fixation cross was displayed. Then the response-stimulus, consisting of the four blue cards, was presented until the subject's response (see figure 3.2).

Each stimulus was presented 15 times at the 4 different delays, for a total of 300 trials. Ord of trials was randomised. Choices and reaction times were collected.

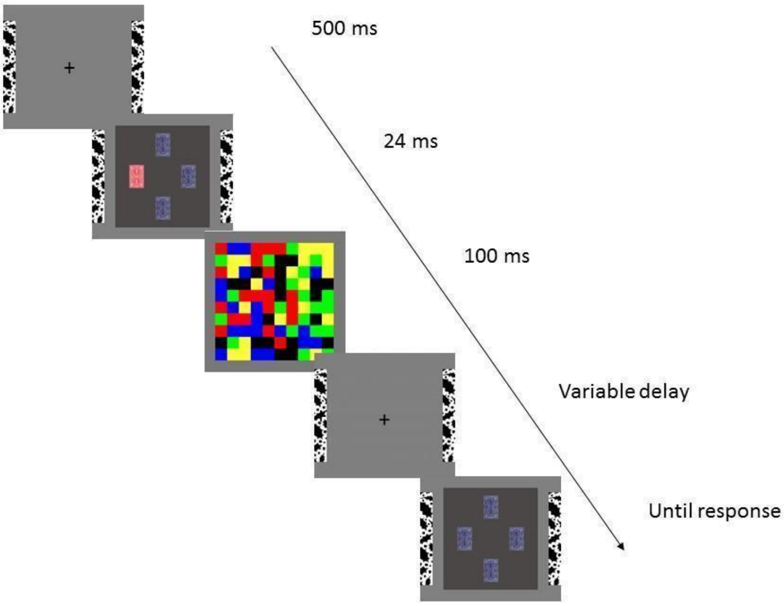


Figure 3.2. Example of a typical trial sequence: images were presented in the middle of the screen. Each trial began with a 500 ms fixation cross; then the subliminal cue appeared for 24ms immediately followed by a mask for 100ms. After a delay of either 500, 1000, 2000, or 5000 ms in which the fixation cross is shown in the middle of the screen, participants were presented with four playing cards and asked to pick the winning card by pressing the corresponding arrow key.

3.3.3 Control Experiment

After the main experiment, every participant performed a control experiment to make sure the prime was not consciously detected. The control experiment employed the same stimuli and procedure of the main experiment, with the exception that (1) participants were explicitly asked to detect the masked red card's position, (2) there was only a 500ms delay between the mask and the response-stimulus, (3) confidence ratings were collected after each choice, as in the previous control experiments.

3.3.4 Results

- *Control experiment*

In order to make sure that any positive result in the main experiment was related to subliminal processing of the stimuli, I had to assess whether any of the participants were able to locate the masked cue significantly better than chance when explicitly asked to do so, and how thoroughly they could evaluate their ability in performing this task. A binomial analysis was then performed to compare individual performance with chance (25%).

Two participants showing significantly above chance performance and were excluded from the experimental analyses.

Following these exclusions, mean confidence ratings on cue-congruent (M= 1.41, sd= .48) and cue-incongruent trials (M= 1.43, sd= .53) were compared by a t-test and showed no significant difference [t (11) = -1.15, p= .27]. This demonstrates that participants were unable to track their performance successfully, so stimuli were properly suppressed from awareness (mean proportion of correct= 25.17, sd =2.4)

As in the previous experiments, I ran a Bayesian binomial analysis with a flat prior to test the strength of the null hypothesis: how likely participants' discrimination of the cue was at chance. I found extreme evidence for H0 (BF01 = 110.843), meaning that performance was not different from chance and thus confirming that participants were unaware of the cue position.

- *Main experiment*

Trials with reaction times higher than 2500ms and lower than 200ms (Whelan, 2008) were excluded from analysis (8.39% of the trials, mean per participant = 24, sd = 21.5, median = 16.5 [range 1, 74]).

A repeated measures one way ANOVA of the different delays performed on mean accuracy showed no significant effect [$F(3, 33) = .147$, $p = .931$ $\eta^2 = .013$]. Binomial analysis sorted by delays showed that performance was at chance at each delay (figure 3.3).

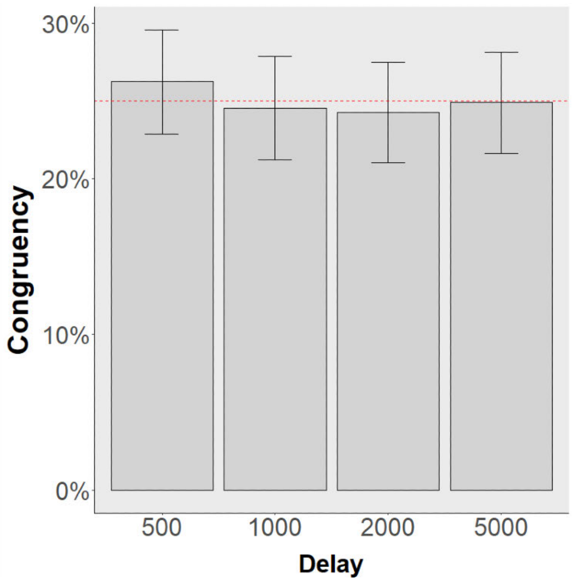


Figure 3.3. The proportion of cue-congruent answers for each delay, the red dotted line indicates the chance level (25%). Performance is at chance at each delay. Bars are SEM.

I ran a Bayesian binomial test sorted by delays with a flat uninformative prior to assess whether the evidence supported the null hypothesis (i.e. accuracy was at chance, 25%) or the alternative (that accuracy was higher than chance). Results showed strong evidence for the null hypothesis over the alternative at each delay [500ms (BF01 = 19.208); 1000ms (BF01= 44.975); 2000ms (BF01= 38.025); 5000ms (BF01= 36.128)].

Reaction times on cue-congruent responses vs responses in uncued trials were analysed through a repeated measures 4 x 2 ANOVA with delay (500, 1000, 2000, 5000 ms) and cue (present, absent) as factors. Results showed a main effect of delay [F (3, 33) = 7.7250, p = .001, η^2 = .397]. As illustrated in Figure 3.4, it is evident that there is a decrease in RTs as delay increases. Follow up t-test comparisons with Bonferroni correction showed significantly longer RTs at 500ms (M= 893.4, sd= 264.5) compared to 5000ms (M= 699.3, sd= 282.4, pbonf=.002). There was no main effect of the cue [F (1, 11) = .172, p = .686, η^2 = .015]. The interaction between cue and delay fell slightly short of the conventional significance level [F (3, 33) = 2.721, p= .060, η^2 = .198]. Although the interaction cannot be considered significant, I explored it to understand better if there was any sign of cue facilitation. Post hoc t-test with Bonferroni correction showed that at a 500ms delay there is a difference between the cued and uncued trials, with uncued trials having faster reaction times (mean= 847.8, sd=242.5) than cued (mean= 398.9 sd= 288.1, p=.010, figure 3.4).

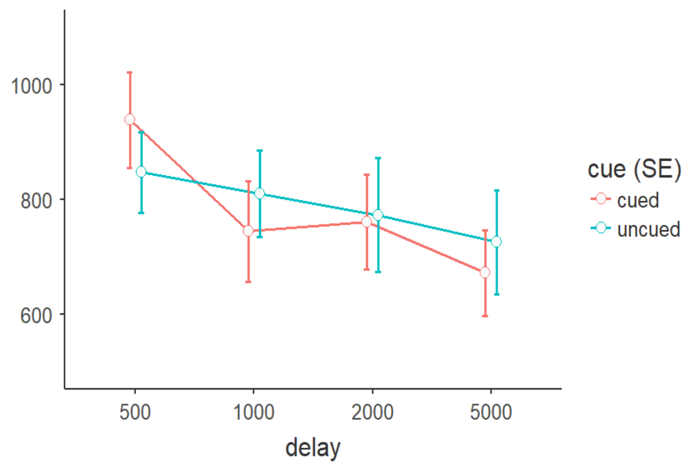


Figure 3.4. The interaction between cue and delay on mean RTs (ms). At 500ms delay RTs tend to be slower in the cued than in the uncued condition. Bars are SEM

Results on RTs do not indicate any facilitation of the cue except in the encoding phase (500ms). Overall, results from this experiment again do not support the hypothesis that subliminal cue was held in WM in order to perform a task, thus supporting the conclusion that the lack of effects in previous experiments was not due to the use of CFS as a masking technique.

One further explanation of the negative results throughout these experiments could be the absence of reinforcement following the prime. It has been demonstrated that top-down modulation can affect the strength of subliminal priming, regardless of the cue saliency (Ansorge, Horstmann, & Worschech, 2010). To address this possibility, I ran a further experiment providing feedback on the choice after each trial, in order to reinforce the choices in which participants were following the cue.

3.4 Experiment 8 - Backward Masking with feedback

A growing number of studies on non-conscious processing demonstrates that the strength of subliminal priming is modulated by top-down mechanisms like motivation and task relevance of the cue (van Gaal, de Lange, & Cohen, 2012). Ansorge et al. (2010), for instance, found an attentional ERP marker during the subliminal presentation of a relevant cue in a visual search task, but the same marker was absent when participants were asked to locate the same subliminal colour cue without any feedback. According to the authors, the impossibility of tracking their own performance and the absence of reinforcement lead participants to abandon their goal in the location task (Ansorge et al., 2010). Similarly, Mealor and Dienes (2013) found an accuracy decrease in unconscious structural knowledge during artificial grammar learning when no explicit feedback was provided.

To understand whether the absence of any feedback weakened the saliency of the subliminal cue in the present task, I ran a further experiment, identical to the previous one with the exception that feedback on the choice (correct/incorrect) was provided after each trial. In this way, participants could track their performance and the cue might assume a stronger predictive validity.

3.4.1 Participants and procedure

19 healthy participants (4 males, mean age= 23) took part in the experiment for course credit or £7. They had normal or corrected to normal vision, and signed

the consent form. Colour vision was assessed by asking to identify 4/4 tables of the Dvorine Colour Test correctly. The procedure was the same as in the previous experiment, with the exception that feedback was shown immediately after each participant's answer for 500 ms: "Correct!" if they picked the right card; "Incorrect!" if they picked a card different from the cued one. The same feedback was also provided in the control experiment, run after the main one to identify participants showing awareness of the cue.

3.4.2 Results

- *Control experiment*

A binomial analysis sorted by subjects was performed to compare individual performance with chance (25%). None of the participants showed significantly above chance performance. Still, three participants were excluded from data analyses because they failed to follow the instructions: rather than trying to guess, they selected the same answer on every trial.

Mean confidence ratings on cue-congruent ($M= 1.26$, $sd= .38$) and cue-incongruent responses ($M= 1.27$, $sd= .39$) were then compared by a t-test and showed no significant difference [$t\ (15) = -0.45$, $p= .65$], with 26% cue-congruent answers ($sd= .02$). So participants' awareness rating was not different for correct and incorrect choices, confirming that they were guessing.

As in the previous experiments, I ran a Bayesian binomial analysis with a flat prior to check how strongly the data supported the null hypothesis (chance performance) with respect to the alternative hypothesis. I found a strong evidence for H0 (BF01 = 19.056), thus confirming that stimuli were properly suppressed from awareness.

- *Main experiment*

Trials with reaction time higher than 2500ms and lower than 200ms (Whelan, 2008) were excluded from analysis (6.3% of the trials, mean per participant = 19, sd = 18.3, median = 10 [range 3, 59]).

A one-way ANOVA with delay as a within subject factor performed on the mean accuracy showed no significant effect [F (3, 42) = .413, p = .745 η^2 = .125]. Binomial analysis sorted by delays again showed that performance was not different from chance (Figure 3.5).

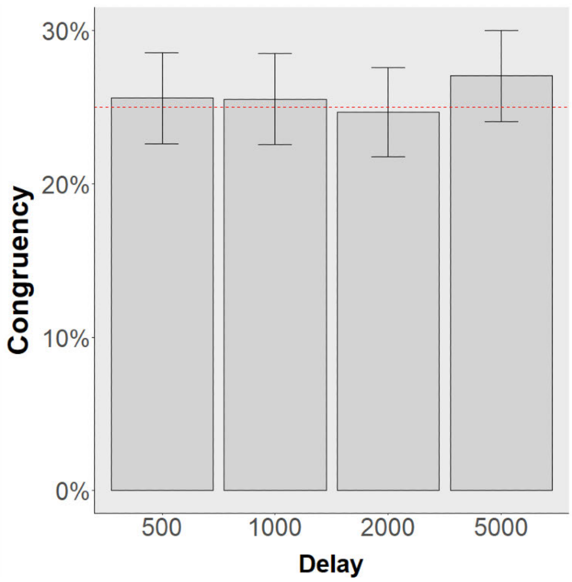


Figure 3.5. Percentage of cue-congruent answers for each delay, the red dotted line indicates the chance level (25%). Performance is at chance at each delay. Bars are SEM

As classical analyses did not allow rejection of the null hypothesis (that performance was no different from chance), I ran Bayesian analyses to test the likelihood of the null hypothesis to be true. Bayesian binomials sorted by delays with a flat uninformative prior supported the null hypothesis over the alternative at each delay [500ms (BF01 = 27.397); 1000ms (BF01= 28.417); 2000ms (BF01= 46.746); 5000ms (BF01= 8.295)].

Reaction times on cue-congruent responses vs responses in uncued trials were analysed through a repeated measures 4 x 2 ANOVA with delay (500, 1000, 2000, 5000 ms) and cue (present, absent) as within subject factors. Results showed a main effect of delay [F (3, 42) = 17.602, p = .000, η^2 = .973]. Pairwise t tests with Bonferroni correction showed significantly longer RTs at 500ms (M=803.5, sd= 228.7) compared to 1000 (M= 722.4, sd= 269), to 2000ms (M= 642, sd= 206) and to 5000ms (M= 577.7, sd= 142.2); p>.05. There was no significant effect of the cue [F (1, 14) = .177, p = .680, η^2 = .068] or interaction between cue and delay [F (3, 42) = 1.162, p = .336, η^2 = .290]

From these results, it appears that participants could not rely on implicit WM maintenance even if reinforcement was given trial by trial through feedback on their performance. Moreover, the priming effect on RTs found at 500ms in the previous experiment did not replicate here.

One more possibility is that implicit activation of WM is linked only to semantic retrieval, as in the case of Hassin (2009), where implicit WM activation was related to well-known geometrical patterns. In a series of studies, Della Sala et al. (2010) also demonstrated that processing of semantic material from long-term memory can take place implicitly, but this does not happen for unfamiliar objects. If this is the case, then the stimuli used in the experiments so far cannot elicit such implicit activation, as the position of a red card among other cards cannot be considered to trigger any semantic representation, and well-known objects would be needed.

To test this possibility, I adapted the paradigm to subliminally cue participants with stimuli belonging to long-term memory representation, and assessed if such cuing would bias participants responses in a delayed choice.

3.5 Experiment 9 - Exploring Semantic Priming Experiment

The implicit activation of WM has been so far reported only in relation to stimuli represented in long-term memory/semantic memory. Della Sala et al. (2010) asked British brain-damaged patients with left-sided unilateral spatial neglect to listen to and read lists of four proverbs. The proverbs could be familiar (British) or unfamiliar (foreign) and were shown alongside a picture depicting one of the proverbs. Patients' recognition of the proverb matching the picture was above chance, even if the key objects of the proverbs were depicted on the left neglected side of their visual field. Crucially, this was true only for familiar but not unfamiliar proverbs. Similar results were obtained with healthy participants, using subliminal presentation of one half of each picture. As the facilitation obtained from the subliminal features of the pictures concerned only familiar proverbs, the authors interpreted the results consistent with direct activation of semantic memory from perception without intermediate stages of processing in working memory.

Thus, it could be the case that the results by Hassin (2009), demonstrating a facilitation in perceptual judgment when stimuli presentation order followed a familiar pattern, are not due to WM activation without explicit intention, as the authors suggested, but to a long-term memory activation similar to the interpretation by Della Sala et al. (2010). Conversely, it is possible that results by Della Sala et al. (2010) are due to an activated representation from LTM that was held present within implicit WM during each trial.

In the previous studies, I tried to assess the presence of an implicit representation in WM with a non- meaningful and subliminal spatial configuration, and results did not support the hypothesis.

To test if implicit WM activation is limited to semantic material, I carried out a study with different materials, where the choice demanded a semantic association. If implicit WM activation is triggered only by semantic material (Della Sala et al., 2010), then priming participants with common objects should bias their choice toward the item sharing the characteristic of the primed object.

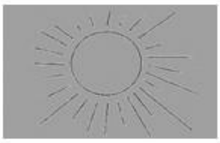
To test this hypothesis, I adapted the guessing game: as cue, I used line drawn pictures of objects commonly associated with a particular colour (e.g., the sun is yellow), and then showed response options consisting of four coloured cards. I hypothesised that this semantic priming would lead participants to choose the card of that particular colour (e.g. a yellow card after being primed with the sun) among cards of other colours unrelated to the primed object.

3.5.1 Stimuli

Stimuli consisted of five line drawing pictures, four of which represented objects commonly associated with a specific colour and one picture without any strong colour association. For the purpose, I selected the pictures of a heart (generally associated with red), a sun (yellow), a snowman (white), and a clover (green) as colour-cue stimuli; a house or a jumper were selected to be used as a control. All the stimuli were selected from the validated database by Snodgrass and Vanderwart (1980), apart from the clover, belonging to the database by Bonin, Peereman, Malardier, Méot, & Chalard (2003).

All pictures background was turned to grey to match the experimental set-up, and dimension was modified to fit the same visual angle of 5°x7°. To test the strength of such colour association, I ran a pilot study in which 12 volunteers (mean age=28, males=3) were asked to associate each of the stimuli with a colour and to rate how strong was the association (see table 3.1). Agreement scores confirmed the strong association for the colour stimuli, while the jumper was found to be a better control than the house, as the latter turned out to be associated with red.

The mask consisted of a black and white pattern flickering at 40Hz



colour		association		name	
yellow	**72.72%**	**very strong**	**63.64%**	sun	100%
orange	27.27%	strong	36.36%		

colour		association		name	
white	**100%**	**very strong**	**81.82%**	snowman	100%
		strong	18.18%		

colour		association		name	
red	**90.91%**	**very strong**	**81.82%**	heart	100%
pink	9.09%	strong	18.18%		

colour		association		name	
green	**100%**	**very strong**	**81.82%**	clover	90.91 %
		strong	9.09%	trefoil	9.09%
		fair	9.09%		

colour		association		name	
blue	33.4%	very strong	8.3%	jumper	16.7%
green	16.6%	strong	0%	sweater	83.3%
grey	8.3%	**fair**	**50%**		
red	16.7%	very weak	25%		
white	16.6%				
pink	8.3%				

colour		association		name	
red	54.55%	very strong	18.18%	house	100%
white	9.09%	strong	27.27%		
brown	36.36%	fair	18.18%		

Table 3.1 . Results from the pilot questionnaire. In the first column there are the responses to the question "what is the colour you associate this object with?", in the second column the frequency of the answers. The third column shows the strength of the association between the indicated colour and the stimulus and the frequency of the answer. The strongest associations are in bold.

3.5.2 Participants and Procedure

Eighteen healthy participants (4 males, mean age= 20) took part in the experiment for course credit or £7. They had normal or corrected to normal vision, and signed the consent form. Colour vision was assessed by asking to correctly identify 4/4 tables of the Dvorine Colour Test. One participant did not follow the instruction and was excluded from data analysis (he always picked the same colour).

Participants sat with their head on the chin – rest and were instructed to perform a guessing game: they were going to see a pattern of dots, a fixation cross and four cards of different colours arranged in a cross shape. There was a winning colour every round, and participants were asked to choose the card of the winning colour by using the arrow keys on the keyboard. The experiment started after eight practice trials. Each trial started with a 500ms fixation cross, then the prime was presented for 2 frames (24ms) in the centre of the screen, then the mask appeared for 8 frames (100ms). The mask was followed by a variable delay period of 500, 1000, 2000 or 5000 milliseconds, during which only a fixation cross was displayed. Then the response-stimulus, representing the four coloured cards (yellow, red, green and white) was presented until the subject’s response (Figure 3.6). The locations of the cards were randomised. Each stimulus was presented 15 times at the 4 different delays, for a total of 300 trials. Trial presentation order was randomised. Choices and reaction times were collected.

As in the previous experiments, after the main experiment participants were asked to perform a control experiment, to exclude participants showing perceptual awareness of the cue. The control experiment resembled the main experiment, with the exception that: the interval between cue presentation and response stimulus was always 500 ms, participants were asked to attend the cue, a subjective measure of the cue visibility was required after each trial on a 4-point PAS scale. Participants were informed that images of common objects were going to appear very briefly before the b/w pattern, and they were asked to pick the card of the colour they associate with the object. After the choice, they were asked to rate how well they saw the picture (1 - nothing, 4- well). Each stimulus was presented 60 times for a total of 300 trials. Trials presentation order was randomised. Choices and confidence ratings were collected.

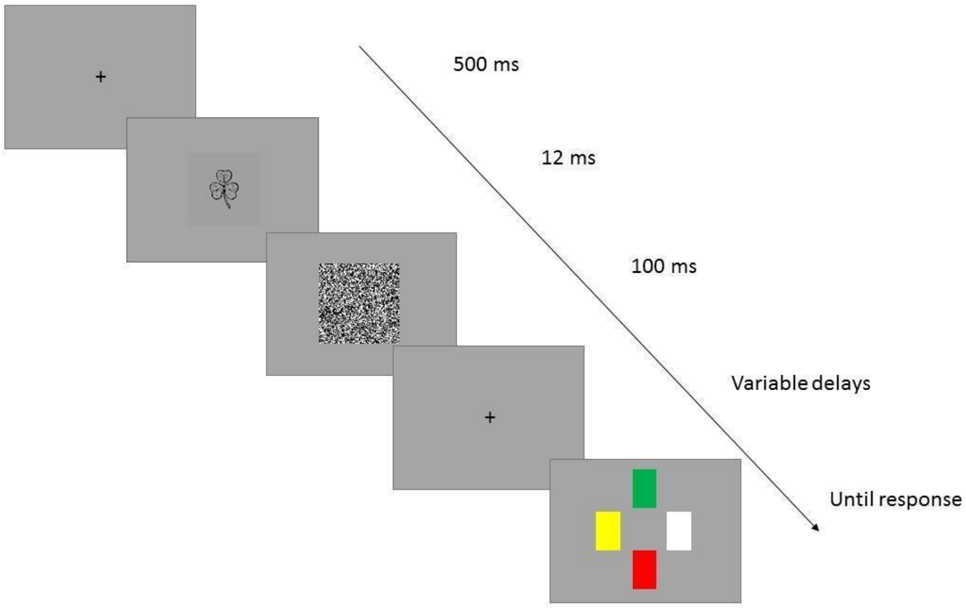


Figure 3.6. Typical trial sequence: images were presented in the middle of the screen. Each trial begins with a 500 ms fixation cross, then the subliminal cue appeared for 24ms immediately followed by a mask for 100ms. After a delay of either 500, 1000, 2000, or 5000 ms in which the fixation cross appeared in the middle of the screen, participants were presented with four cards of different colours (colour was randomly assigned to each position in each trial) and asked to pick the winning card by pressing the correspondent arrow key.

3.5.3 Results

- *Control experiment*

A binomial analysis sorted by subjects was performed. Three participants showed a performance significantly different from chance (proportion of accuracy: 34%, 32%, 19%) were excluded from data analyses.

Mean confidence on cue-congruent (M= 1.93, sd= .09) and cue-incongruent responses (M= 1.93, sd= .10) were then compared by a t-test showing no significant difference [t (13) = 1.77, p= .38]. So stimuli were properly suppressed from awareness. As in the previous experiments, a Bayesian binomial analysis with a flat prior on the mean proportion of correct (mean = 0.24, sd = .01) showed a very strong evidence for the hypothesis that it was not different from chance level (0.25, BF01 = 46.043)

- *Main experiment*

Trials with reaction time higher than 2500ms and lower than 200ms (Whelan, 2008) were excluded from analysis (3.19% of the trials, mean per participant = 7.4, sd = 12.4, median = 2 [range 0, 42]).

A repeated measures one-way ANOVA of delay performed on the mean accuracy showed no significant effect [$F(3, 39) = .702$, $p = .557$ $\eta^2 = .185$].

Binomial analysis sorted by delays again showed that performance was not significantly different from chance at any delay (Figure 3.7).

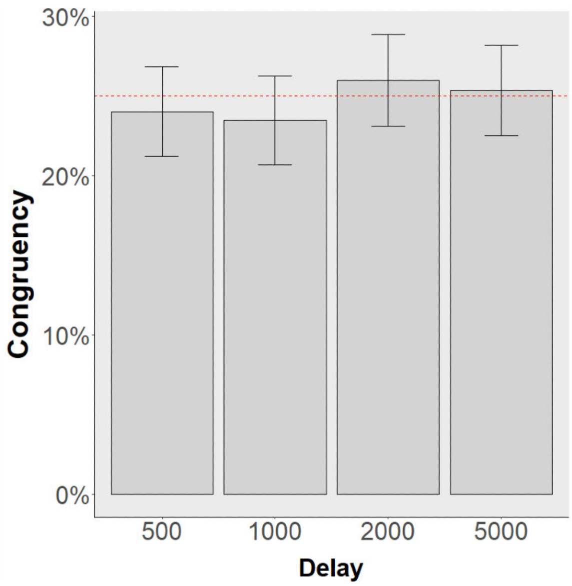


Figure 3.7. Percentage of cue-congruent answers for each delay, the red dotted line represents the chance level (25%). Performance does not differ from chance. Bars are SEM.

A Bayesian binomial sorted by delays with a flat uninformative prior showed very strong evidence for the null hypothesis over the alternative at each delay [500ms (BF01 = 57.493); 1000ms (BF01= 74.658); 2000ms (BF01= 18.464); 5000ms (BF01= 27.670)].

Reaction times on cue-congruent responses vs responses in uncued trials were analysed through a repeated measures 4 x 2 ANOVA with delay (500, 1000, 2000, 5000 ms) and cue (present, absent) as within subject factors. Results showed a main effect of delay [F (3, 39) = 5.245, p=.004, η^2 = .901]. Post hoc t-test with Bonferroni correction showed significantly longer RTs at 500ms (M= 779.2, sd= 214.2) compared to 2000ms (M= 675.9, sd= 203.2, p=.02, Figure 3.8). The Cue effect was not significant [F (1, 13) = 3.544, p = .082, η^2 = .214], nor was the interaction between cue and delay [F (3, 39) = 1.970, p = .144, η^2 = .128].

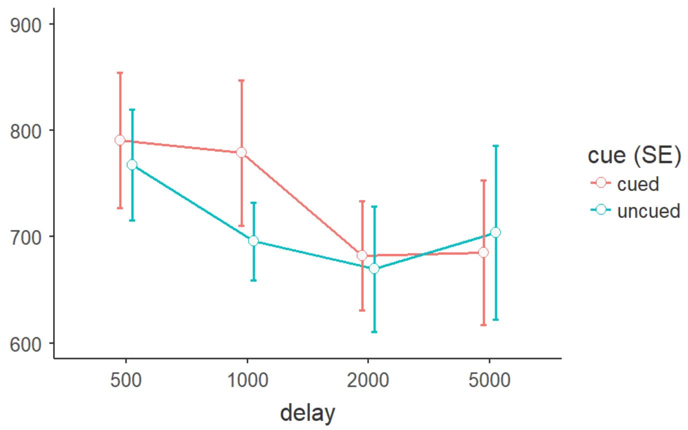


Figure 3.8. Mean RTs in cued and uncued conditions for each delay. Bars are SEM

Again, results do not support the hypothesis of an implicit WM activation with subliminal stimuli.

3.6 Conclusions

After a series of 6 experiments described in the previous chapter, exploring the implicit WM activation with stimuli masked by CFS and leading to weak and inconclusive results, in this chapter I presented three further experiments that aimed to investigate the same question by facing some possible methodological issues: first, would another masking technique give more robust results? Second, could the weakness of the effects found be linked to insufficient motivation? Third, could implicit WM activation be related only to semantic information retrieval?

In the first experiment of the chapter I addressed the issue of the masking method, as differences in subliminal processing have been reported under CFS and BM (e.g., Dubois & Faivre, 2014). However, even by using BM instead of CFS we could not find any facilitation of the subliminal cue on performance. It is worth noting that, compared to CFS studies reported in the previous chapter, there was very little evidence of possible break-through of the suppressed cues into awareness in the control experiments: the number of participants excluded from main data analyses on the basis of their performance in the perceptual task was much lower than the number of participants excluded with CFS. Nevertheless, in the first BM experiment, there was evidence of a priming effect on RTs at early delay (500 ms) expressed by longer time to process cued trials than uncued trials. No effect was found at longer WM delays. This could be interpreted as a demonstration of BM being a stronger way to suppress priming stimuli from awareness, but any comment would be speculative and beyond the scope of the current investigation, also considering that such a priming effect did not replicate in the other BM experiments.

In the second BM experiment, participants were given feedback after each trial, to examine the possibility that motivational factors might modulate the results, given the absence of any reinforcement and the inability for participants to track their performance in the previous experiments. Even with this manipulation, the subliminal cue did not bias participants' choices, and they performed at chance.

The third BM experiment assessed the possibility of implicit WM activation with the semantic material, measuring whether a subliminally presented everyday object would bias participants' choice toward the card sharing that object's typical colour. Implicit activation of WM has been reported, in fact, in relation to semantic retrieval, as in the case of Hassin (2009) with familiar geometrical patterns, or Della Sala et al. (2010) with familiar but not with unfamiliar objects. Nevertheless, here I found no effect of a well-known subliminally presented object on subsequent choices.

In summary, the present paradigm failed to demonstrate the existence of implicit activation in WM with subliminal stimuli, although in 9 experiments I used different stimuli characteristics and meaning, masks and masking techniques. It remains possible that subliminal stimuli require explicit instruction to be retained in WM, as Soto speculatively suggested (Soto & Silvanto, 2014) and that the WM activation without conscious intention (Hassin, 2009) only happens with visible stimuli.

To try to answer these questions, I ran a further series of experiments, with a more similar approach to the previous literature. In these experiments, I performed conceptual and exact replications of the main experiments supporting maintenance of subliminal stimuli in WM.

4 REPLICATIONS

4.1 Introduction

Based on recent evidence that WM can retain subliminal stimuli (Soto et al., 2011, Bergstrom et al., 2015), and that WM can also be activated without conscious intentions (Hassin, 2009) I built a paradigm aimed to assess whether WM can be implicitly activated by subliminal stimuli in order to perform a simple task. A total of nine experiments, using different masking techniques, stimuli and manipulations, did not show any relevant effect.

As mentioned in the previous chapters, finding no facilitation of a subliminal cue in a delayed choice could mean that even if WM may process non-conscious stimuli, this processing might require explicit instructions to take place. The idea that some awareness might be required for WM to be activated has been suggested by Soto and Silvanto (2014). This claim refers to a study by Pan, Lin, Zhao, & Soto (2013), demonstrating that stimuli matching the content of WM, and masked through CFS, broke into awareness faster than other stimuli. Crucially, this was true even when the stimulus held in WM was masked, but only if participants were instructed to hold the subliminal stimulus in memory. The conclusion by Soto and Silvanto (2014) is speculative, as it draws on a paradigm in which no visible context was given (subliminal cue and subliminal target) and whose primary aim was to investigate the role of WM in biasing visual attention. This notwithstanding, the need for explicit instruction as the reason for experiments to demonstrate implicit WM activation with a subliminal cue is intriguing. Therefore, I performed a series of replications of the study by Soto (2011). Finding a same pattern of results would be a basis for defining the conditions for implicit WM activation, which has been investigated rarely in the literature.

For this purpose, I ran some conceptual replications, i.e. adapting my paradigm to previous studies' experimental conditions; and some exact replications, by strictly following the original paper by Soto et al. (2011). The reason why there are several exact replications reported here is that, following some methodological issues that emerged during the first replication attempt, further adjustments have been suggested by the original authors from whom I sought advice. These will be detailed below.

4.2 Conceptual replications

In order to understand if the lack of effect throughout the 10 experiments described in Chapter 2 and 3 was due to the need of giving explicit instruction to allow WM retention of subliminal stimuli, I ran an experiment with similar conditions and instructions as those used by Soto (2011). His first study demonstrated maintenance of subliminal stimuli in WM. Soto maintained that WM might require conscious intention to be activated (Soto & Silvanto, 2014). Accordingly, I tested the subliminal maintenance of stimuli when participants were explicitly instructed to do so. Also, in a further experiment, I tested whether some exposure to visible cues is required to allow subliminal cues to be processed.

Bergstrom et al. (2015), in a delayed match-to-sample task employing stimuli masked by CFS, alternated visible and invisible cues to be retained in WM. Soto et al. (2011) also used visible and invisible cues during the practice session of their experiment, which consisted of 48 trials. The importance of a visible context for subliminal priming has been actually pointed out in literature. Gayet et al. (2014), for instance, found a cueing effect of subliminal arrows only when they were intermixed with visible arrow cues, concluding that a visible context is needed for subliminal priming to occur. I ran two conceptual replications: in the first one, participants were explicitly instructed to attend to the red card, even if they could not consciously perceive it - thus replicating Soto et al.'s (2011) instructions; in the second replication, along with explicit instructions, visible and invisible cues were alternated in the task.

4.2.1 Experiment 10 - Explicit instruction

In the first conceptual replication, I asked participants to keep in mind the position of the red card even if they could not consciously perceive it, mimicking Soto et al.'s (2011) instructions. Similar to Soto et al. (2011), an awareness rating on the cue visibility was required after each trial on a 4-point PAS scale. The paradigm was similar to that reported by Soto (see Fig 4.5), insofar as participants were instructed to retain a subliminal cue in mind, but stimuli and presentation times were the same as used in my previous experiments.

4.2.1.1 Stimuli

Apparatus and stimuli were the same as in the first backward masking experiment (Experiment 7).

4.2.1.2 Participants and procedure

A total of 10 healthy participants (1 male, mean age= 20.5) were recruited from the University of Edinburgh students. They had normal or corrected to normal vision (colour vision was assessed through Dvorine Colour tables), and took part in the experiment for course credit or £7.

Participants sat with the head on the chin – rest and were presented with instructions. They were informed that they would be presented very briefly with a picture of four cards, one of which was red, followed by a pattern of colours, a fixation cross and four cards. They were asked to try keeping in mind the position of the red card, even if they could not see it, and indicate it by using the arrow keys of the keyboard. After each choice, they would be asked to rate how well they saw the red card. The experiment started after eight practice trials.

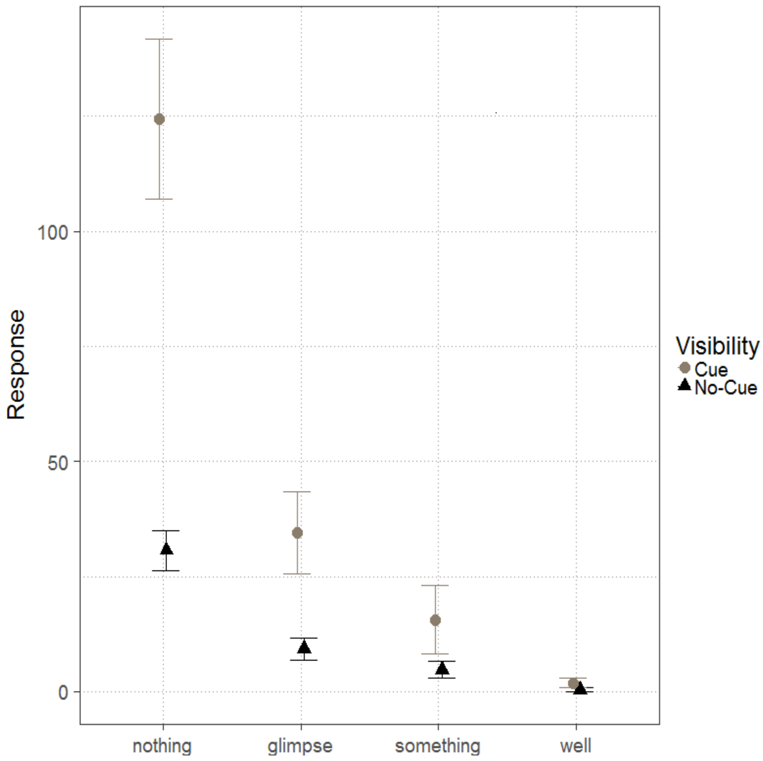
Trial sequence was the same as the backward masking experiment (Experiment 7), with the exception that PAS ratings were collected after each trial instead of running a control experiment, and only trials with a confidence rating of 1 ('I have seen nothing') were analysed (akin to Soto et al., 2011). Each stimulus was presented 12 times for each of the 4 different delays, for a total of 240 trials.

Trial order was randomised. The frequency of choice and reaction times were collected.

4.2.1.3 Results

Trials with reaction time higher than 2500ms and lower than 200ms were excluded from analysis (4.4% of trials, mean per participant = 18.5, sd = 13.4, median = 15 [range 5; 40]). After Soto et al. (2011), only trials receiving a PAS rating of 'nothing' (71% of the trials, considering only the cue-present ones) were analysed (Fig. 4.1).

a)



b)

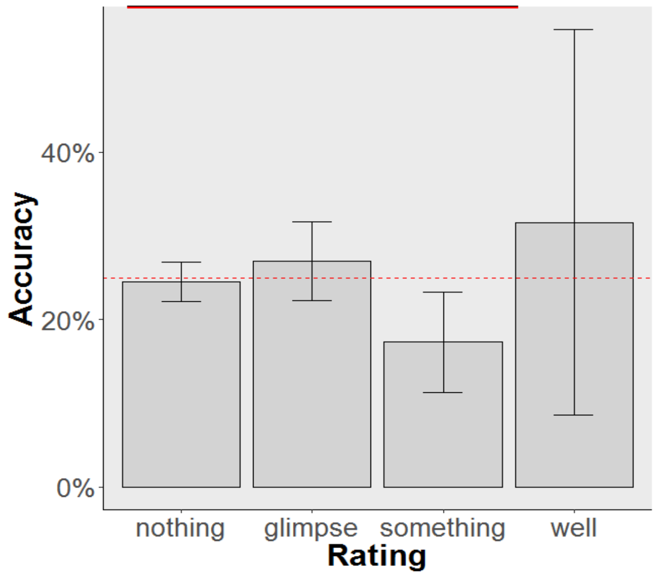


Figure 4.1. (a) Mean number of trials for each rating in the cued and uncued condition. The cued trials were mostly rated as ‘nothing’ (71%), showing a good cue suppression. (b) Percentage of accuracy for the different ratings (on cued trials). The red dotted line represents the chance level (25%). Bars are SEM.

A one way repeated measures ANOVA with delay as within-subject factor performed on the mean accuracy of trials rated as 1 showed no significant effect [$F(3, 27) = .552$, $p = .651$ $\eta^2 = .058$]. I performed a binomial analysis sorted by delays only on trials with a confidence rating of 1. Results showed that performance was at chance at each delay (Figure 4.2), thus failing to replicate with our stimuli results from previous studies on WM maintenance of subliminal stimuli, showing an above chance performance in delayed choice tasks with subliminal to-be-remembered cue (e.g. Soto et al. 2011, Bergstrom et al., 2015).

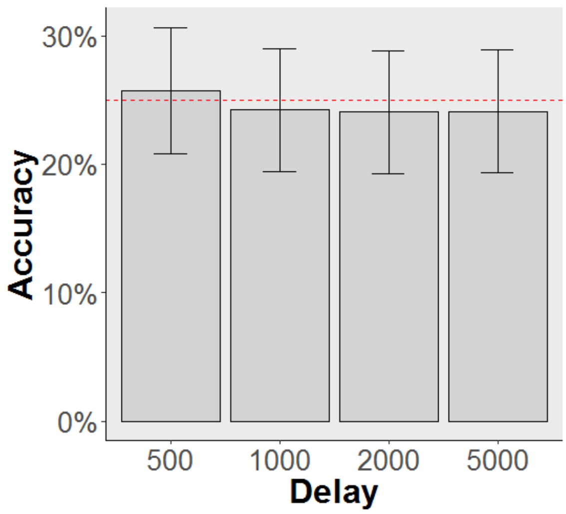


Figure 4.2. Percentage of correct answers for each delay in the trials rated as "nothing". The red dotted line represents the chance level (25%), bars are SEM

A Bayesian binomial test sorted by delays with a flat uninformative prior was run to compare the probability that the accuracy was at chance with the probability that it was higher than chance. Results showed strong evidence for the null hypothesis over the alternative at each delay [500ms (BF01 = 18.186);1000ms (BF01= 30.249); 2000ms (BF01= 31.555) 5000 ms (BF01= 30.822)].

In order to verify a possible facilitation of the subliminal cue on reaction times, reaction times on cued correct responses vs responses in uncued trials were analysed through a repeated measures 4 x 2 ANOVA with delay (500, 1000, 2000, 5000 ms) and cue (present, absent) as within-subjects factors. Results showed no significant main effect of the delay [$F\ (3, 27) = .217$, $p=.884$, $\eta^2 = .086$] or of the cue [$F\ (1, 9) = 0.18$, $p = .897$, $\eta^2 = .052$] as well as the interaction between cue and delay [$F\ (3, 27) =1.262$, $p = .307$, $\eta^2 = .298$, fig 4.3].

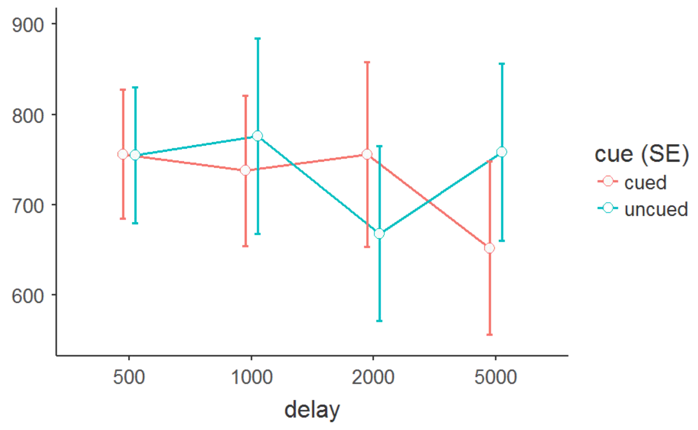


Figure 4.3 The interaction between cue and delay on mean RTs (ms). Bars are SEM

In contrast with previous experiments, where analyses on RTs consistently showed an effect of the delay with responses getting faster at longer delays, here such effect is absent. This difference is likely to be due to higher data variability considering the small sample, as is evident from the error bars in figure 4.3.

Overall, results from this experiment reinforce results from my previous experiments in providing no evidence for WM retention of stimuli of which the participant is unaware, despite in the present experiment explicitly instructing. In a further conceptual replication, visible and invisible cue were alternated, following Bergstrom et al. (2015) along with the practice session used by Soto et al. (2011).

4.2.2 Experiment 11 - Explicit instruction with visible trials

Instructing participants to attend to the subliminal memory cues did not help them in retaining such cues in working memory. One other manipulation used in studies on WM maintenance of subliminal stimuli is the alternation of visible and invisible trials.

Bergstrom et al. (2015) alternated three visibility conditions (visible, invisible, and absent) in a delayed match to sample task that aimed to investigate WM maintenance of subliminal stimuli. Similarly, Soto (2011) alternated visible and invisible cues during a relatively long practice session (48 trials).

There is some evidence that this manipulation can have an impact on subsequent performance: there are studies showing that subliminal cues bias participants' performance only if they are intermixed with visible predictive cues, whereas non-predictive visible cues (not matching the position of the following target) lead participants to ignore invisible predictive cues. Reuss, Pohl, Kiesel, & Kunde (2011), presented participants with visible and invisible arrow cues. In one experiment only 50% of the arrows (both visible and invisible) were actually predictive of the target position, while in a second experiment cue validity was raised to 80%. Visible arrows were found to bias attention in both experiments, while invisible arrows biased participants' attention only with higher cue validity.

In a similar paradigm, Gayet et al., (2014), confirmed that visible nonpredictive arrow cues lead participants to elude predictive masked arrows, concluding that subliminal cues require a visible predictive cue to be detected.

For this reason, in the following conceptual replication, I presented participants with visible and invisible cues.

4.2.2.1 Stimuli

Apparatus and stimuli were the same as in the previous experiment.

4.2.2.2 Participants and procedure

Seventeen healthy participants were recruited from the University of Edinburgh students (mean age= 21.15, 10 males) for course credits or £7. They had normal or corrected to normal vision and their colour vision was assessed through Dvorine Colour tables (4/4 correct).

Participants sat with their head on the chin – rest and were presented with instruction. They were informed that a picture of four cards, one of which was red, would be presented very briefly, followed by a pattern of colours, a fixation cross and a picture of four blue cards. They were asked to try to keep in mind the position of the red card, even if they could not always see it clearly, and indicate it by using the arrow keys of the keyboard. After each choice, they would be asked to rate how well they saw the red card. The experiment started after eight practice trials.

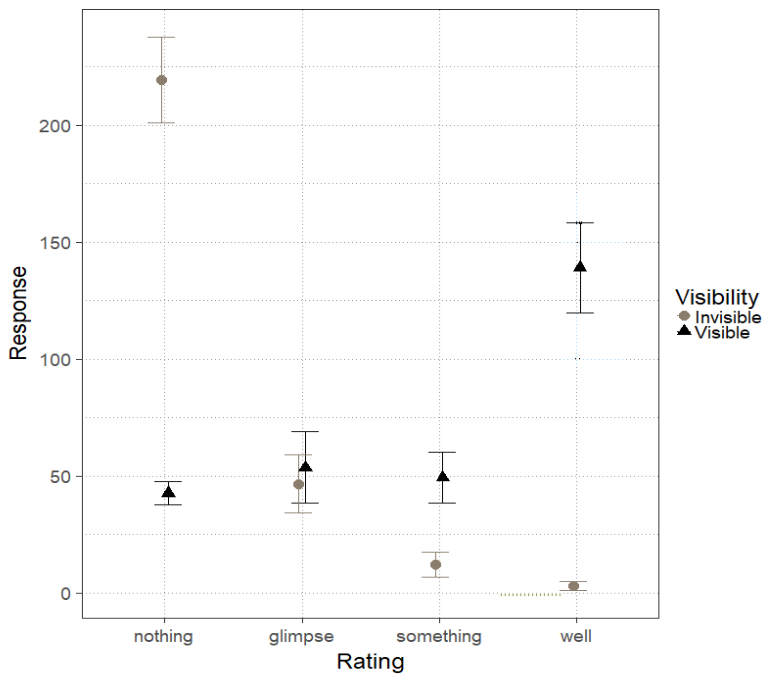
The trial sequence was the same of the previous experiment (experiment 8), but the cue was presented at two different presentation times: 2 frames (24 ms) for the subliminal condition and 10 frames (120 ms) for the visible condition. Each stimulus was presented 15 times at the 4 different delays and 2 visibility conditions, for a total of 600 trials. Trial presentation order was randomised.

Choices and reaction times were collected. Only trials with a confidence rating of 1 (‘I have seen nothing') were analysed (Soto et al., 2011).

4.2.2.3 Results

Trials with reaction times higher than 2500 ms and lower than 200ms (see Whelan, 2008) were excluded from analysis (5.9% of trials; mean per participant = 34.4, sd = 27.4, median = 30.5 [range 7, 89]). 40% of the answers on cued trials were rated as “nothing”, 96% of these belonging to the subliminal condition (2 frames presentation time, see Fig. 4.4 a and b).

Considering the subliminal condition specifically, 79% of the cued trials were rated as "nothing", thus achieving a satisfying level of suppression.



a)

b)

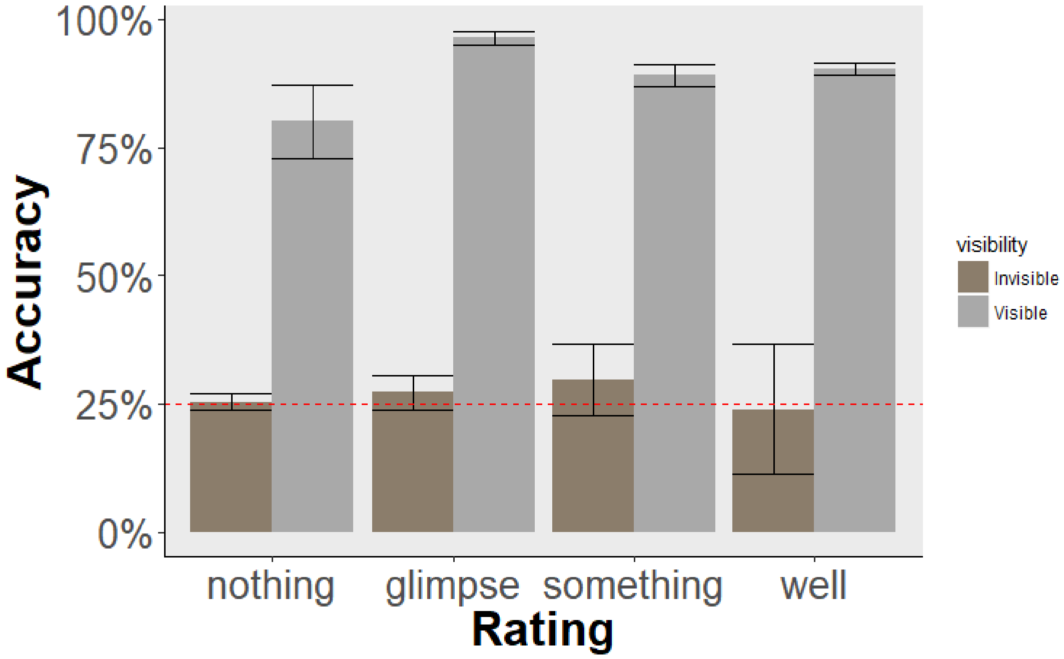


Figure 4.4. a) proportion of trials rating in the visible and invisible condition 78% of the trials in the subliminal condition (PT = 2 frames) were rated as nothing. b) percentage of accuracy in the invisible and visible conditions sorted by ratings. Bars are SEM

A one way ANOVA with delay as within subject factor performed on the mean accuracy showed no significant effect [$F(3, 51) = .191$, $p = .902$, $\eta^2 = .011$].

I performed a binomial analysis sorted by delays only on trials with a confidence rating of 1 in the subliminal condition (39% of the total cued trials). Results showed that performance was at chance at each delay (Figure 4.5), thus failing once again to replicate results from previous studies on WM maintenance of subliminal stimuli (Soto et al., 2011, Bergstrom et al., 2015).

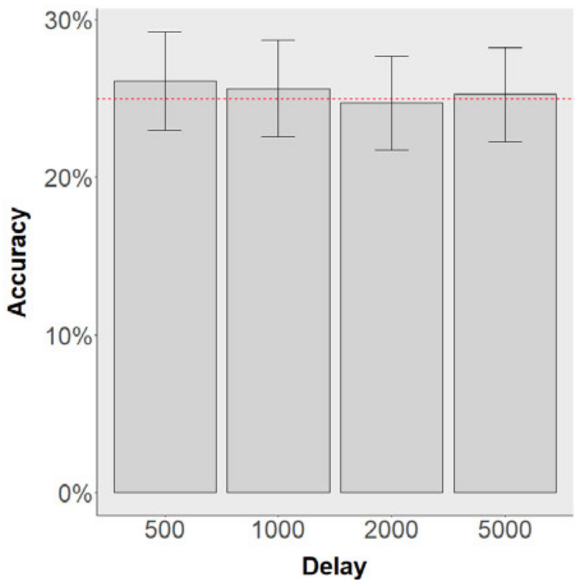


Figure 4.5. Percentage of correct answers for each delay in the trials rated as 1 (I have seen nothing) in the invisible condition. The red dotted line represents the chance level. Bars are SEM.

A Bayesian binomial sorted by delays with a flat uninformative prior to compare the probability that the accuracy was at chance with the probability that it was higher than chance showed strong evidence for the null hypothesis over the alternative at each delay [500ms (BF01 = 19.435); 1000ms (BF01= 26.457); 2000ms (BF01= 44.906); 5000 ms (BF01= 33.915)].

Reaction times on cued correct responses vs responses in uncued trials were analysed through a repeated measures 4 x 2 ANOVA with delay (500, 1000, 2000, 5000 ms) and cue (present, absent) as within subjects factors. Results showed a main effect of delay [F (3, 51) = 5.590, p = .002, η^2 = .247]. Post hoc comparisons with Bonferroni correction showed that RTs were significantly longer at 500ms (M= 756.79 sd= 236.09) than 1000 ms (M= 639.99, sd= 177 p= .01), 2000 ms (M=600.72, sd= 177.15 p=.01) and 5000 ms(M= 574.62, sd=

182.82, p= .004, see figure 4.7). The effect of the cue was not significant [F (1, 17) =1.240, p = .281, η^2 = .068] and neither was the interaction between cue and delay [F (3, 51) = 0.551, p = .650, η^2 = .031, Figure 4.6]

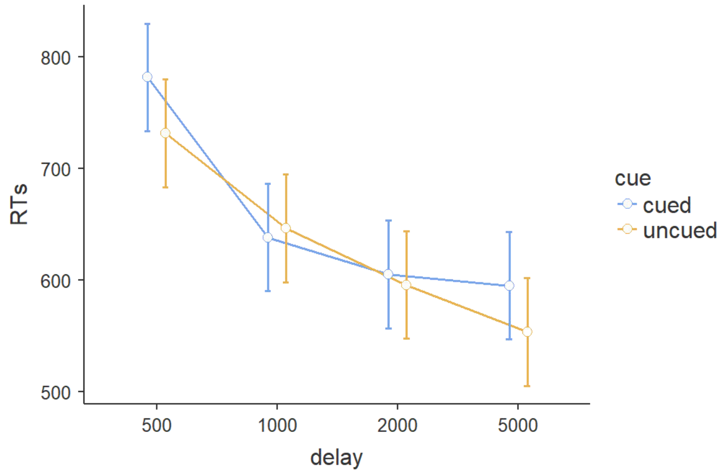


Figure 4.6. Mean RTs across delays on correct cued vs uncued trials, bars are SEM

4.3 Exact replications

In his 2011 paper, Soto et al. concluded that WM is not restricted to consciously perceived stimuli by demonstrating that stimuli of which participants are not aware can be retained for more than 2 seconds. After them, other studies using different manipulations seemed to confirm the same idea (Eriksson, Bergström, & Eriksson, 2015; King, Pescetelli, & Dehaene, 2016; Trübutschek et al., 2017). Bergstrom et al. (2015) demonstrated that participants could retain stimuli masked by CFS for 15 seconds to perform a delayed match to sample task. Similarly, Trübutschek et al. (2017), found that participants could successfully recognise the location of a stimulus masked through BM after a delay of 4s, despite the presence of visible distractors or conscious WM load. The study by King et al. (2016) is the closest one to Soto's study in terms of stimuli and results, but the retention interval was much briefer (800 ms) and performance in the unseen trial was "*weakly but significantly above chance*" to use the author's worlds (p. 1124).

Although all these experiments seem to confirm the results by Soto et al. (2011) with different experimental paradigms, I couldn't find any evidence of WM maintenance of subliminal stimuli in my own experiments, neither with implicit or explicit instruction. So, finally, I decided to replicate the exact experiment by Soto et al. (2011).

The importance of exact replications has been pointed out extensively, especially with regard to unconscious cognition studies (see Shanks, 2016).

As already mentioned, Shanks (2016) recently demonstrated that some of the statistically significant results reported in unconscious cognition studies, commonly using a post-hoc data selection, might be explained by the statistical phenomenon of regression to the mean. As explained in Chapter 2, this refers to the mathematical necessity that participants with extremely low or high score on one measure will get closer to the group's mean score on another measure (Shanks, 2016), in this case performance in the main task and in the perceptual judgment.

Also, Stein et al. (2016) noted that in Soto's paper the analyses to measure the participants' awareness of the cue (i.e., the d') were carried out in a way that is susceptible to bias. The sensitivity index (d'), is a measure derived from signal detection theory and quantifies the ability to discriminate the signal from the noise. It is calculated on the ratio of hits (reporting that there is the signal when the signal is actually present) and false alarms (reporting that there is the signal when the signal is absent). A d' of zero means that there is no distance between the two distributions of hits and false alarms, i.e. participants are unable to discriminate the signal from the noise.

Following these criticisms, in replicating the study I ran some additional analyses: along with t-test against chance on the accuracy on the trials rated as invisible (replicating the previous study analyses), I ran Bayesian analyses. After Shanks (2016), in case of positive results I would have performed a further analysis examining odd- and even-numbered trials separately, to control for the possibility that results are biased by the effect of regression to the mean.

Replicating the experiment would contribute to the debate in the literature: finding the same effect, on a larger sample and supported also by Bayesian analyses (using Soto et al.'s 2011 effect size as the prior), would firmly support Soto's claim that non-conscious processing is more elaborate than previously supposed, but it might as well be related to some specific experimental conditions. Conversely, a failure to replicate the results would support the idea that experiments on non-conscious processing need stricter criteria and control before interpretation, and there is still not enough evidence to challenge the link between WM and consciousness (Stein et al., 2016).

4.3.1 Experiment 12 - Exact replication 1

The first exact replication attempt followed all the parameters of the original paper. Where some more information was required, we contacted the authors asking for clarification. The authors also provided us with their participants' mean performance score to be used as prior for the Bayesian analyses.

4.3.1.1 Apparatus

The experiment was run on a DELL Latitude P991 laptop running Windows 7 Professional with a Nvidia GeForce GT 610 graphics device and an 18'' Mitsubishi colour display set on 800 x 600 px resolution at 60 Hz refresh rate, in order to match the original study's set-up.

Participants' head was stabilised by a chin-rest placed at a viewing distance of 57 cm. The experiment was implemented on PsychoPy2, whereas the original study was run on Eprime, due to the former having a better timing for a brief presentation of visual stimuli (Garaizar et al., 2014).

4.3.1.2 Stimuli

Stimuli were generated on Psychopy following the parameters of the original paper. They consisted of Gabor patches with a spatial frequency of 1 cycle/deg and a diameter of 3.8 deg of visual angle from a viewing distance of 57 cm. They could be tilted 10 deg, 40 deg, 70 deg, 100 deg, 130 deg and 160 deg clockwise from the vertical. The background was grey with luminance of 20.54 cd/m2 (original paper: 19.75 cd/m2). The luminance of the Gabors was 22.19 cd/m2 (original paper: 22.25 cd/m2). The experiment took place in a fully illuminated room (personal communication with Soto, December 2017).

4.3.1.3 Participants and Procedure

To have an 80% probability of detecting an effect as low as 1/3 of the original effect size, Simonsohn (2015) shows that the sample should be 2.5 times the original report's size. So I tripled the original sample size (7 participants) to meet this requirement. 22 healthy participants (7 males, mean age 18.7) were recruited from the University of Edinburgh students. They gave written consent and rewarded with course credit or £7.

The procedure followed the original paper. Participants were presented with the instructions accompanied by examples of trials and the same disclaimer reported by the authors in the supplemental material, which instructed participants to attend and maintain the cue in memory even if they could not consciously perceive it. Each trial started with a black fixation point in the middle of the screen for 1000 ms, followed by a blank screen for 500 ms, then the memory cue appeared for 16.67 ms (1 frame). The cue was randomly selected and it was absent in 50% of the trials. A black circle (the mask) followed immediately for 100 ms. After a delay period of 2000ms, another Gabor appeared for 200 ms, tilted 30 degrees either to the left or right of the memory cue. Participants were asked to indicate whether the target Gabor was clockwise or anticlockwise oriented with respect to the memory cue, by pressing the left or right arrow key. They were then asked to rate how well they saw the memory cue on a 4 point scale (1 = nothing; 2 = glimpse; 3= something;

4 = well), selecting their choice with the arrow keys. Participants performed 2 blocks of 48 trials, for a total of 96 trials (see Figure 4.7).

Before the main experiment, participants performed two blocks of practice containing 24 trials each. In half of these trials the duration of the cue was 16.67 ms, and 216.67 ms in the other half, in random order. There were no cue-absent trials in the practice. Every other parameter resembled the experimental trials.

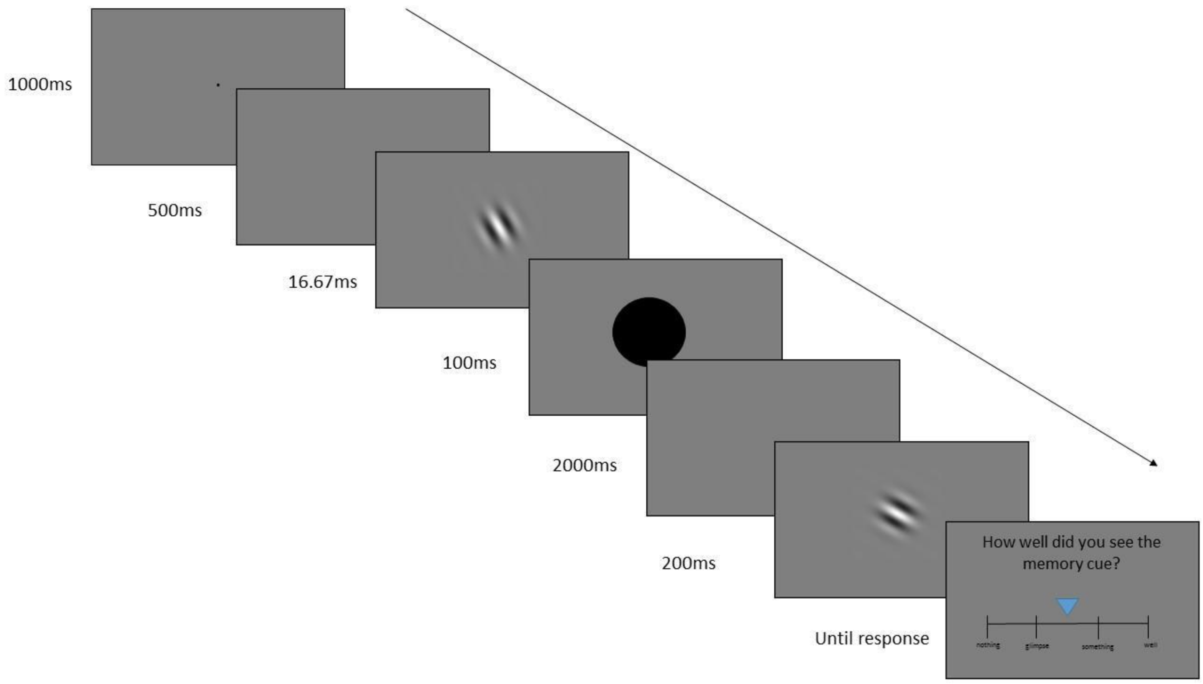


Figure 4.7. Trial sequence. Each trial started with a black fixation point in the middle of the screen for 1000 ms, followed by a blank screen for 500 ms, then the memory cue appeared for 16.67 ms (1 frame). The cue consisted in a Gabor patch tilted either 10, 40, 70, 100, 130 or 160 deg to the right from the vertical (randomly selected). The cue was absent in 50% of the trials. A black circle (the mask) followed immediately for 100 ms. After a delay period of 2000ms, another Gabor appeared for 200 ms, tilted 30 degrees either to the left or right of the memory cue. Participants were asked to indicate whether the target Gabor was clockwise or

anticlockwise oriented with respect to the memory cue, by pressing the arrow keys. They were then asked to rate how well they saw the memory cue on a 4 point scale.

4.3.1.4 Results

First, I performed the same analyses as the original paper. I performed a t-test against chance (50%) on the average performance (mean = 0.51, sd = 0.28) on the trials rated as 1 (I have seen nothing). Results showed no significant difference from chance [t(21)= 0.27, p= 0.78, two-tailed, Figure 4.8].

It must be noted that 55% of the total trials were given a rating of " seen nothing" in the PAS, 19% of the total trials were given a rating of "nothing" when the cue was present (see Fig. 4.9). This suggests that participants were mostly able to discriminate the presence of the memory cue, a possibility confirmed by signal detection analyses. The sensitivity measure was calculated using the probability of hits and false alarms. Hits were defined as the proportion of trials rated as 1(seen nothing) when the cue was absent over the total number of cue absent trials (meanPHits = 0.72, sd= 0.22). False alarms were defined as the proportion of trials rated as 1(seen nothing) when the cue was present, out of the total number of cue-present trials (meanPFA = 0.37, sd= 0.35). A t-test revealed that, across participants, d' was significantly different from 0 [t(21) = 8.07, p< .01, two tailed], with an average of 1.20 (sd = 0.69). This means that participants were able to distinguish the presence of the signal, and thus can't be assumed to have been unaware of the cue.

I performed these analyses also with the Bayesian method. A Bayesian t-test comparing accuracy with chance (50%), using the distribution values of Soto's data as priors (mean performance=. 58, sd= .05), consistently supports the null hypothesis that performance was not significantly different from chance (BF01 = 4.331). Participants' performance on trials rated as unconscious was not significantly different from chance.

A Bayesian t-test on individual d' distribution confirmed that sensitivity index was different from 0, with extreme support for the alternative hypothesis (BF 10= 207661.915). This indicates that participants were able to discriminate between the presence or the absence of the memory cue.

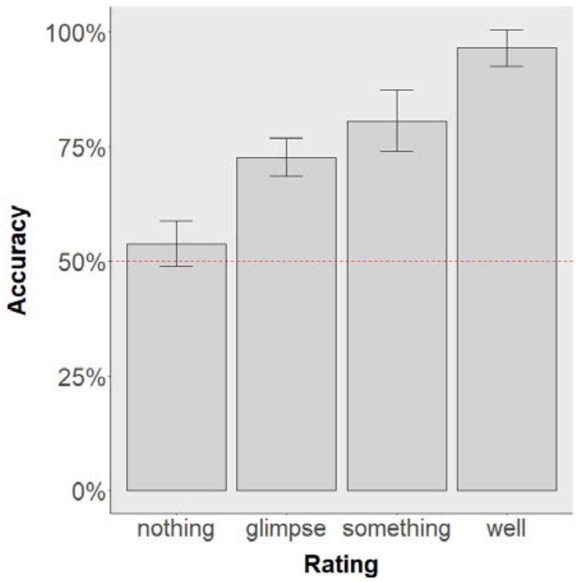


Figure 4.8 Proportion of correct responses for each rating in the cued condition. The red dotted line represents the chance level (50%), bars are SEM.

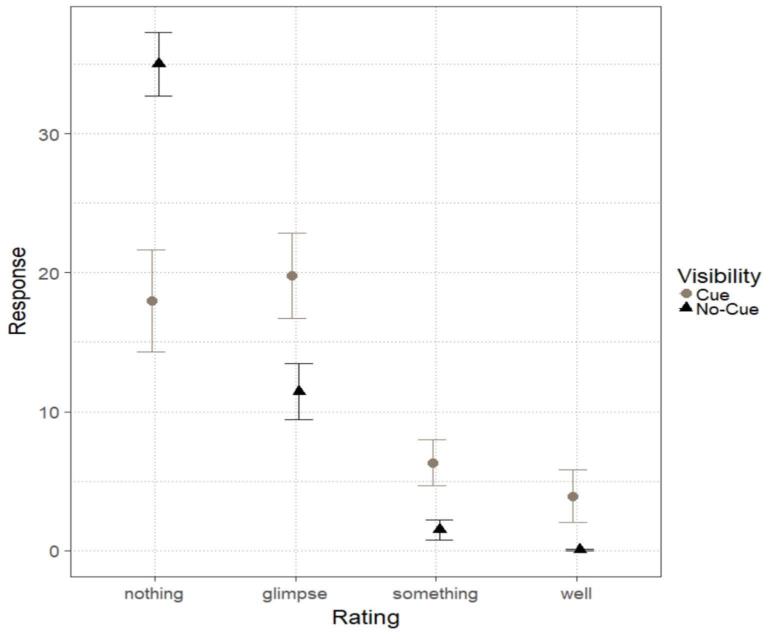


Figure 4.9 Proportion of responses for each rating in the cued and uncued conditions. The 36% of the total number of trials was rated as nothing when no cue was actually presented (50% of the total trial number). Bars are SEM.

4.3.2 Experiment 13 – Exact replication with a checkerboard mask

The failure in achieving a good suppression with the stimuli resembling the original paper by Soto et al. (2011) was already clear from the debriefing of the first participants. For this reason, I programmed another identical experiment with a different mask, in order to obtain better suppression.

Considering the short duration of the exact replication experiment, I asked the participants to perform this second experiment after the main one (the exact replication reported in Experiment 12). The decision of no counterbalancing the order of presentation is based on the fact that the main goal was to replicate

Soto et al. (2011) as closely as possible, so I didn't want to interfere with the original procedure by adding an "experiment order" variable.

4.3.2.1 Stimuli

The stimulus set was the same as in the previous replication, with the exception of the black mask, which was substituted here by a radial checkerboard covering 3.8 deg of visual angle and consisting of 3 radial cycles and 4 angular cycles, with 0.5 radial phase, 0.1 Michelson contrast and a Gaussian mask.

4.3.2.2 Participants and procedure

Twelve participants took part in the experiment after running Experiment 12. The procedure was the same as in the previous experiment, including the practice trials (Figure 4.10). Participants were told they were going to see a checkerboard instead of the black circle, and to keep in mind the orientation of the patch appearing before the checkerboard, even if they could not consciously perceive it.

Figure 4.10. Trial sequence. The trial started with a black fixation point in the middle of the screen for 1000 ms, followed by a blank screen for 500 ms, then the memory cue appeared for 16.67 ms (1 frame). The cue consisted in a Gabor patch tilted either 10, 40, 70, 100, 130 or 160 deg to the right from the vertical (randomly selected). Cue was absent in 50% of the trials. A radial checkerboard (the mask) followed immediately for 100 ms. After a delay period of 2000ms, another Gabor appeared for 200 ms, tilted 30 degrees either to the left or right of the memory cue. Participants were asked to indicate whether the target Gabor was clockwise or anticlockwise oriented with respect to the memory cue, by pressing the arrow keys. They were then asked to rate how well they saw the memory cue on a 4 point scale.

4.3.2.3 Results

The percentage of trials receiving a rating of 1 in the PAS (I have seen nothing) slightly increased, with 69% of the total number of trials rated as "nothing". The 27% of the total number of trials was rated “nothing” when the cue was present (see Figure 4.11). So, although the checkerboard mask was more effective than the black circle, the suppression was still weak. The sensitivity index calculated on the probability of hits (mean= 0.84 sd=0.15) and false alarms (mean=0.53 sd=0.37) defined as described in the previous experiment. A t-test confirmed that the d' was significantly different from 0 [t (11) = 3.61, p< .01, two tailed], with an average d' of 1.07 (sd = 1.02, table 4.2). This indicates that participants' discrimination was not at chance.

Again, I performed a t-test against chance on the average performance (mean=0.54 sd=0.16) on the trials rated as 1. Results showed no significant difference from chance [50% t(11)= 0.95, p= 0.36, two-tailed, Figure 4.12].

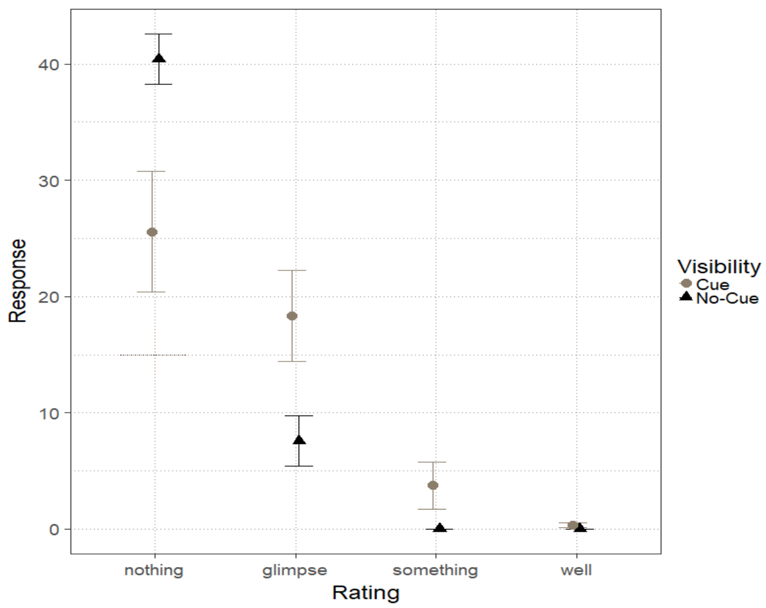


Figure 4.11. The proportion of responses for each rating in the cued and uncued conditions. The 42% of the total number of trials was as rated 'I have seen nothing' when the cue was actually absent.

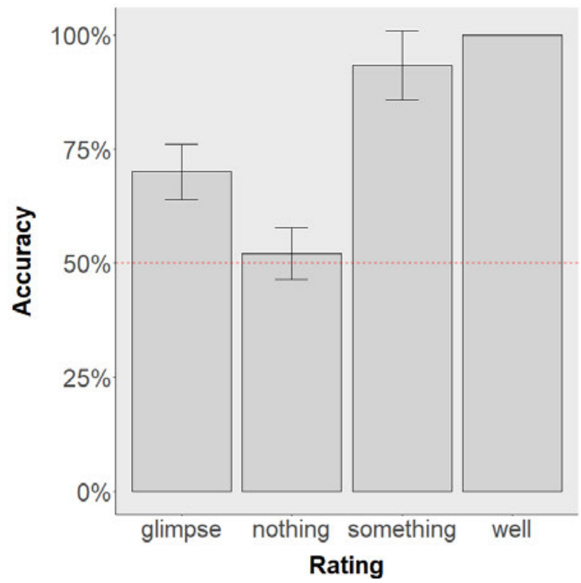


Figure 4.12 Proportion of correct responses for each rating in the cued condition. The red dotted line represents the chance level (50%), bars are SEM.

I also performed these analyses with the Bayesian method. A Bayesian t-test comparing accuracy with chance (50%), still using the distribution values of Soto's data as priors (mean performance= 0.58, sd=0.05) also showed support for the null hypothesis (BF01 = 1.701), although it can be considered anecdotal (Jarosz & Wiley, 2014). Participants' performance on trials rated as 1 can be considered at chance.

A Bayesian t-test on individual d' distribution also confirmed the classical analysis, with strong support for the alternative hypothesis (BF 10= 12.416) over the null, which means that sensitivity index was different from 0. This indicates that participants were likely able to discriminate between the presence or the absence of the memory cue.

4.3.3 Experiment 14 -Exact replication 3 (Authors' exact instructions)

After my failure to replicate the results by Soto et al. (2011), I contacted the authors to make sure that my replication had followed their original work precisely. I shared with them screenshots of the stimuli, the experiment code and the instructions. Although my stimuli followed the specifications in their paper, Soto and Silvanto (personal communication, December 2017) kindly pointed to some differences in the stimuli they actually used in the experiment (see stimuli section below). So, following their instructions, I programmed two more experiments: the first one has been confirmed to be an exact replication by the authors of the original paper; the second one follows Soto's suggestion to strengthen the suppression by using a noise pattern as a mask instead of a black circle.

Once again, participants performed both the experiments in a specific order: exact replication first, followed by the experiment with the different mask. As before, my principal aim was to run an exact replication and this is why I did not counterbalance the experimental order.

4.3.3.1 Stimuli

Stimuli were generated on Psychopy following the parameters provided by the authors through correspondence (Soto, personal communication, November 2017). There are some differences in the characteristics described in the original paper. The authors indicated that their stimuli were not Gabor patches but sinusoidal gratings with a spatial frequency of 0.1 cycles per pixel. All the other parameters remained the same (3.8 deg of visual angle from a viewing distance of 57cm). Authors confirmed that the stimuli set up in this way matched their own.

4.3.3.2 Participants and Procedure

Again, I tested 22 participants to have an 80% probability of detecting an effect as low as 1/3 of the original effect size (Simonsohn, 2015). Participants (4 males, mean age= 18.9) were students of the University of Edinburgh who gave written consent and were rewarded with course credit or £7/hour.

The procedure followed the original paper and was the same as the previous experiments (Figure 4.13).

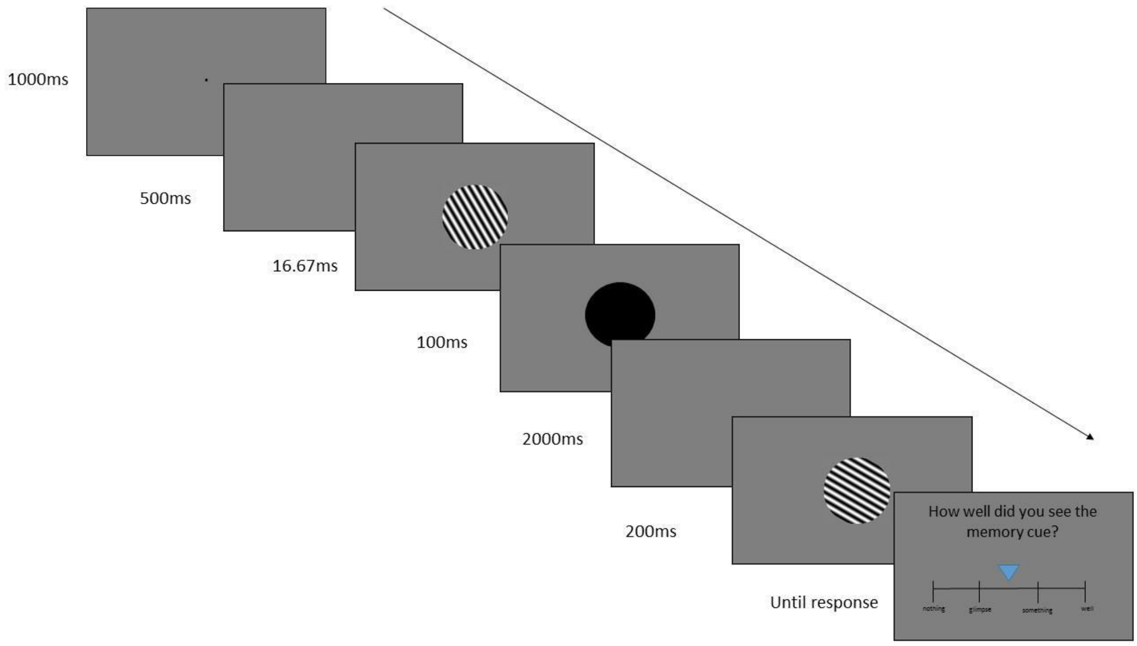


Figure 4.13. Trial sequence. The trial started with a black fixation point in the middle of the screen for 1000 ms, followed by a blank screen for 500 ms, then the memory cue appeared for 16.67 ms (1 frame). The cue consisted of a grating tilted either 10, 40, 70, 100, 130 or 160 deg to

the right from the vertical (randomly selected). The cue was absent in 50% of the trials. A black circle (the mask) followed immediately for 100 ms. After a delay period of 2000ms, another grating appeared for 200 ms, tilted 30 degrees either to the left or right of the memory cue. Participants were asked to indicate whether the target grating was clockwise or anticlockwise oriented with respect to the memory cue, by pressing the arrow keys. They were then asked to rate how well they saw the memory cue on a 4 point scale.

4.3.3.3 Results

46% of the total number of trials was rated as “nothing”, with only 6% of the total number of trials rated as “nothing” when the cue was present (see figure 4.14). So, although I modified the stimuli according to the authors' instruction, it seems that they were not properly suppressed. In order to measure the ability of participants to discriminate the presence of the cue, I calculated the sensitivity index. The proportion of trials rated as 1 when the cue was absent on the total number of cue absent trials was considered as "hits" (mean Phits= 0.81, sd=0.24), and the proportion of trials rated as "nothing" when the cue was present as "false alarms"(mean Pfa= 0.11 sd=0.19). The sensitivity measure of d' was calculated on the individual probability of hits and false alarms. A t-test revealed that the d' was significantly different from 0 [$t(21) = 11.82$, $p < .01$, two tailed], with an average of 2.75 (sd = 1.09). A Bayesian t-test on individual d' distribution confirmed that the sensitivity index was different from 0, with extreme support for the alternative hypothesis (BF 10= 196200000). This indicates that participants were able to discriminate between the presence or the absence of the memory cue.

I performed a t-test against chance (50%) on the average performance (mean= 0.54, sd= 0.39) on the WM orientation discrimination task on the trials rated as 1 (I have seen nothing). Results showed no significant difference from chance [t(21)= 0.51, p= 0.61, two-tailed, Figure 4.15].

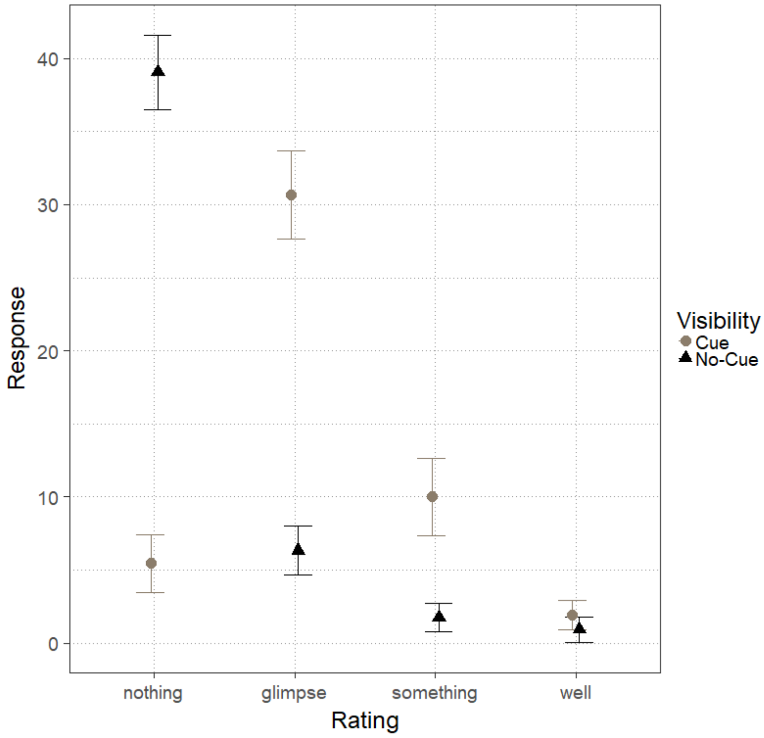


Figure 4.14 Proportion of responses for each rating in the cued and uncued conditions .40% of the total number of trials was rated 'nothing' when the cue was absent.

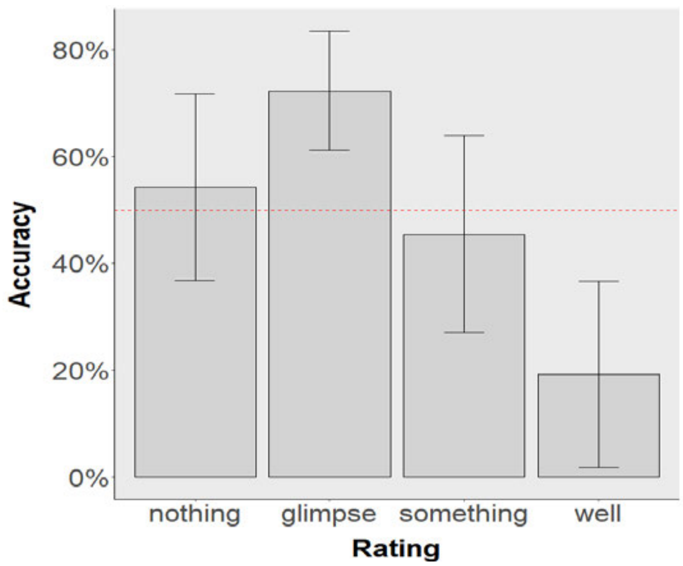


Figure 4.15 Proportion of correct responses for each rating in the cued condition. The red dotted line represents the chance level (50%), bars are SEM.

A Bayesian t-test comparing accuracy with chance (50%), using the distribution values of Soto's data as priors supports the null hypothesis (BF01 = 8.192) that participants' performance was at chance.

4.3.4 Experiment 15 - Exact replication 4 (Noise mask Experiment)

After corresponding with Soto and Silvanto about my difficulties in masking stimuli with their parameters, they suggested me to use a different mask consisting of a dots noise pattern, which they were using in a current experiment, providing me also with the code (David Soto, December 2017, personal communication).

4.3.4.1 Stimuli

Stimuli were the same as the previous experiment, with the exception of the mask, consisting of a random noise pattern generated in Psychopy with a code provided by Soto (personal communication, December 2017) and resembling the noise mask described in Dalmaijer (2016) . The mask consisted of a grating of 3.8 degrees of visual angle whose texture consisted of a randomly generated pattern of black and white dots with a density of 128x128 pixels.

4.3.4.2 Participants and Procedure

All participants ran this experiment after completing the previous one, thus they were the same participants as in Experiment 14. The procedure was also the same as in the previous experiments, including the practice trials (figure 4.16).

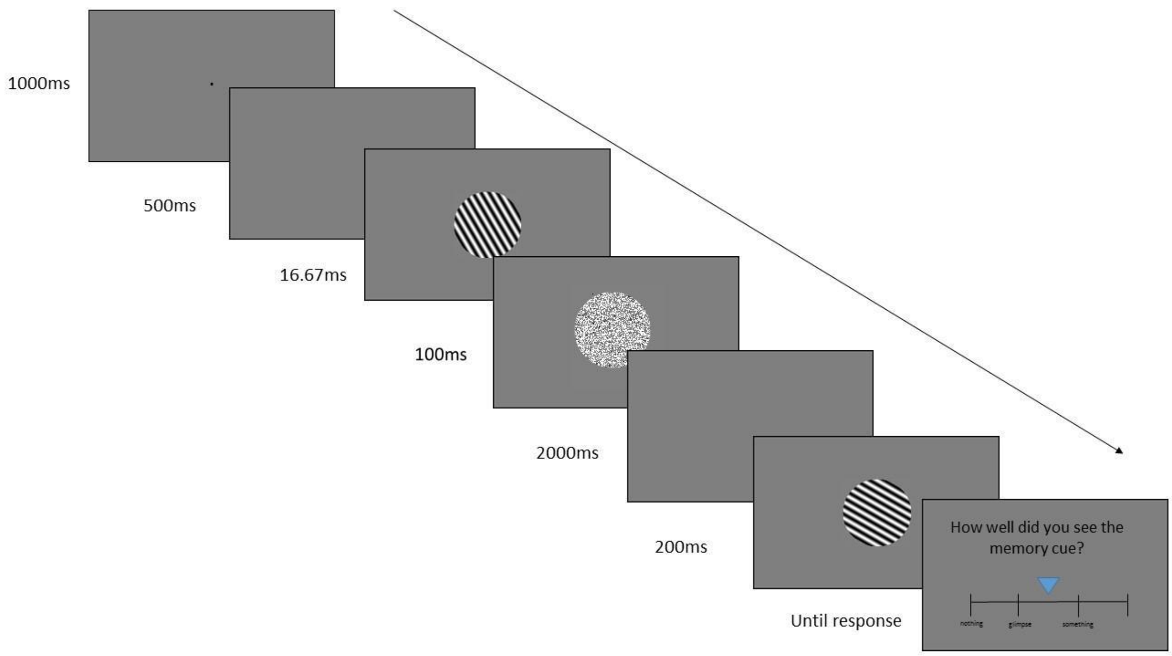


Figure 4.16. Trial sequence. The trial started with a black fixation point in the middle of the screen for 1000 ms, followed by a blank screen for 500 ms, then the memory cue appeared for 16.67 ms (1 frame). The cue consisted of a grating tilted either 10, 40, 70, 100, 130 or 160 deg to the right from the vertical (randomly selected). The cue was absent in 50% of the trials. A dot-noise pattern (the mask) followed immediately for 100 ms. After a delay period of 2000ms, another grating appeared for 200 ms, tilted 30 degrees either to the left or right of the memory cue. Participants were asked to indicate whether the target grating was clockwise or anticlockwise oriented with respect to the memory cue, by pressing the arrow keys. They were then asked to rate how well they saw the memory cue on a 4 point scale

4.3.4.3 Results

59% of the total number of trials were rated as "nothing", 23% of the total number of trials were rated as “nothing” when the cue was present (Figure 4.17).

The sensitivity index was calculated following the same procedure of the previous experiments, with the probability of hits scored as the ratio between the number of trials rated as “nothing” when the cue was absent and the total number of cue-absent trials (mean Phits= 0.73,sd= 0.31) and the probability of false alarms as the ratio between the number of trials receiving the rating of “nothing” when the cue was present and the total number of cue-present trials (mean Pfa= 0.46, sd= 0.33). A t-test was performed to assess whether d’ was reliably close to 0. Results revealed that the d' was significantly different from 0 [$t(21) = 5.67$, $p < .01$, two tailed], with an average of 1.04 (sd = 0.74).

A Bayesian t-test on individual d' distribution confirmed that the sensitivity index was different from 0, with extreme support for the alternative hypothesis (BF10= 1786.143). This indicates that participants were able to discriminate between the presence or the absence of the memory cue, which, again, was not suppressed.

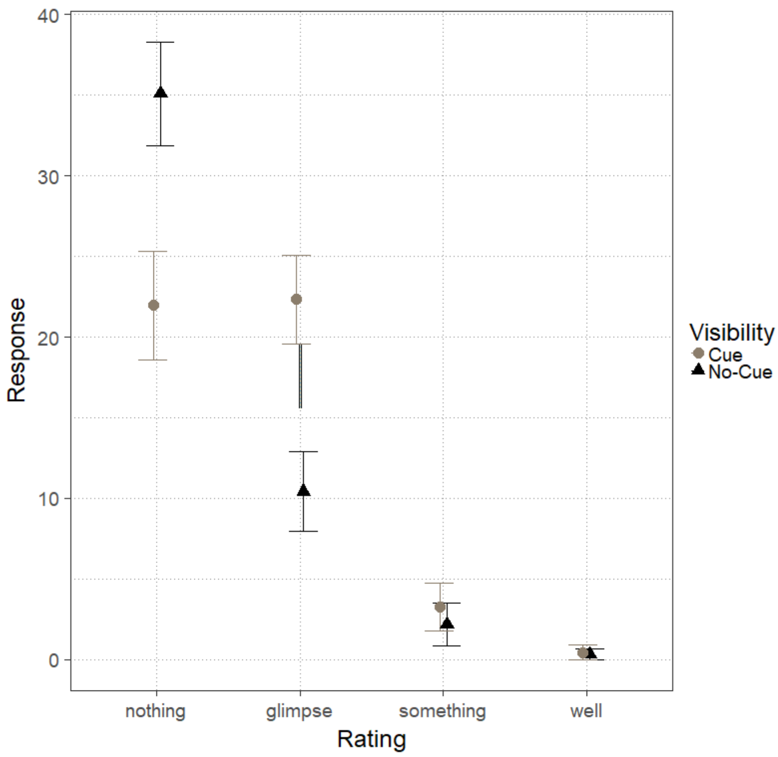


Figure 4.17 Proportion of responses for each rating in the cued and uncued conditions .36% of the total trial number was rated 'nothing' when the cue was absent (50% of the total trials). 61% of the trials rated as nothing (59% of the total trial number) were trials in which no cue was actually presented. Bars are SEM.

I still performed a t-test against chance (50%) on the average performance (mean= 0.50, sd= 0.15) on the trials rated as 1 (I have seen nothing). Results showed no significant difference from chance [t(21)= - 0.77, p= 0.44, two-tailed, Figure 4.18].

A Bayesian t-test comparing accuracy with chance (50%), using the distribution values of Soto's data as priors extremely supports the null hypothesis (BF01 = 237.321) that performance on trials rated as 1 was at chance.

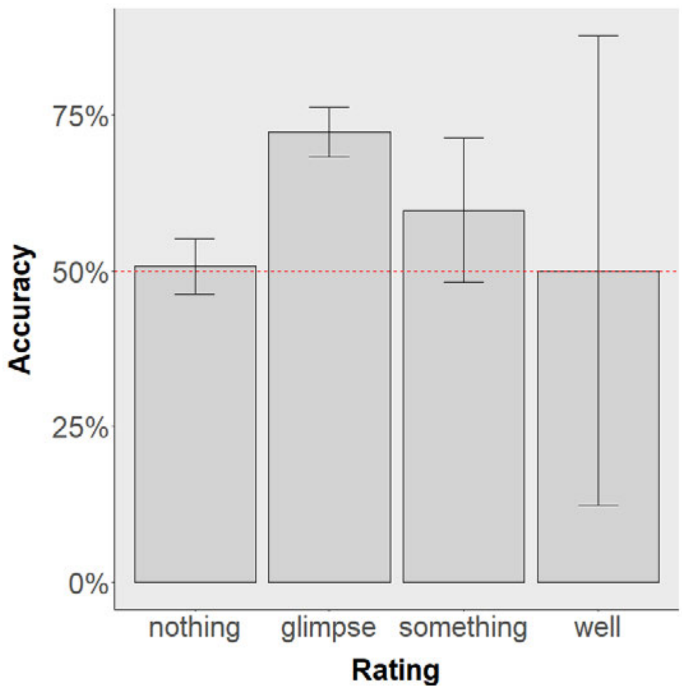


Figure 4.18. Mean accuracy as a function of rating in the cued condition. The red dotted line represents the chance level (50%). Bars are SEM.

4.4 Discussion

In the present chapter, I presented a series of conceptual and exact replications of the first study investigating the WM maintenance of stimuli suppressed from awareness (Soto et al., 2011). These replications were essential to clarify the outcomes of the ten experiments described in the previous chapters and failing to demonstrate an implicit WM activation with subliminal stimuli.

While the WM maintenance of subliminal stimuli seems to be encountered in different experimental situations (Bergstrom et al., 2015; King et al., 2016; Trübutschek et al., 2017)., the WM activation without being explicitly requested has been reported only once in literature, to the best of my knowledge (Hassin et al., 2009). So, it might have been the case that such an implicit activation needs specific conditions to happen, not fulfilled by the present paradigm.

Before reaching such a conclusion, I tried to replicate previous findings of WM processing of subliminal stimuli. Two conceptual replications, using the same stimuli as my previous experiments, but instructing participants to attend the red card, did not show any facilitation of the cue on performance or reaction times. Providing visual context (Gayet et al., 2013) by intermixing visible and invisible trials did not elicit any effect either.

No effect of the subliminal cue was found even by running an exact replication of the original study (Soto et al., 2011, Experiment 1), on a larger sample. Replicating the same effect would have confirmed that subliminal stimuli can be held in WM, although only under specific experimental conditions to be better investigated and outlined, and which the experiments in the previous chapters did not adhere to. This was not the case: in the trials for which participants claimed to be unaware of the stimulus, performance was at chance level. Furthermore, in all the exact replications attempts, stimuli were not suppressed from the awareness and participants were statistically able to discriminate the presence of the stimulus.

The first replication described resembles all the parameters reported in the original paper as closely as possible. Some additional information was kindly provided by the authors of Soto et al. (2011), like the mask details and the participants mean score to calculate the priors for the Bayesian analyses. The following replications were designed in light of the observation that stimuli were not properly suppressed (Experiment 13) and used some clarifications provided after further enquiries to Soto and Silvanto (Soto, personal communication, December 2017) about the actual stimuli characteristics (Experiment 14). The authors clarified that their stimuli were gratings and not Gabor patches, that the spatial frequency was in a different unit, and they suggested trying a different mask, providing the code for the dot noise used in Experiment 15.

None of these manipulations was effective in suppressing stimuli from awareness, and none of these experiments showed evidence of above chance performance in the "unconscious" trials.

One possible concern is that, due to different monitors and apparatus, stimuli did not precisely match those used for the original published experiments, thereby failing to elicit the same effect. Also, it might be argued that it is not possible to consider these experiments as exact replications due to the difficulty of getting a proper suppression. This latter problem would have been worrying in case of significant results, to be reasonably attributed to a breakthrough suppression. This was not the case, as performance remained at chance in the unseen trials. Moreover, in the conceptual replications suppression was properly achieved, but still no effect was found (71% and 79% of the cued trials receiving a rating of 1 in my two conceptual replications vs the 59% of cued trials receiving a rating of 1 in Soto et al. (2011, according to personal communication, December 2017).

Acknowledging the difficulty of precisely recreating all the experimental parameters as in the original laboratory, I put all my efforts into replicating the study as closely as possible, to the point of sharing my experimental code and screenshots with Soto and Silvanto and asking them for suggestions.

Hence, if this was not enough to replicate findings showing the retention of subliminal stimuli into WM, then any generalisation should be drawn very carefully because it means that the effect described by Soto et al. (2011) is only linked to very specific experimental conditions.

Replicating or re-analysing the data of other above mentioned studies supporting Soto's results (Bergstrom et al., 2015; King et al., 2016; Trübutschek et al., 2017;), would also be very beneficial to clarify the nature of such effect, especially to rule out the possibility that they are reflecting the phenomenon of regression to the mean described by Shanks (2016).

More extensive conclusions are drawn in the next chapter.

5 GENERAL DISCUSSION

The present work addressed the question of whether a stimulus of which one is not aware can be held in Working Memory in order to perform a task. Results from a considerable number of experiments led to a negative answer, not showing any support for such a possibility.

WM is defined as the mental workspace where we keep information for a brief period of time in order to achieve a goal. Some authors define it as the place where thinking takes place (Baars & Franklin, 2003), and it is commonly associated with conscious experience (e.g. Baddeley, 2007), which means that we can report its content and the operation we perform on it.

Recent advancements and findings in the study of non-conscious cognition lead to questioning this close relationship, based on the observation that high-level cognition is shown to take place without the need for consciousness (for a review see Hassin, 2013). If it is possible to extract the meaning of sentences or do arithmetic without being aware of it (Sklar et al., 2012), then it is possible that we can also maintain in WM information we are not aware of, especially considering that WM is involved in many high-level functions (Persuh, LaRock, & Berger, 2018).

Previous studies have suggested that processing of subliminal stimuli can, in fact, be carried out within WM (Soto et al., 2011, Bergstrom et al., 2015; Trubushek et al.,2016; King et al., 2016). Soto et al. (2011) demonstrated that participants were able to determine whether a Gabor patch was oriented clockwise or anti-clockwise with respect to a subliminal Gabor prime after a delay of 2 seconds. Hassin et al. (2009) demonstrated that WM can be engaged without explicit instructions, by finding that participants' performance was facilitated in the perceptual judgment of dots appearing on the screen according to a specific pattern (e.g., a zigzag) rather than in a random order. Dots appeared on the screen one at time, so participants had to keep it in mind the previous dot's location to recognise a pattern. Strikingly, participants claimed to be unaware of any pattern. According to Hassin et al. (2009), this means that participants were engaging in WM processes without being aware of it.

These findings have prompted the proposal of new views of WM and its relation to consciousness. The most extreme proposal is the conscious copy model (Jacobs & Silvanto, 2015), according to which WM is never consciously experienced, but what we can access is a conscious representation of its actual content.

If WM can be completely dissociated from consciousness- as it can retain stimuli which are not available to conscious awareness and can also be activated without conscious intention by visible stimuli - then it follows that WM should be unconsciously activated by subliminal stimuli that must be retained in order to perform a task.

5.1 The present work

In the current work I addressed the issue of whether, in order to perform a task, people can engage WM to retain a subliminal prime without being instructed to do so and without awareness of both the prime and WM activation. Participants were engaged in a guessing game in which they had to guess which of four playing cards was the winning card. The location of the winning card was subliminally primed before every selection, within a delay of 500, 1000, 2000 or 5000ms.

Differently from previous experiments on implicit WM activation, which used stimuli for which there were existing long-term memory representations (Hassin et al., 2009), in the present study no semantic processing was required, it was a simple but pure Visual WM task. This is particularly important considering that the conditions for implicit WM activation are still not clear, and I wanted to rule out the possibility that such activation is due to long-term memory retrieval bypassing WM. Della Sala et al. (2010), in fact, demonstrated unconscious processing of stimuli matching familiar but not unfamiliar proverbs, concluding that semantic retrieval does not require consciousness and WM.

With the present paradigm, I also tried to address some criticisms raised about previous studies on WM without awareness. I controlled for the possibility of a conscious maintenance of a guess due to subliminal perception (Stein et al., 2016) by using different delays. Such guess maintenance would have biased performance similarly for all delays, and possibly even at the shortest delay of 500ms.

A further criticism I addressed concerns the way to assess for awareness of the stimuli. I collected both objective and subjective measures of prime awareness, using a perceptual experiment as a control after the main experiments. This allowed me to perform a stringent control for stimulus awareness.

My exclusion criterion was not based on subjective awareness ratings, which is commonly considered to underestimate the actual stimulus perception (e.g. Eriksen, 1960). Rather, participants were excluded if performance on a subliminal perceptual task resembling the main experiment was above chance (Stein & Sterzer, 2014). Therefore, not only did I exclude participants for whom the prime may have broken through the suppression, but also those with a stronger 'blindsight perception' who were not necessarily aware of the stimulus (e.g. Hesselmann, 2013; Sterzer, Stein, Ludwig, Rothkirch, & Hesselmann, 2014). Such a strict control makes me more confident that I was assessing genuinely unconscious processing. This is particularly relevant for the present paradigm, the nature of which does not allow me to assess subjective awareness after each trial.

On the other hand, this method is susceptible to regression to the mean, as described by Shanks (2016), whereby selection of the data based on extreme scores in only one of the two measures, is likely to result in less extreme scores for the second measure. In other words, excluding participants on the basis of an extreme score (no awareness) on one task may bias the findings on the other task's scores. For this reason, I was cautious in interpreting any positive results and I ran Bayesian analyses along with the traditional analyses based on null hypothesis testing. This has been strongly recommended with this kind of task (Sterzer, Stein, Ludwig, Rothkirch, & Hesselmann, 2014; Dienes, 2015; Vadillo et al., 2015; Sand & Nilsson, 2016), where testing for unawareness of the stimuli is based on the acceptance of the null hypothesis.

5.1.1 Overview of findings

A pilot Experiment, were the stimuli were not masked, confirmed that participants used the red card as a cue for their choice even if they were not instructed to do so. Further perceptual pilots Experiments were run to make sure that stimuli luminance was adequate to get a proper suppression under CFS.

The first series of experiments employed CFS, a technique based on binocular rivalry, which allows the suppression of a stimulus from awareness by presenting it to one eye while the other eye is presented with a dynamic mask (Tsuchiya and Koch, 2005).

Experiment 1 was inconclusive. However, its results presented me with the interesting question of whether a colour in the Mondrian mask could affect the colour processing of a suppressed stimulus. This indicates how important it is to pay considerable attention to the method chosen to suppress stimuli from awareness (e.g., Dubois and Faivre, 2014).

In the subsequent study (Experiment 2) I observed significantly above chance performance after the 2000ms delay. If this result were to replicate, it would indicate that participants were implicitly engaging their WM with subliminal stimuli after a consolidation period with subsequent decay of the memory trace. However, this finding did not replicate (Experiment 3) when using a prime of a different colour. In this experiment, a significantly above chance performance emerged for the 5000ms delay. To ascertain whether the difference between these two outcomes was due to the physical characteristics of the colours (red vs green) or to a statistical fluke, I performed a further experiment (Experiment 4) by intermixing trials in which the target was a red card with trials in which the target was a green card, with respective masks that did not contain the prime's colour. The outcome was at odds with the previous findings: no significant effect for the green card and a weak effect with the red card after 500ms.

In a further CFS study (Experiment 5) the green prime and the red prime were presented in blocks, in counterbalanced order, again with their respective Mondrian masks. This experiment showed a partial replication of the effect with the green prime (above chance performance after 5000ms delay), but chance performance at all delays with the red prime.

Finally, I tried to replicate the effect found in experiment 2, by repeating precisely the same experiment. Once again, the previously found results did not replicate, with performance at chance at each delay.

The occasional finding of significantly above chance performance in some conditions of the above-mentioned experiments might make it tempting to claim that WM could be engaged without awareness. This finding was very inconsistent though, none of the specific findings replicated, and none were strongly supported by Bayesian analyses. The occasional significant results could be due to statistical flukes. Rabagliati et al. (2018), for instance, after a series of failed replication attempts and computational simulations, concluded that false positive results are easily encountered in CFS studies, due to skewed response distributions and post hoc data selection. These conclusions, however, are based on RTs analyses.

It remains possible that the inconsistency of the results was due to methodological issues, like the nature of CFS. It has been recently noted how different suppression methods can differently affect stimulus processing (Dubois & Faivre, 2014; Peremen & Lamy, 2014), and that CFS in particular allows processing of fractionated representations of the stimuli, and only restricted to low-level features (Moors et al., 2017; Peremen & Lamy, 2014), differently from what was previously thought (e.g. Hassin, 2013; Sklar et al., 2012; Yang et al., 2014). Also, the number of participants excluded by the control experiments was very high in each of my CFS studies, leading to potentially underpowered analyses.

Because of the above issues, I performed a second series of experiments where I used Backward Masking instead of CFS to suppress stimuli from awareness.

Reproducing the same experiment, with the only difference being the masking method (experiment 7) confirmed the ineffectiveness of the subliminal prime, with performance at chance.

One possible concern is that, as noted by various authors (Ansorge et al., 2010; Mealor & Dienes, 2013), top-down mechanisms like motivation and feedback on performance can affect the processing of subliminal stimuli. I assessed whether the lack of task relevance and motivation was affecting the results found so far by running a further experiment (Experiment 8), again using BM, where participants received feedback after each choice. Still, performance was not different from chance.

Finally, I wanted to explore the possibility that implicit activation of WM may only be linked to semantic retrieval, as in the case of Hassin et al. (2009) and Della Sala et al. (2010). To test this hypothesis, I carried out another experiment (Experiment 9) where primes consisted of line-drawn everyday objects, and participants had to select targets from an array of coloured cards among which one was of the colour commonly associated with the primed object. Again, the prime did not affect the card choice.

It has to be noted that the use of BM instead of CFS had an impact on the number of participants excluded on the basis of their objective performance in the control experiment. This number was much lower in the BM experiments than in the CFS experiments. Nonetheless, despite the increased power with BM, where fewer participants needed to be excluded from data analyses, the absence of effects was even more robust than in the previous CFS experiments.

Considering that none of the experiments yielded evidence for non-conscious WM activation, in the last series of experiments I went back to basics and performed conceptual and exact replications of published studies that have found such evidence. WM maintenance of subliminal stimuli has been reported by various labs, using different stimuli and techniques (e.g. Eriksson, Vogel, Lansner, Bergström, & Nyberg, 2015; King et al., 2016; Trübutschek et al., 2017), so I started by trying to replicate this effect with my stimuli. Finding above chance performance after instructing participants to retain the subliminal prime in memory, thus departing from one aspect of my newly-designed paradigm (with no explicit instruction to remember the prime) but conceptually replicating previous studies (which included such an instruction), could have been the basis to question the condition for implicit WM activation. This was not the case, as I still found no effect of the subliminal primes on participants' performance, even when participants were instructed to attend the subliminal prime (Experiment 10), as in the published literature. I found no effect of subliminal primes on performance even when they were intermixed with visible primes (Experiment 11), to account for primes validity (Gayet et al., 2014; Reuss et al., 2011).

At this point, I ran an exact replication of the pioneering study by Soto et al. (2011), specifically their Experiment 1. It could have been the case that subliminal WM retention is related to some particular categories of stimuli. Van Gaal et al. (2012) point out that some categories of stimuli, like the oriented gratings used by Soto et al., are apparently processed unconsciously without the need for any top-down modulation, differently from other kinds of stimuli. This may be due to line-orientation processing occurring very early in the visual stream in primary visual areas (e.g. Haynes & Rees, 2005; Rajimehr, 2004).

Alternatively, as for other unconscious cognition studies (e.g. Rabagliati et al., 2018), the effect may be less robust than thought and difficult to replicate by independent labs. As mentioned above, WM retention of subliminal stimuli has been demonstrated by different labs, but each of these studies uses different analyses and techniques, and are accompanied by different statistical concerns (Dubois & Faivre, 2014; Garaizar et al., 2014; Persuh et al., 2018; Marcus Rothkirch & Hesselmann, 2017; Sandberg, Timmermans, Overgaard, & Cleeremans, 2010; Shanks, 2016; Vadillo, Konstantinidis, et al., 2015). Replicating the original experiment using pre-registered parameters and variables that are as close as possible to the original ones would thus make a paramount contribution.

I made every possible effort in reproducing the same experiment, and I am grateful for the help provided by David Soto and Juha Silvanto, the original study's authors. Nonetheless, the results were problematic: under the original display parameters, the prime was not consistently suppressed from awareness. Furthermore, performance in the trials where participants claimed to be unaware of the prime was at chance. Using a different, more effective, mask did not change the results. I continued corresponding with David Soto until reaching an agreement on the stimuli's features, which turned out to be slightly different from the ones described in the paper (David Soto, December 2017, personal communication), but another replication attempt still yielded null result.

Four attempts at exact replication did not show any effect. It has to be noted that, as mentioned above regarding the first replication attempt, the level of stimulus suppression in all replication experiments was quite weak. Apart from different hardware (monitor and computer), I replicated all the experimental conditions as closely as possible to the original paper, also following instruction obtained from the authors (David Soto, December 2017, personal communication). The lack of suppression might render my attempt not definable as an exact replication (Juha Silvanto, November 2017, personal communication); however, if this is the case, it remains unclear which aspect of the original study led to better suppression and why such suppression would be associated with greater non-conscious WM. The difference itself is due to subtle differences, indicating that the effect is weaker than thought and probably dependent on extremely specific monitors or conditions. Furthermore, the level of suppression reached in the conceptual replication (Experiment 12) was high, but there was still no sign of maintenance of the suppressed stimuli.

In summary, in a series of eleven originally-designed studies encompassing different techniques, stimuli and manipulations, I could not find any evidence of WM processing outside of consciousness. Four additional replication attempts also failed to demonstrate WM maintenance of subliminal stimuli, in line with my previous results and contrary to the original findings (Soto et al., 2011).

5.2 Implications related to previous literature

In line with the present results, Stein et al. (2018) in a work assessing unconscious WM presented in a conference talk, described evidence supporting a weakly conscious WM rather than unconscious WM, questioning the possibility of WM processing without awareness.

My work adds on the increasing number of studies demonstrating that conclusions from unconscious cognition studies must be drawn very carefully (Persuh et al., 2018; Rabagliati et al., 2018; Shanks, 2016; Stein et al., 2016; Hesselmann & Moors, 2015; Vadillo, et al., 2015).

Some authors (Lau, 2009; Persuh, Emmanouil, & Ro, 2016; Persuh et al., 2018), for example, have speculated that results from studies of unconscious cognition might be artefacts due to shortcomings of current masking methods. Different methodologies affect perception and processing in different ways (Marcus Rothkirch & Hesselmann, 2017) and their underlying mechanisms are still unclear and a matter of debate (Dubois and Faivre, 2014). This, along with differences in the awareness assessments and statistical concerns (Rotrichk and Hesselmann, 2017; Shanks, 2016; Vadillo et al., 2015; Garaizar et al., 2014), makes it very hard to draw convincing conclusions from unconscious cognition studies, especially considering the difficulty in replicating their results (Rabagliati et al., 2018; Shanks, 2016; Moors et al., 2017).

There is currently great enthusiasm about the possibility of studying the conscious and the unconscious mind through new paradigms and techniques. However, it seems premature to declare overreaching rules like the Yes It Can principle (Hassin, 2013) or to reappraise existing theories of WM, especially in favour of claiming WM is utterly non-conscious (Jacobs & Silvanto 2015).

In their commentary on the paper by Hesselmann & Moors (2015), which pointed out some criticism of the YIC principle (Hassin, 2013), Goldstein & Hassin (2017) wonder why scientists and other people have the strong intuition that there are cognitive functions that cannot be carried out outside of conscious awareness. They reply to this question following Dan Gilbert (2006), with the idea that humans need to distinguish themselves from all the other beings, and this is why they value their consciousness so much. As with many questions, though, reversing it leads to the complementary strong intuition: following the question by Goldstein and Hassin, I wonder why researchers and other people have the strong intuition that we are not aware of many of the things we do, perceive and know?

If it might be true that human beings congratulate themselves for having something considered as unique as consciousness, and believe it as the reason they can perform functions that other beings cannot; it is also true that consciousness brings a big moral responsibility (Levy, 2014). The idea that what makes us human is the extent of our unconscious abilities (Goldstein & Hassin, 2017; Hassin, 2013; Neisser, 1963) can reassure us not only about the limitations of consciousness (Baddeley, 2007) but perhaps also about the responsibility that comes with it.

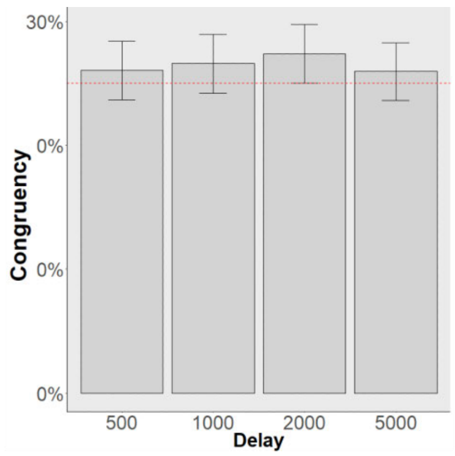
Philosophical speculation is outside of the scope of the present work, but it is worth mentioning this point because contrary to the observation of Goldstein and Hassin (2017), strong intuitions exist on both sides of the debate about unconscious cognition, which is a particularly controversial topic. The present work, in fact, started with the idea that non-conscious WM might exist, but results from a substantial number of experiments did not show any empirical evidence to support this possibility.

On the other hand, this does not mean that consciousness is definitely necessary for WM, or that WM processing cannot take place outside of it, but it does show that the jury is still out - more evidence is required. Future work should address the possibility of a graded relationship between WM function and consciousness (Logie, 2016), employing strict control criteria and analyses and possibly relying not only on laboratory masking methods but also on neuropsychological and clinical evidence (Persuh et al., 2018).

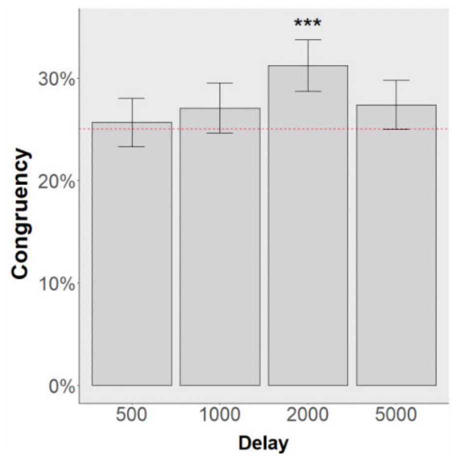
In conclusion, the present work does not provide support to the hypothesis of the existence of non-conscious WM and raises doubts about the replicability of previous studies that have claimed to demonstrate it.

6 SUPPLEMENTAL MATERIAL

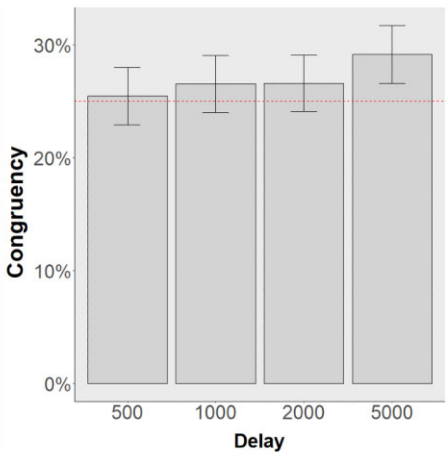
a) Proportion of cue-congruent answers sorted by delay and including all the participants for each of the nine experiments involving a control task. The overall consistency of these results with the ones obtained after participants' exclusion is important to rule out the effect of regression to the mean (see section 1.1.1), following the application of post-hoc data selection. The red dotted line represents the chance level. Bars are SEM.



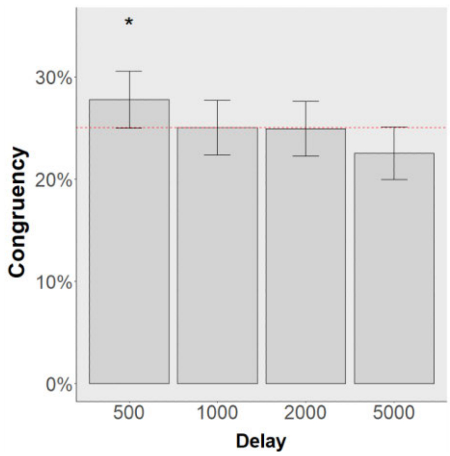
Experiment 1



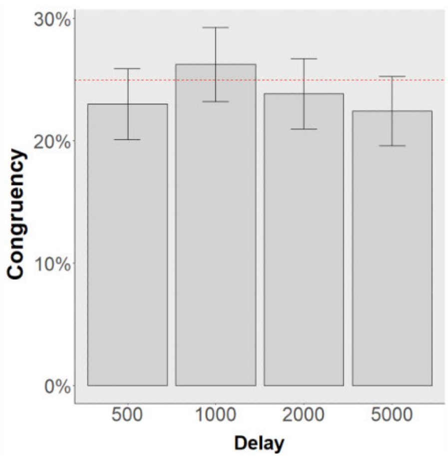
Experiment 2



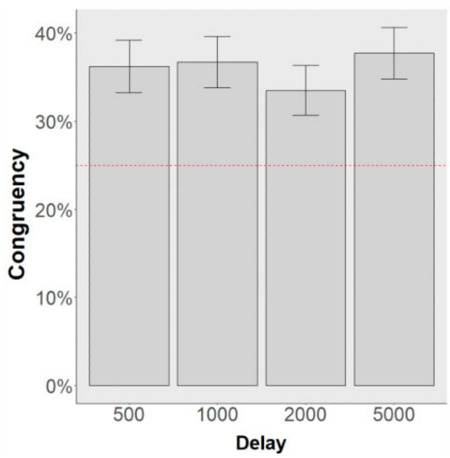
Experiment 3



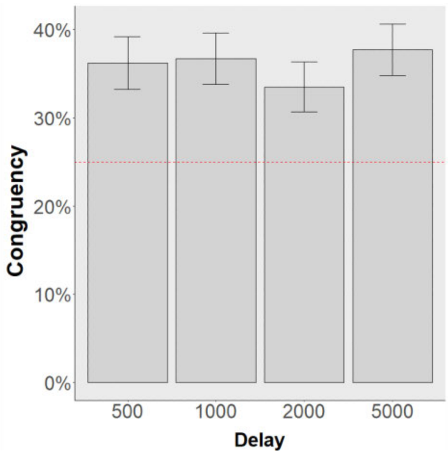
Experiment 4 red



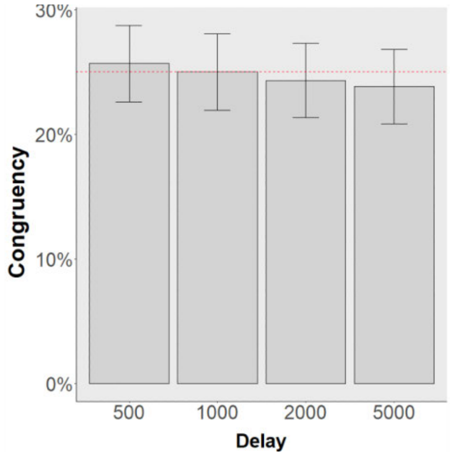
Experiment 4 green



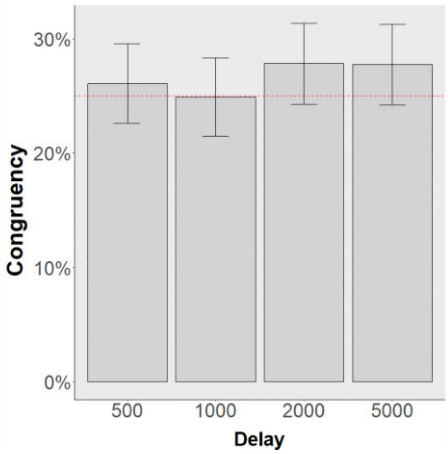
Experiment 5 green



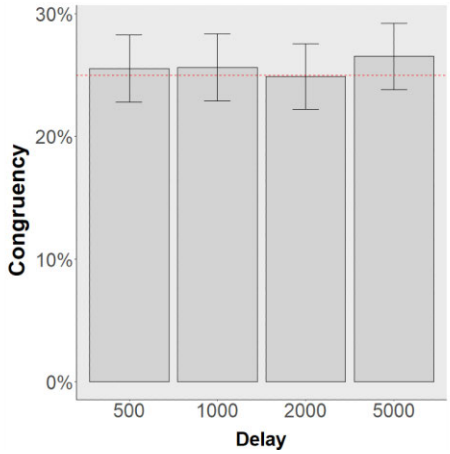
Experiment 5 red



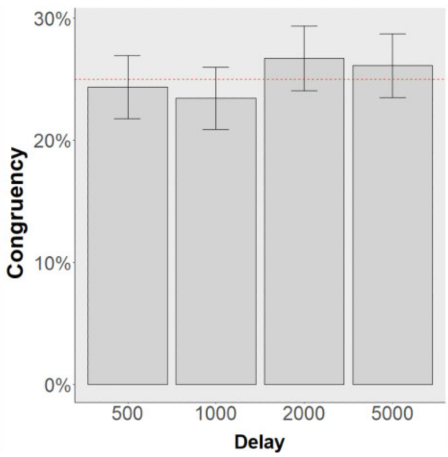
Experiment 7



Experiment 6



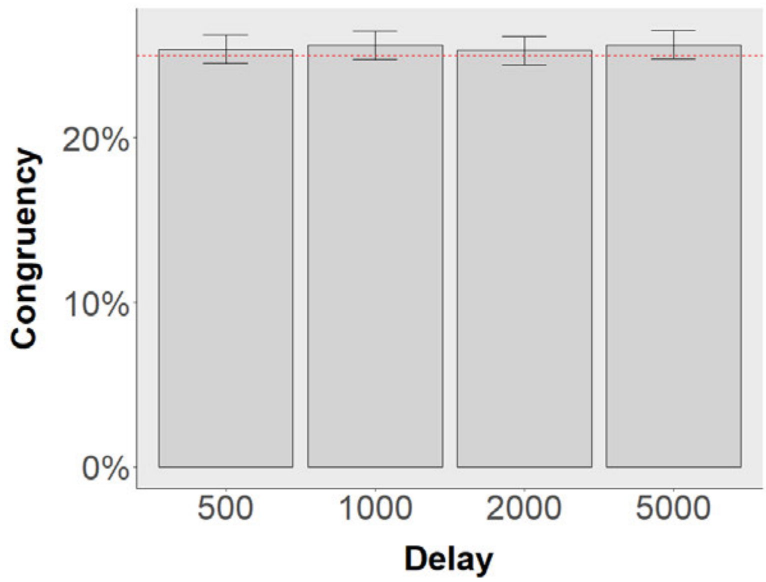
Experiment 8



Experiment 9

b) Overall analysis of experiments 1-11, with pooled data. Participants or trials were excluded according to the criteria described in each experiment. The similarity between the experiments makes this analysis a meaningful way to address the low statistical power of each single experiment after participants' exclusion.

For each delay the proportion of cue congruent answers was not different from chance, represented by the red dotted line. This finding strongly supports the conclusion that the few above-chance results were false positives and that there was no unconscious WM process involved. Bars are SEM.



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