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Tracing Subliminal Memory Traces

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This study aims to explore subliminally encoded memory traces over time in an Attentional Blink (AB) paradigm. The AB paradigm consisted of a Rapid Serial Visual Presentation (RSVP) of numbers among which two targets (T1) a simple math task, and (T2) a single letter (A, S, D, or F) were to be identified. Two direct behavioral measures, T2 accuracy and T2 Response Time (RT) were used. Conscious perception was measured with the subjective Perceptual Awareness Scale (PAS). The expectations was to find a decline in T2 accuracy, and increase in RT over three memory storage lengths (150ms, 3000ms, 7000ms). There were 21 participants, 21-32 years of age, out of which 8 were female. Each of the memory storage lengths showed significant behavioral effects ($p < .001$), which indicates unconscious perception. However, the repeated measure ANOVA did not find any significant differences for the three memory storage lengths ($p > .05$) over time. Thus, it was concluded that subliminally encoded memory traces seem to be able to persist for at least 7000ms without end in sight. The result challenge the 500ms limit usually accepted, and thus there is reason to continue to trace subliminal memory traces.

Consciousness research has received a recent revival, with renewed respectability among scientists. This recent turn of events is much owed to technological and scientific advancements in fields such as cognitive neuroscience and functional magnetic resonance imaging (fMRI) (Dehaene & Naccache, 2001) coupled with a growing dissatisfaction with (substance) dualistic explanations of the mind (Zeman, 2001). The field of consciousness research lacks a stringent and coherent framework, and it can loosely be said that there are an equal amount of conceptualizations of consciousness as there are practitioners in the field. Nevertheless, a gathered effort to move towards a unified science of consciousness has been voiced, and the proposed hub, around which a fundamental framework needs to be agreed upon, is the growing empirical body of cognitive neuroscience (Revonsuo, 2006, 2000; Dehaene & Naccache, 2001). The ultimate aim of such a science of consciousness is a complete theory of consciousness as a biological phenomena, a goal that as of now is distant, which is why the current focal point is on finding the neural correlates of consciousness (NCC) as a necessary first step towards a theory of consciousness. There are more than one field within consciousness research, e.g. visual consciousness, consciousness of volition, and consciousness of self. This study is within the field of visual consciousness where its focus is on unconscious memory processing. As such, it is essential to understand the involved concepts and their relationship with each other. Namely consciousness and unconsciousness because contrasting the two is vital to further understand their functions and capacities. Attention because it shares an intimate and complex relationship with consciousness, and is methodologically manipulated to achieve subliminal processing. Memory because durable information maintenance is the prime focus in this study, and the extent to which memory can be used unconsciously is still controversial.

Consciousness

Consciousness is in itself all but a straightforward concept as it is ambiguous and semantically irreconcilable (Revonsuo, 2006; Block, 2001; Zeman, 2001). There are two kinds, or main categories, of consciousness. Both of which are distinctly dissociable yet dependent on each other. The first refers to the levels of consciousness, or depth of unconsciousness, also known as (global) states of consciousness. The different states of consciousness can roughly be explained as the level of arousal (wakefulness), and plotted as a function of the level of arousal and representational capacity of (content) consciousness (see figure 1.). The deepest levels of unconsciousness are brain death, coma, vegetative state, minimally conscious state, and general anesthesia; these terms are usually used by medical clinicians when diagnosing patients with brain damage (Blumenfeld, 2009; Revonsuo, 2006). Increasingly higher levels of consciousness include deep sleep, REM sleep, drowsiness, and progresses all the way to complete wakefulness (Mormann & Koch, 2007). These are descriptions of different states of consciousness, but they do not encompass all of what consciousness is.

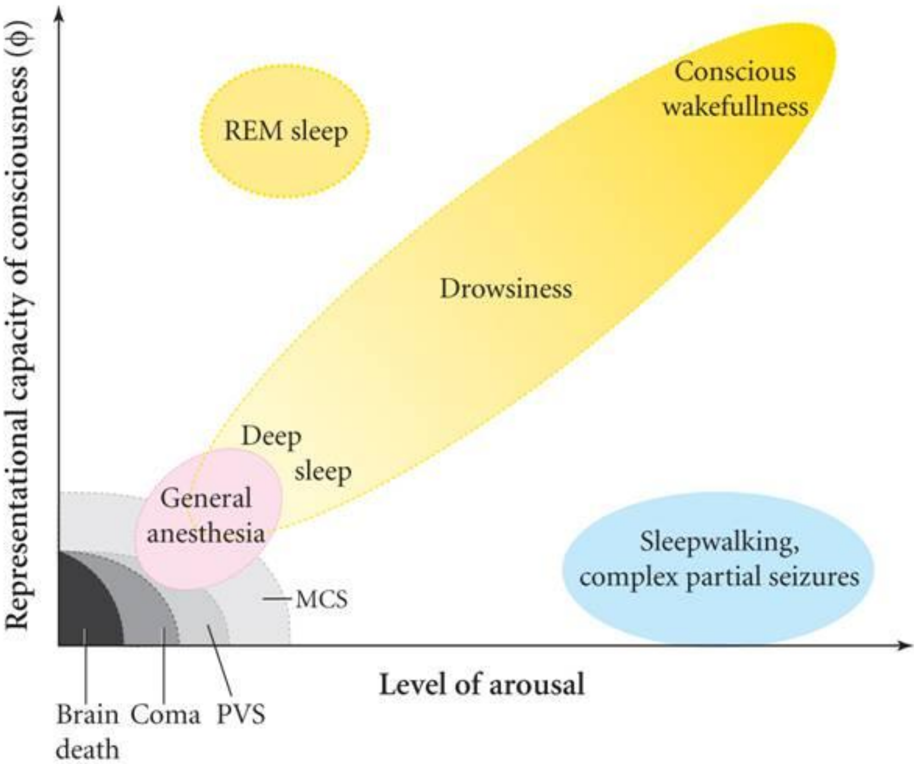

Figure 1. States of consciousness (Mormann & Koch, 2007)

The second kind refers to content consciousness, also known as phenomenal consciousness. It seems impossible to define phenomenal consciousness without circularity. That is because more fundamental constituents do not exist, and the use of equally fundamental levels will render it circular (Block, 2002; Chalmers, 1996). What is possible, however, is to describe phenomenal consciousness. Perhaps the most famous description comes from Nagel (1974) who describes phenomenal consciousness as the subjective character of experience; what it is like to be something. Phenomenal consciousness thus encompasses the experience/awareness of things such as sensations, feelings, perceptions, thoughts, wants, and emotions. That is, the blueness of blue, pain, happiness, etc. The whole of one's phenomenal consciousness at any given time consists of qualia, which are the most elementary building blocks of phenomenal experience (Revonsuo, 2006). There are several different opinions on phenomenal consciousness and its relation to the underlying cognitive processes. Chalmers (1996) makes a distinction between phenomenal and psychological properties. Where the latter are the causal and physical neuronal mechanisms underlying cognition, and the former are co-occurring metaphysical mysteries (see property dualism) that exist everywhere. Chalmers describes the scientific unveiling of phenomenal consciousness as the hard problem, and the unveiling of psychological properties of consciousness as the easy problem, which at least from his perspective, is an ontological distinction. Dennett (1991) argues that phenomenal consciousness does not exist, and that subjectivity is unscientific nonsense because science presupposes objectivity. Searle (2000) counters Dennett by pointing out the distinction between ontological subjectivity and epistemic objectivity, and that the former does not preclude the latter. Block (2002) makes a distinction similar to Chalmers, but without the metaphysical property dualism. The distinction is made between phenomenal (p-) and access (a-) consciousness, where p-consciousness is concerned with the subjective character of experience, and a-consciousness concerns information that is available for verbal report, reasoning, and control of behavior. P-consciousness and a-consciousness are interacting intimately with each other, but are nonetheless completely separate and distinct, as there is a double dissociation between them.

To make matters more intricate, some authors make further distinctions of consciousness. Namely reflective consciousness (Revonsuo, 2006), which is the higher-order form of reflecting on a phenomenal experience, and subsequently having a meta-phenomenal experience. Furthermore, Zeman (2001) distinguishes self-consciousness from ordinary phenomenal consciousness. Many of these perspectives on phenomenal consciousness are controversial, and there are combinatory adaptations. Eriksson (2007) agrees on the p-conscious and a-conscious distinction, but disagrees on the level of dissociation, arguing for a single dissociation, where it is impossible to have p-consciousness without a-consciousness. He maintains that some of the a-conscious properties are separate from p-consciousness, but are more accurately described as unconscious processes. Eriksson also strips any higher-order phenomenal properties from reflective and self-consciousness to make them no different from the standard phenomenal distinction of consciousness.

Content consciousness clearly depends on state consciousness since different states have different capacities for representing different content. Yet, the two are not the same kind because there appears to be a double dissociation between level of arousal and phenomenal consciousness. This dissociation is shown by states of low levels of arousal with rich phenomenal experience (e.g. REM sleep), and high levels of arousal with low phenomenal experience (e.g. Inattentional blindness) (Eriksson, 2007; Mormann and Koch, 2007).

In a sentence, a state of consciousness has a phenomenal content consisting of qualia, and the phenomenal aspects of consciousness are considered separate from other underlying cognitive processes. For the purpose of this paper the kind of consciousness that is relevant is phenomenal consciousness, and that is what is referred to when terms such as consciousness, conscious awareness, conscious perception and conscious experience are used henceforth. It is also presupposed that phenomenal consciousness adheres to Block's definition of it, and is ontologically monistic and deterministic (see physicalism in Papinau, 2003; and determinism in Kane, 2002). That is, the problem of consciousness is essentially a problem of biology, grounded in the physical sciences.

Unconsciousness

A common approach to the study of consciousness is to contrast it with unconscious processes, and thus try to differentiate behavioral properties and neural correlates that are specific to consciousness. For this purpose different methods (see the subsection Techniques that Induce Subliminal Processing) are used to present stimuli below the limen of conscious perception. Unconscious cognition is essentially any cognitive process that is unaccompanied by phenomenal experience. In this paper any process that is unconscious will be synonymously referred to as subliminal. There are several complex problems with the study of unconscious processing: (i) There is the technical issue of how to achieve subliminal processing. (ii) The theoretical issue of using objective and/or subjective measures. (iii) The methodological issue of how to measure non-conscious influences, and how to show an absence of conscious perception. (iv) The epistemological issue of why experiments with subliminal processing have proven hard to replicate (Kouider & Dehaene, 2007). Before briefly exploring (for detailed reviews see Dehaene & Changeux, 2011; Kouider & Dehaene, 2007; Van den Bussche, Van den Noortgate, & Reynvoet, 2009) to what level contemporary scientists have found subliminal processing it is necessary to further expand on (ii) and (iii).

Objective, Subjective and Process-Dissociation Criteria

When using an objective behavioral measure to define the limen for consciousness it is assumed that accurate choices under forced conditions are indications of conscious processing, with or without, reported phenomenal experience. With this definition unconscious processing only occurs in non-intentional behaviors (Seth, Zoltán

Dienes, Cleeremans, Overgaard, & Pessoa, 2008). As such, it is common practice to first use direct measurements (e.g. identification, discrimination, or detection) to show null sensitivity, and thus define the limen. Followed by an indirect measure (e.g. masked priming) to identify subliminal behavioral effects that might occur despite of the direct null sensitivity (Kouider & Dehaene, 2007). The objective definition is by many considered to be the more robust, and trustworthy measurement (Merikle, Smilek, & Eastwood, 2001). Which it probably is, but it is also the most conservative measurement, and as such, it might very well be underestimating the depth of unconscious processing, and its behavioral effects.

When using a subjective behavioral measure to define the limen for consciousness one will define conscious awareness as reported conscious perception. Thus, if the stimulus is not reportedly perceived, the subject is assumed to be unconscious of it. If the subject 'guesses' significantly more accurately than baseline or chance it is assumed to be an indication of subliminal processing. One can use either direct or indirect behavioral measurements. Generally, direct measures are more demanding in nature and therefore might be less sensitive, yet, pack more 'oomph', while indirect measures might be more sensitive, but less 'impressive'. Two advantages with subjective definitions are that one can discern a range of different mental states (e.g. level of perceptual awareness, and knowledge) (Seth, Dienes, Cleeremans, Overgaard, & Pessoa, 2008; Merikle, Smilek, & Eastwood, 2001). The disadvantage of using a subjective definition is that one has to rely on the report from subjects, which could be biased, and therefore give an incorrect (often overestimated) result.

Since the objective measure usually is seen as an underestimation and the subjective measure as an overestimation, Debner & Jacoby (1994) devised a process dissociation procedure to derive a more accurate estimate of conscious and unconscious contributions. The procedure contains inclusion tasks where the subject tries to use information and exclusion tasks where the subject tries to avoid using information. The difference between the inclusion and exclusion result is assumed to be conscious knowledge, and the use of information despite the exclusion criteria is assumed to be unconscious knowledge.

Subjective Methods to Report the Absence of Conscious Perception

There are different kinds of subjective methods that can be used to determine absence and degrees of conscious perception. Three common subjective methods are (i) post-decision wagering (PDW) in which subjects are to wager something (e.g. money or sweets) on the correctness of each decision. Since they will either win or lose the amount wagered, they are expected to wager greater amounts when stimuli are consciously perceived to some extent and the lowest amount when they did not. (ii) The confidence rating (CR), with which subjects are to estimate the level of confidence they have about each decision from 'not confident at all' to 'very confident'. (iii) With the perceptual awareness scale (PAS) the subjects are to report their perceptual experience of the stimuli from 'no experience' to 'clear experience' (Overgaard, Timmermans, Sandberg, & Cleeremans, 2010). Persaud, McLeod, & Cowey (2007) argues that PDW is an objective direct measurement of conscious awareness and therefore also a more accurate, and less uncertain than verbal reports and CR. However, Seth (2008) argues that PDW cannot be direct for two reasons. First, they nevertheless need some criterion to evaluate consciousness (e.g. pushing a button). Second, such behavioral criterion does not single out conscious from unconscious behavior. Simply put, Seth argues that no behavioral measure can be direct because consciousness is ontologically subjective in nature, and thus precludes any direct access to its content. However, it is important to note that both subjective and objective measures are epistemologically objective since their data can be shared publically. Overgaard et al. (2010) did a review of PDW, CR, and PAS to see which measure that most consistently correlated with performance, and how the scales related to subliminal processing. They found that CR correlated to a greater extent with performance than PDW, but that PAS correlated to a greater extent than CR. It was speculated that PDW can be biased by risk aversion, or gambling strategies, and as CR entail a (second-order) judgment of one's perceptual awareness it is less direct. Furthermore, having a vague experience is still compatible with not being confident about the correctness of one's decision. PAS benefits from only being about the visual experience, and thus making it a more direct measurement of conscious perception. Dienes & Seth (2010) concur on PDWs weaknesses, but maintain CRs superiority over PAS. Their conclusion is based on the fact that PAS presumably would be too general, in that it would not make the distinction between a perceptual awareness of something, in contrast to a perceptual awareness of the target stimuli (e.g. its semantic meaning).

Depth of Unconscious Processing

So, with the above in mind, to what depth, if any, does unconscious cognition occur? Most people have heard of the infamous 'Eat Popcorn/Drink Coke' study. The study was supposedly conducted in a cinema in the 1950's by James Vicary. Messages urging customers to consume popcorn and Coke were briefly flashed under the limen for consciousness during the movie. The success of the subliminal persuasion was claimed to result in a hefty sales increase (58% in popcorn and 18% in Coke). What might not be equally known is that Vicary later admitted that the study was a fake, and was engineered to prevent his advertisement business from failing. No data from the 'study' was ever provided, countless studies trying to replicate similar findings have failed, and it is now widely accepted (in the scientific community) that such subliminal persuasion does not exist (Pratkanis, 1992). So if subliminal persuasion does not exist, how deep does subliminal processing reach and affect our behavior?

There are three theoretical positions that are held by scientists (Kouider & Dehaene, 2007). The first claims that consciousness and mental representations go together, and although unconscious processing does exist, it is non-representational and therefore cannot involve semantic processing. The second position, being the former's polar, claims that all information processing in principle can occur unconsciously. The third position claims that the existing unconscious processes are limited, and that they contain simple automatic processes rather than the strategic and volitional that are attributed to consciousness. The author of this paper is currently of the belief that unconscious processing probably is limited to some extent, precluding the second position, but that its capability is greater than what the third position posits. Finding the limitations for unconscious processing, or lack thereof, is an ongoing empirical quest.

Thence, let us review the accumulated empirical research in the field so far. Empirical research on the subject of unconscious perception appeared during the nineteenth century as psychology broke away from philosophy to become its own domain. One of the most prominent classical works during this era came from Sidis (1898) who found (among other things) that subjects were better than chance at discriminating between letters and digits in a forced-choice task when the stimuli was placed too far away in distance for reported conscious perception. Similar kinds of studies followed until Eriksen (1960) criticized the use of subjective measures of conscious awareness on account of the uncertainty of biases, and thus that an objective limen for consciousness should be defined as having a forced-choice performance at chance. The scientific community became highly skeptical to the existence of subliminally processed semantic information. However, around the 1980's several studies, mainly using objective measures, but also process-dissociation procedures, began converging on the existence of semantic priming. Alas, almost all of them suffered from methodological flaws (Holender, 1986). During the period up to the 1990's the focal point was on subliminal lexical and orthographical processing, the existence of which could be supported by the findings of that time. However, the existence of subliminal semantic and phonological processing was still largely uncertain. At the end of the 1990's methodological improvements had occurred and subliminal processing in general was accepted, the only controversy regarded the level of depth (Kouider & Dehaene, 2007). Today the debate about subliminal semantic processing mainly concerns the effect confounding factors have on the behavioral results. Some of the confounding factors that have been identified to influence subliminal semantic effects are prime novelty, category size, target set size, target repetitions, and number of trials. Nevertheless, a meta-analysis of subliminal semantic priming by Van den Bussche et al. (2009) not only showed that said confounding factors does influence the effect size, but also that smaller, yet significant subliminal semantic effects do occur without confounding factors. Some of the generally assumed limitations to subliminal processing are that the effects quickly dwindle as a function of both processing depth and time. Neither does subliminal processing seem to have any lasting effects on executive control, the ability to adapt strategies based on goals and contextual information (Dehaene & Changeux, 2011). However, these limitations have met recent challenges (Lau & Passingham, 2007; Hassin, Bargh, & Zimerman, 2009, Stapel & Koomen, 2006; Mudrik, Breska, Lamy, & Deouell, 2011). The formation of contextually goal based strategies combines several psychological processes such as initiation, inhibition, shifting, and monitoring (Purves et al., 2008). A vital aspect of monitoring is attention, which has an important relationship with consciousness.

Consciousness and Attention

Thus, it is necessary to delve into the relationship between consciousness and attention. According to Tsuchiya & Koch (2009), and Koch & Tsuchiya (2007), the relationship is intimately and intricately interwoven. Some proponents claim that consciousness and attention are identical, while others claim that they are dissociable. Most contemporary scientists argue that the two are dissociable, but that still leaves the question about the nature of their relationship open. Is selective attention necessary and sufficient for conscious awareness, or can conscious awareness exist without selective attention? Attention has, much like consciousness, been divided into different kinds, and is thus not a unitary concept. Furthermore, attention and consciousness seems to have quite different functional roles. The attentional system is used to pick out the most important bits of information for the organism at any given point in time, and essentially ignoring all the other massive amounts of information. That is an effective solution for the limited brain and its resources to handle exceeding amounts of information. The attentional system is divided into the exogenous (bottom-up) sub-system and the endogenous (top-down) sub-system. Endogenous attention is directed by volition, usually based on individual goals, knowledge, desires, and expectations. It can, metaphorically, be seen as a spotlight with high capacity to process whatever is in it, but limited capacity to attend to several things and large spatial areas at once. Exogenous attention is automatically and reflexively used, and has a low capacity for extensive processing, but can cover large areas of the visual field. If any important stimulus (e.g. evolutionarily significant) is detected by the exogenous sub-system it will reflexively signal the endogenous sub-system to immediately focus attention on that area/stimulus for more extensive processing (Purves et al., 2008). It is thought that consciousness is responsible for unifying all relevant internal and external information, and making the unity available for complex processing such as planning, long-term goal setting, decision-making, rational thought, language, error detection, and inferring the state of other minds. When comparing the functional role of attention and consciousness there is a clear difference, which in itself is an argument for accepting the two as separate and distinct systems as, indeed, most contemporary scientists do (Tsuchiya & Koch, 2009). It is important to notice that the kind of attention we are going to be contrasting with consciousness is selective (endogenous) attention, and that is what is meant when using the term attention from here on forth.

Dehaene, Changeux, Lionel Naccache, Sackur, & Sergent (2006), and Kouider & Dehaene (2007) proposes a tripartite taxonomy based on the global workspace model (for details on GWM see Baars, 2005), and the notion that there cannot be consciousness without attention. They argue that even though consciousness and attention are separate their relationship remains complex. According to them both top-down attention and sufficient bottom-up stimulus strength is necessary, yet not always sufficient, for a stimulus to lead to a conscious percept. Thus, two subtypes of non-consciousness, subliminal and preconscious, are added to being fully conscious and completely unconscious (see figure2). Subliminal processing occurs when top-down attention is present, but the bottom-up activation is not strong enough for global conscious access. Examples of methods that cause subliminal processing are backward and forward masking. Preconscious processing occurs when the bottom-up activation is strong enough to reach global conscious access, but is hindered by a lack of top-down attentional amplification. Examples of methods that cause preconscious processing are attentional blink and inattentional blindness. Preconscious processing carries information higher (closer to conscious awareness), and does therefore have a greater impact on behavior.

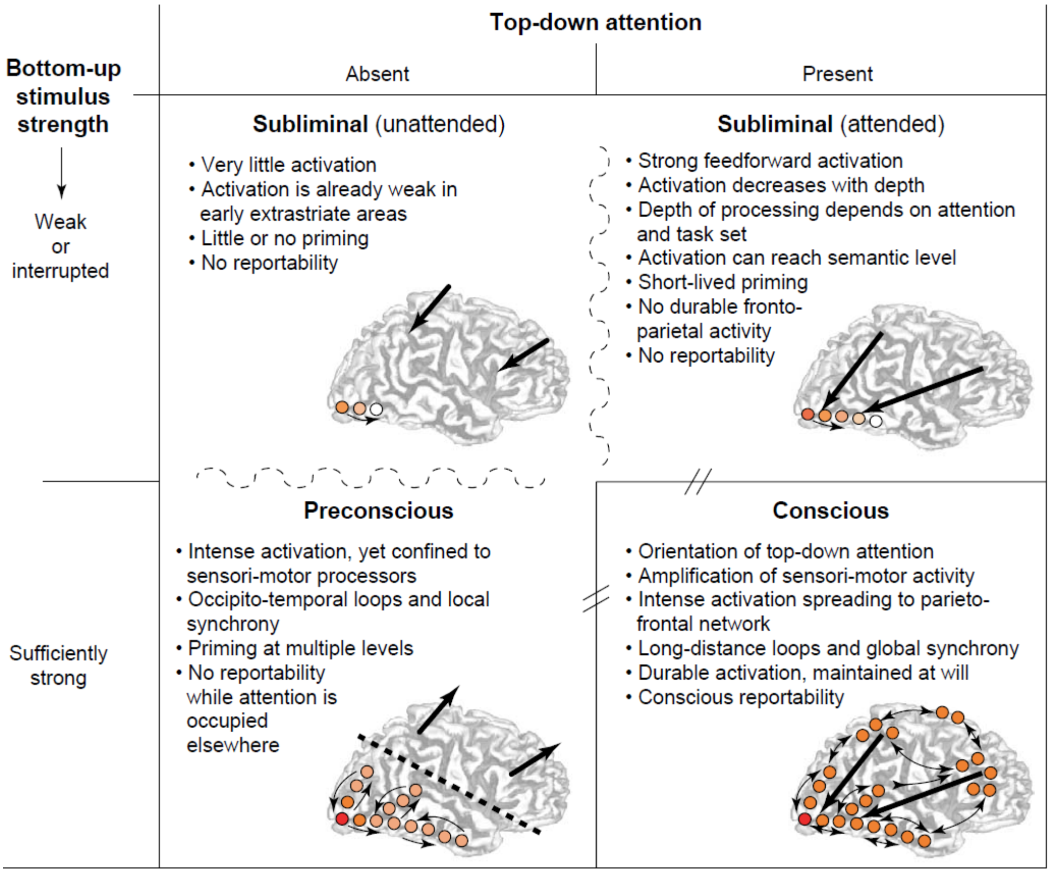

Figure 2. A tripartite taxonomy of the relation between consciousness and attention (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006)

Tsuchiya & Koch (2009) disagree on one point, namely, that conscious perception cannot exist without attention. Thus, they suggest a quadruple taxonomy of the relationship between consciousness and attention (see table 1.). Some support for consciousness without attention are that the gist taken in from the periphery visual fields, that is, outside of focused attention, are immune to inattentional blindness. For example, when photographic scenery was unexpectedly flashed on a screen the subjects were able to accurately summarize the content, or gist, of the photograph (see Mack & Rock, 1998). Furthermore, in dual task paradigms it has been shown that subjects can accurately report complex images of animals or vehicles, male or female faces, but shows an inability to discriminate between less complex stimuli such as red-green or green-red bisected disks, or the rotated letter L from T. Thus, it seems like some tasks can be confidently and accurately performed with conscious awareness, but without attention. Less controversial, and in agreement with Dehaene et al. (2006), is the idea that attention does not necessarily lead to conscious awareness. Tsuchiya & Koch (2009) cites research on continuous flash suppression where male/female nudes caught attention despite being completely invisible, and blindsight patients showing normal reaction-times when visually cued in their blind spot. There can even be some processing without neither consciousness nor attention. Examples of such processes are visuo-motor reflexes like the accommodation and pupillary reflexes, and that non-salient stimuli can leave negative afterimages. Even more evidence towards dissociation between consciousness and attention can be seen in the attentional blink phenomenon, and Koivisto & Revonsuo's (2007) studies on event-related potentials. In this study it is assumed that consciousness and attention are two completely dissociable concepts/systems. This dissociation can be methodologically manipulated to render experimental stimuli subliminal.

Table 1. *A quadruple taxonomy of consciousness and attention with related percepts and behaviors (Tsuchiya and Koch, 2009)*

	May not give rise to consciousness	**Gives rise to consciousness**
Top-down attention is not required	Formation of afterimages Rapid vision (<120ms) Zombie behaviors Accommodation reflex Pupillary reflex	Pop-out Iconic memory Gist Animal and gender detection in dual-tasks Partial reportability
Top-down attention is required	Priming Adaptation Processing of objects Visual search Thoughts	Working memory Detection and discrimination or unexpected/unfamiliar stimuli Full reportability

Techniques that Induce Subliminal Processing

Henceforth follows a brief review of some of the visual masking methods commonly used for investigating NCC's, their relationship with consciousness, attention, and stimuli strength. A common and well used visual masking technique is the forward and backward masking methods (F/BM) (Dell'Acqua & Grainger, 1999; Diaz & McCarthy, 2007; Kouider & Dehaene, 2009; Dehaene et al., 1994), where a target stimuli is presented for a very short amount of time quickly followed (BM) or preceded (FM) by a distracter stimuli. This technique will halt the processing duration of the target stimulus, which renders the target subliminal because of the low stimuli strength, while attention is maintained on the target. By having the same stimuli presented with onset times below and above the conscious limen one can study the behavioral effects and neural correlates of subliminal and supraliminal processing of the same stimuli. However, the short onset times that are needed makes it impossible to create prolonged states of subliminal perception (Kim & Blake, 2005).

Another technique is to evoke bistable perception with the use of binocular rivalry (BR), which can be sustained for longer periods of time. BR is achieved when two different conflicting stimulus are presented to each eye simultaneously. The way the brain solves this conflict is to suppress one of the images while consciously processing the other. The brain unpredictably switches between the two images, making the study of subliminal and supraliminal processing possible, but uncontrollable. A way to make it more controllable is by continuous flash suppression (CFS). In CFS one uses several strong and complex stimuli to continuously flash in front of one eye (every 100ms) creating a moving complexity that attracts attention. Thus, the brain will never switch to the other eye's input, where it is possible to hide a target stimulus from consciousness (Tsuchiya & Koch, 2005, 2006). However, recent studies (Almeida, Mahon, Nakayama, & Caramazza, 2008; Fang & He, 2005) have found that CFS (and presumably bistable perception in general) seems to suppress the information from reaching the ventral ('what') visual pathway in the brain, only allowing the hidden target access to the dorsal ('where') visual pathway. The implication being that stimuli identification will not be processed, as shown when priming effects on images of animals, human faces and vehicles do not exist during CFS, while they do during BM (Almeida, Mahon, Nakayama, & Caramazza, 2008). The dorsal visual pathway does however seem to process images of tools, maybe because of their relation to motion and spatial relations that the dorsal stream is known to process. Furthermore, Bahrami et al. (2010) found significant priming effects of symbolic numerosity, and suggest it to be because of the functional overlap of the intraparietal sulcus that is linked to symbolic numerosity and visuospatial tasks such as reaching. Another relatively unused BR manipulation method is dichoptic color masking (DCM), which is achieved by presenting two identical stimulus with inverted colors (of the same luminance level), and having them rapidly flash with a blank screen in between presentations. Thus, there is not enough sustained time for BR to occur, and the brain will instead fuse the image and its colors until only a single unified color field is consciously perceived, while the stimulus is subliminal. Studies that used DCM (for other purposes) did not find a significant subliminal behavioral effect when using direct behavioral measures (Moutoussis & Zeki, 2002; Schurger, Pereira, Treisman, & Cohen, 2010). It is worth mentioning that the author of this paper previously investigated such a paradigm, and did find indications of a possible subliminal behavioral effect, alas, not strong enough for present purposes.

A visual technique that exploits the lack of attention to achieve subliminal processing of targets is inattentional blindness (IB). This method manipulates the subject to focus selective attention on a cognitively demanding task while presenting a target stimulus in the periphery, unknowingly to the subject (Mack & Rock, 1998). This enables a much stronger stimuli strength with onset times of up to 200ms (Merikle & Smith, 2005), which would have been clearly seen by the subject, had their attention not been elsewhere. Its perk lie within the stimuli strength, but its weakness is that once a subject is aware of the design he/she is forfeit. If only one trial is possible per subject, a lot of subjects are needed for a robust result (Mack and Rock, 1998). Though, Merikle & Smith (2005) did circumvent this issue by using a stem-completion task, thus, never revealing the true purpose after the trials.

The last visual technique to be reviewed is the attentional blink (AB) method. The AB effect is well documented, and is achieved by presenting two targets in close temporal proximity in a rapid serial visual presentation of distracters. When the subject focuses attention on the first target in order to identify it an attentional blind spot is created between 100ms and 500ms, and if the second target falls within this range it is not consciously perceived about half of the time. If the two targets are <100ms a part both will be consciously perceived, a phenomenon called lag1-sparring (Martens & Wyble, 2010). It seems that the more cognitively demanding the first target is, the more powerful the AB effect will become. However, if the attention somehow is disturbed or ’thinned-out’, the AB effect will weaken and make it more likely to consciously perceive both targets (Martens & Wyble, 2010). The AB effect is effective to use in consciousness research and have been found to have significant subliminal priming effects (Harris & Little, 2010; Pesciarelli et al., 2007; Sergent, Baillet, & Dehaene, 2005). It have also been suggested that AB effects can be so effective that little or no difference in semantic processing between conscious awareness and attentional blinks (Kouider & Dehaene, 2007). The AB is, similarly to IB, achieved while the target is inattentively processed, which means that the stimuli strength can be somewhat strong. In contrast to IB, the AB effect makes it possible for the invisible stimulus to be within focal view instead of the periphery. It is also easier to control the AB effect because even if the subject is aware of the effect they will nevertheless succumb to it. This brief review (for more extensive see Kim & Blake, 2005) will serve as a foundation for the reader to better comprehend the reasoning behind the particular technique chosen for this study. Now, given that consciousness and attention are manipulated so that unconscious perception occurs, we know that subliminal processing to some extent is possible. We also know that subliminal processing can be measured as behavioral effects. However, for subliminally encoded and processed information to affect behavior, at any other point in time other than directly at the moment of perception, the information need to have been stored in memory.

Consciousness and Memory

The central function of working memory (WM) is to maintain, and manipulate information in an active state for a brief amount of time to achieve specific goals. WM is highly interconnected with the other cognitive systems in the brain. Its input and content mostly comes from perception and long-term memory (LTM) and they are thus intimately connected. WM is also linked to motor and premotor systems as it can contain information about potential actions to obtain goals, and attention as it sometimes is referred to as a system of attention on internal representations. Furthermore, WM is essential for language which in turn has been seen to improve WM capacity, and many complex executive functions that, to some extent, overlap with reasoning and problem solving, are involved in WM. (Purves et al., 2008)

Arguably the most influential WM model is Baddeley & Hitch's (Baddeley, 2003), but the exact nature of the relationship between consciousness and WM is still not specified (Baars & Franklin, 2003) even though the active components of WM usually are presumed to be conscious (Eriksson, 2007) (see figure3). There are, however, a few suggestions on the relationship between consciousness and WM. Baddeley & Andrade (2000) claims that WM is essential, and thus, necessary for consciousness. Baddeley (2003) mentions that the episodic buffer, that binds and integrates information, is open for access by consciousness. Baddeley suggests that the episodic buffer is a key feature in making WM a global workspace. Baars & Franklin (2003) claims that consciousness is necessary for WM and that only a subset of WM content are conscious. According to them, consciousness is what creates the global workspace.

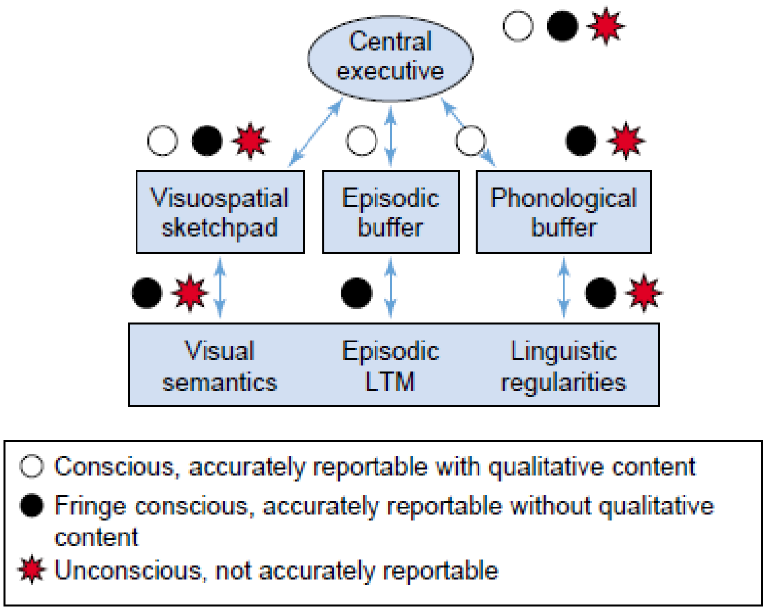

Figure 3. WM and its relationship to consciousness (Baars & Franklin, 2003)

LTM is usually divided into declarative (explicit), and non-declarative (implicit) memory based on if learning and retrieval are conscious or unconscious (Henke, 2010). Because research into unconscious memory has found relatively limited memory duration it is usually assumed that consciousness is necessary for LTM encoding and retrieval, while LTM storage is seen as the epitome of unconscious content. It has also been suggested that the content of consciousness affect the kind of memory that can be stored (Eriksson, 2007). It should be noted that it has recently been proposed that consciousness is an unsuitable criteria for distinguishing between different kinds of memory. Recent empirical evidence suggests that episodic and semantic memory can be encoded and retrieved with or without conscious awareness (Henke, 2010).

However, to what extent can subliminally encoded information be stored in memory? Reviewing the relatively meager supply of studies on unconscious memory encoding we find Greenwald, Draine, & Abrams (1996) that arguably have the most robust, and generally accepted findings. They systematically varied the stimuli onset asynchrony, and found that subliminal semantic priming effects were at its strongest within 67ms and 100ms after which it quickly faded. Further support for short-lived subliminal memory can be seen when reviewing priming studies in general. The studies that successfully find subliminal priming usually does so when using a stimuli onset asynchrony of 50ms to 150ms, while longer stimuli onset asynchrony usually fails to find subliminal priming effects (Dehaene & Naccache, 2001). It is generally understood that subliminal information lasts for no more than 500ms (Dehaene & Changeux, 2011) and the idea that it would last longer is controversial. Some recent studies have nevertheless tried to show that there can be longer lasting subliminal behavioral effects. Examples of such are Sohlberg & Birgegard (2003), and Merikle & Smith (2005), the latter used an inattentional blindness and stem-completion task paradigm to show that subliminal effects could last for up to 32min. Merikle & Smith (2005) also referred to studies that found priming effects from suggestions given to patients under anesthesia, lasting for 36 hours even when controlled for level of anesthesia. Both of the above studies have received critique, the first for using doubtful methods to measure conscious perception, and the second for not being peer-reviewed (Eriksson, 2007). For instance, Merikle & Smith (2005) considered trials were subjects reported seeing a few letters of the target word to be without conscious awareness. A recent study by Yang, Xu, Du, Shi, & Fang (2011) has shown that emotional priming effects seem to be able to retain for up to 3 min regardless if the encoding was conscious or unconscious. It is important to be aware that Greenwald, Draine, & Abrams (1996) and Dehaene & Changeux (2011) that propose very short memory traces used, and reviewed studies that used, objective measures of consciousness, while e.g. Merikle & Smith (2005) used subjective measures of consciousness. Such significant methodological difference between these memory studies surely affects the outcome.

Purpose

The studies on longer lasting memory traces following subliminal encoding are few, some are methodologically questionable, and show varying results. Taken together this makes an interesting field for further scientific inquiry. The experimental paradigm used to investigate subliminally encoded memory traces contained the AB technique, a subjective measurement of consciousness (PAS), and direct behavioral measurements. The AB method was used because it (i) allowed for high stimuli strength in the fovea (ii) enabled several trials to be run on the same subject without compromising the subliminal effect. A subjective measure of consciousness was used since the idea was to explore the upper fringes of subliminal effects, and therefore a liberal measure would be more accurate than a conservative (objective) measure. Additionally, studies that have examined the stimuli onset asynchrony of subliminal priming have more frequently used objective measures in the past. As for the kind of subjective measure it was determined that PAS was most suitable for the reasons mentioned by Overgaard, Timmermans, Sandberg, & Cleeremans (2010), namely, that it is the most direct measure. As Dienes & Seth (2010) noted about PAS it can be interpret to be about the perceptual experience in general, but that was circumvented by adding specific instructions to make clear that it is the perceptual experience of the target stimuli that is to be estimated. A direct behavioral measure was used because it requires more than reactive reflexes, and thus has more 'oomph'.

The main aim of this study is to explore subliminal memory traces in behavioral effects over time. For this purpose three different memory storage lengths (150ms, 3000ms, 7000ms) between target encoding and recall were implemented. The lengths were based on previous research, 150ms was the smallest possible length, and is more than the 100ms suggested by Greenwald, Draine, & Abrams (1996). However, since the current study was not exclusively concerned with semantic memory traces it was expected that 150ms would be short enough to elicit a subliminal behavioral effect, and it was less than the 500ms that Dehaene & Changeux (2011) suggested as the limit for subliminal memory traces in general. Since the current study also used subjective measures of consciousness there was reason to believe that longer lengths, such as 3000ms and 7000ms, could show some weaker effects of subliminal memory traces. Thus, the expected result was to see a decline in T2 accuracy and an increase in the in T2 RT as a function of time. Those expectations were based on the assumption that memory traces decline over time. Furthermore, stronger memory trace would cause a faster and more accurate response, while a weaker memory trace would cause slower and less accurate responses. The sub goals of this study were to (i) show that a proper AB effect was obtained in the experiment, (ii) that the subjects elicited significant subliminal behavioral effects, and (iii) to evaluate the paradigm for use in a future fMRI study. Sub goal (i) was needed to validate experimental method and thus the main findings. In order to look at subliminal memory traces over time it is necessary to first establish the existence of subliminal perception at all three memory storage length. The confirmation of sub goal (ii) is therefore a necessary prerequisite for the main goal.

Method

Participants

The 21 participants were within the range of 21 and 32 (M: 24, SD: 3) years of age, and 8 were female. They had different cultural backgrounds with the only limitation that they had to speak English or Swedish, been brought up with the Latin alphabet and Arabic numerals. Before participating they had to sign a contract of informed consent. They were all naïve to the true purpose of the study.

Equipment

E-prime 2.0 was used to design the experimental procedure and collect data for the experiment. The same computer and 60Hz Samsung SyncMaster 204B TFT-LCD monitor with 1024x768 was used for all participants.

Procedure

The experimental paradigm consisted of 220 trials of rapid serial visual presentations (RSVP) with two targets, T1 and T2. Where T1 was a simple math task and T2 was a letter. The participants first read the instructions of the experiment, which was in Swedish or English depending on the participant's language preference. The instructions briefly explained the experimental procedure and the participant's objectives.

During the experiment each trial began with a delay consisting of a centralized cross for 3000ms. Each individual stimulus presentation is called a lag and is the smallest unit of time in any trial procedure. Thus, a lag can be one three digit distracter, T1, or T2, and has by default a duration of 133ms. The first 20 trials were used to calibrate individual sensitivity to the lag duration, and were not included in the final analysis. Depending on the subject's T1 score the lag duration would change to accommodate the subject's sensitivity, and make sure that it was possible for subjects to perceive T1 despite of individual differences. If the subject scored >85% the lag duration decreased to 117ms, and if the score <60% the lag duration increased to 150ms. The reason for the lag duration adjustment was to balance out the number of trials where T2 was reportedly perceived versus not perceived. That was an important factor to gain robust data, and there is a pronounced individual difference in AB effect sensitivity e.g. with video game players and non-video game players (Green & Bavelier, 2003). Because of the flexibility of lag duration it was necessary to make sure that the length between T2 presentation and T2 response always was 150ms, 3000ms, and 7000ms. The lengths were kept constant by automatic regulations (based on lag duration) of number of lags, and durations of the blank screen.

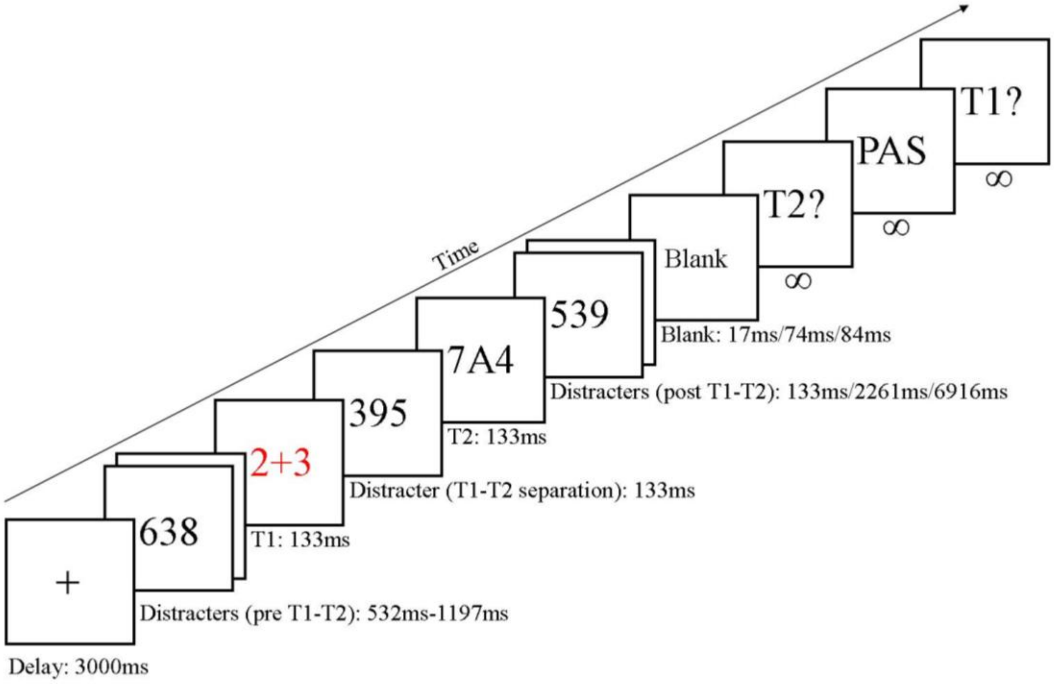

Figure 4. The standard experimental trial procedure with default lags (133ms)

After the delay a randomized time period of four to nine lags (distracters pre T1-T2) with numerical distracters appeared. The distracters were black numbers, three at a time, and every individual number were randomized between one and nine. Thus, a new three digit number was randomly generated every time lag. T1 was presented for one lag, and was a simple math task (always addition) in red. The addition task consisted of individually randomized numbers between one and four, rendering the correct result within the range of two to eight. T1 was constructed in order to achieve a strong enough attentional blink effect to allow for a prolonged exposure, and thus more stimuli strength, of T2. T2 was a letter (A, S, D, or F.) that was flanked by two randomized numerical distracters and was presented for one lag. After T2 more lags followed (distracters post T1-T2), this time, randomized between three sets of time: as close to (dividable by the current time lag) 150ms, 3000ms, and 7000ms. A blank screen ends the RSVP and was used as a ‘time-filler’ solely to make sure that the length between T2 presentation and T2 response always was exactly 150ms, 3000ms, and 7000ms. These three time ranges were used to see how long the unconscious behavioral effect could remain in memory. Next, three response frames followed, they were all shown until the subject responded. The first asked what letter T2 was, the second asked how well T2 was perceived (PAS), and the third asked what the correct answer to T1 was. 20 trials were designed to have a longer T1-T2 separation (Lag10), and therefore had slightly different trial procedures. Lag10 trials always had a constant T1-T2 separation of 10 lags (1330ms), and another 10 lags between T2 presentation and T2 response. The Lag10 trials were added to control for the AB effect, and kept the subjects from knowing when T2 would appear if they missed its presentation.

Specific attention was put on several vital aspects of the study. (i) The importance of focusing on T1 because trials with incorrect T1 responses did not count even if T2 was correct. (ii) That the mental calculation of T1 had to be done when the task was presented. The real reason behind (i) and (ii) was to make sure that a proper AB effect was induced. (iii) When T2 was not perceived the subject should guess the first letter that came to mind, and not make decisions based on probability or any other strategy. Such strategies would not single out the use of any latent subliminal memory trace. (iv) Specific instructions on how to interpret the PAS were given to make the already subjective measure scale less ambiguous, and thus leave less room for individual interpretations. Firstly, it was important to clarify that the response "1.No experience" on the scale was only to be used if there was no perception at all of any specific letter (T2) that influenced the decision. If any feature that influenced the decision was perceived the subject should respond with "2.Vague experience". If the subject thought they perceived a specific letter, but not entirely clear they should respond with "3.Almost clear experience", and "4.Clear experience" if a letter was clearly perceived. It was made clear that the perceptual awareness evaluated referred to the semantic content of the letter, and not a general perceptual awareness. E.g. an undistinguishable black 'something' would still constitute a "1. No experience". This strict definition was used to counter Dienes & Seth's (2010) critique, and is also the reason why the cut-off is PAS=1, compared to Merikle & Smith (2005) whom had a softer cut-off (comparable to PAS≤2).

Results

From the 21 subjects that participated two were excluded from all statistical analyses for not following the instructions when using PAS and/or guessing T2 when it was not perceived. The amount of trials where T2 was reported perceived versus not perceived varied between individuals, and some subjects did not have a balanced amount of the two. It was determined that any subject with less than 10 trials within one of the lengths with either PAS=1 or PAS>1 were to be excluded from any specific data analysis using that data. The number of subjects will therefore vary depending on what data the statistical analysis is using.

The first sub goal was to show that a proper AB effect was obtained, and therefore the relationships between mean accuracy and T1-T2 separation were plotted (see figure 5.) for both T1, and T2 given that T1 was correct (T2│T1). First a two-by-two repeated measure ANOVA was done on 13 subjects with accuracy and T1-T2 separation as factors. It showed a significant difference between T1 and T2│T1 over T1-T2 separation $F(1, 12) = 58.088$, $p < .001$. To further elucidate their exact relationship several paired sample T-tests were implemented. The results were consistent with the AB effect, which is a failure to consciously perceive T2 at Lag2. There was a significant difference $t(12) = 8.647$, $p < .001$ between Lag2(T2│T1) and Lag10(T2│T1), and Lag2(T1) and Lag2(T2) $t(12) = 6.676$, $p < .001$, while there was no significant difference $t(12) = 0{,}709$, $p > .05$ between Lag2(T1) and Lag10(T1). For further support the subjective PAS measure was also plotted (see figure 6.) and shown to be significant t (12) = 10.710, p< .001.

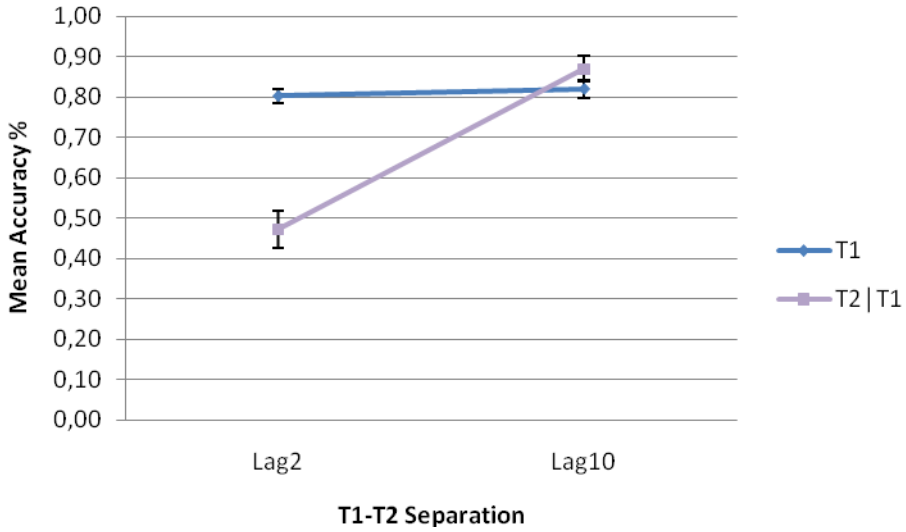

Figure 5. T1 and T2│T1 as a function of accuracy and T1-T2 separation (SEM error bars)

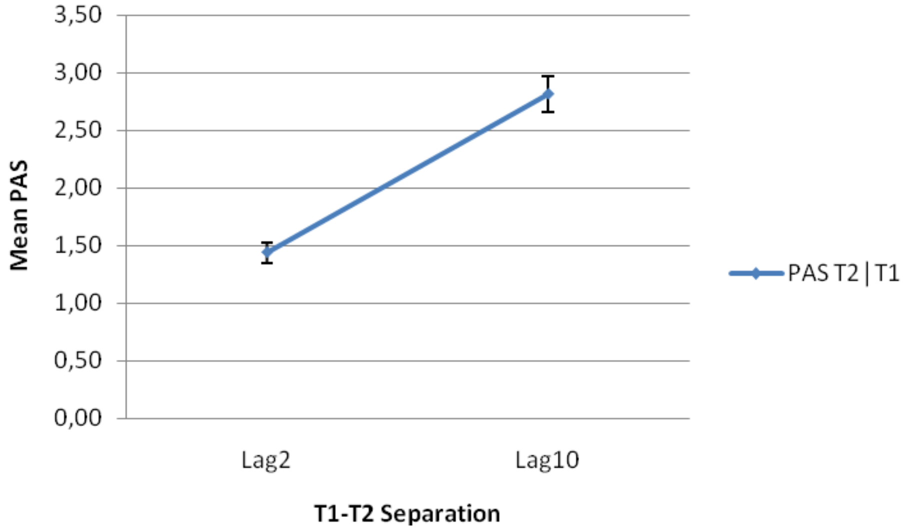

Figure 6. PAS T2│T1 as a function of PAS and T1-T2 separation (SEM error bars)

The second sub goal was to attain a subliminal behavioral effect, and to discern any such effects a chi square test was made on each time length comparing the observed T2 accuracy given that PAS=1, to that of chance (25%). The time length of 150ms showed x^2 (1) = 24.536, p< .001 mean behavioral effect of 36.2% (SEM: 3.6%), the time length of 3000ms had an x^2 (1) = 39.447, p< .001 mean behavioral effect of

37.9% (SEM: 4.0%), and the time length of 7000ms an x^2 (1) = 32.853, $p < .001$ mean behavioral effect of 37.4% (SEM: 4.0%). Thus, all three lengths showed robust significance.

The main goal was to explore the subliminal memory traces. For the first analysis eight subjects were included because of the cut-off at 10 trials. First two repeated measure ANOVAs with two factors, perceptual awareness (PAS=1, PAS>1) and time (150ms, 3000ms, 7000ms), was implemented on T2 accuracy (see figure 7.) and T2 RT (see figure 8.) separately. The difference between perceptual awareness and no perceptual awareness was significant on both T2 accuracy $F(1, 7) = 43.799$, $p < .001$ and RT $F(1, 7) = 32.139$, $p < .001$. However, when examining T2 accuracy over time there was no significant difference $F(1, 7) = 4.161$, $p > .05$, while T2 RT over time was significant $F(1, 7) = 13.233$, $p = .001$. To increase the sample size to 13 subjects, and thus gain a more accurate estimate of T2 accuracy (see figure 9.) and T2 RT (see figure 10.) over time another analysis was done on PAS=1 only. Showing a similar result, T2 accuracy was not significant over time $F(2, 24) = .161$, $p > .05$, while T2 RT was significant over time $F(2, 24) = 7.872$, $p = .002$).

However, since the significant RT result was inconsistent with the accuracy result relative to expectations a hypothesis as to why was formed. It seemed as if the T2 RT for 150ms was higher than the other lengths when it was expected to be shorter. The accuracy for 150ms was lower (though not significantly) than the other lengths when it was expected to be higher. Those two inconsistencies coupled with verbal reports from subjects that indicated surprise and temporary tumult at the abruptness of the 150ms trials relative to the other lengths. That led to the hypothesis that a methodological flaw was responsible for the significant RT result, and the inconsistencies surrounding the 150ms trials. To test the hypothesis a new two-by-two repeated measure ANOVA was done, but this time excluding all 150ms trials (thus 14 subjects was valid for analysis). Again, T2 accuracy was not significant $F(1, 13) = .334$, $p > .05$, and this time neither was the RT $F(1, 13) = 1.064$, $p > .05$.

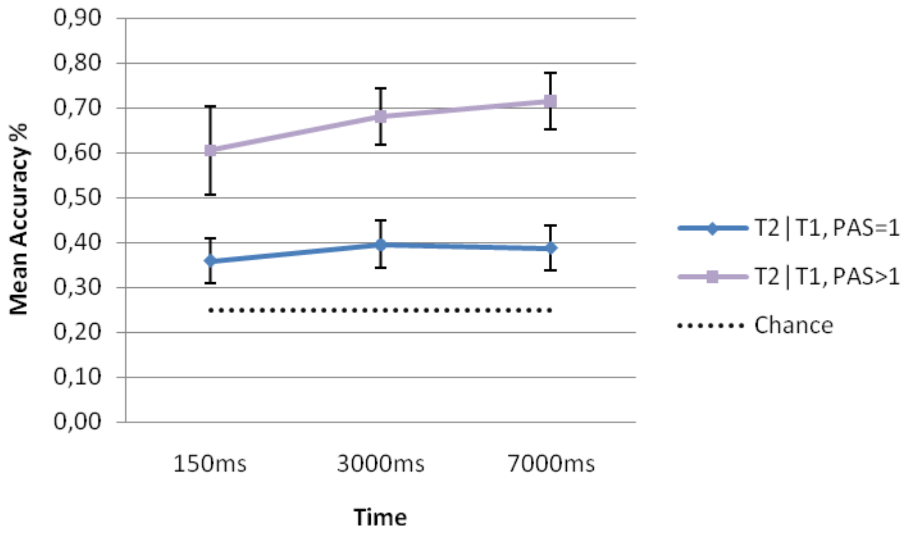

Figure 7. Behavioral effects in accuracy over time for PAS=1 and PAS>1 (SEM error bars)

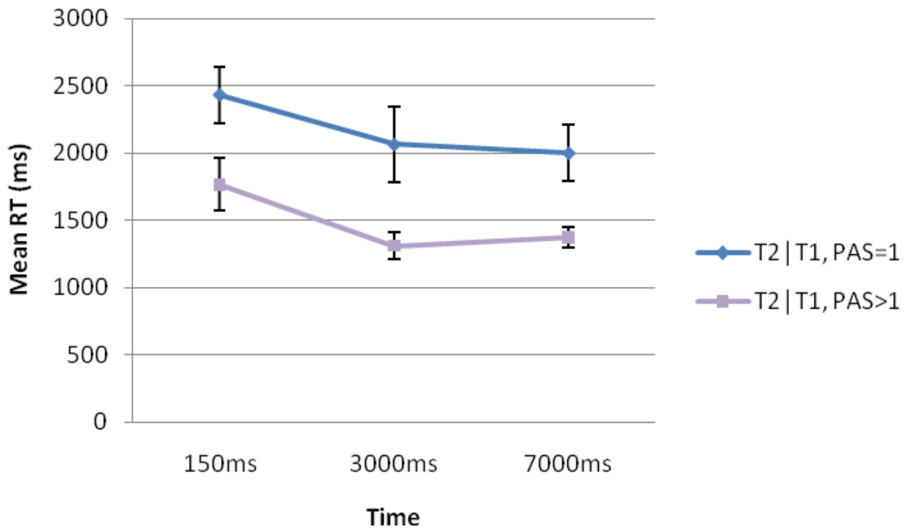

Figure 8. Behavioral effects in RT over time for PAS=1 and PAS>1 (SEM error bars)

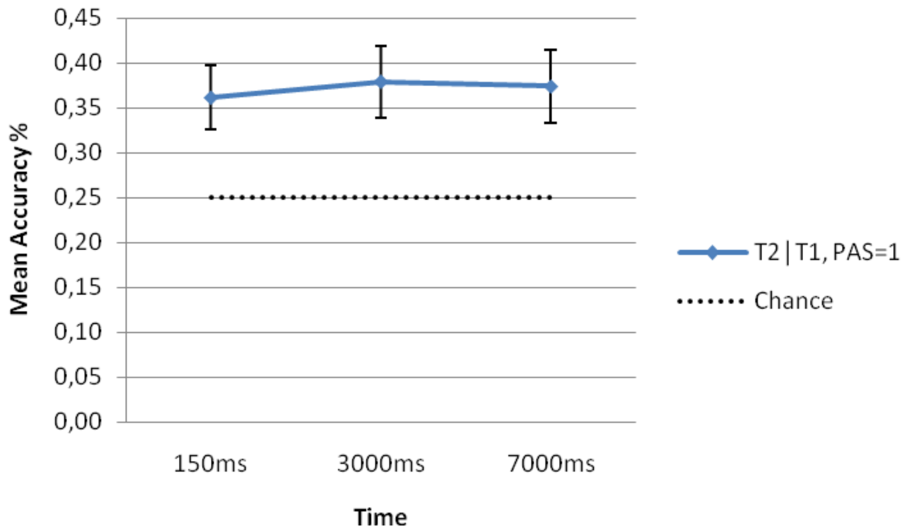

Figure 9. Behavioral effects in accuracy over time for PAS=1 only (SEM error bars)

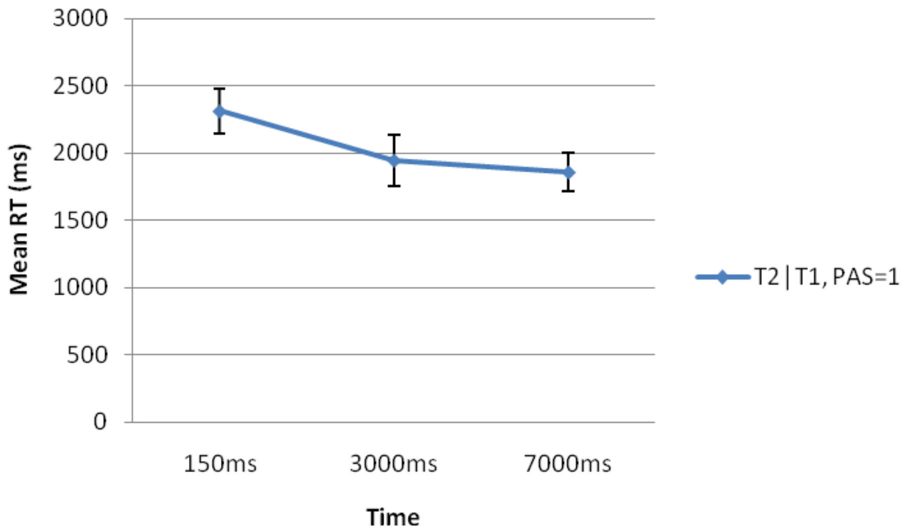

Figure 10. Behavioral effects in RT over time for PAS=1 only (SEM error bars)

Discussion

The first sub goal of showing a proper AB effect was confirmed. The significant difference between T2│T1 lags show that the effect is not due to a general lack of attention by the subjects, nor a backward masking effect. Because if either of those had been the case, it would likely not have been a significant difference between lag2 and lag10. The T1 accuracy shows that the subjects had an equally high performance on both lags. That is noteworthy because performing the T1 task is a prerequisite for achieving an AB effect. The subjective measure PAS T2│T1 demonstrates that the perceptual experience of T2 was significantly lower at Lag2 then Lag10, which supports the objective behavioral data. Taken together, it is reasonable to conclude that a proper AB effect was accomplished during this study. The result increases the validity of the main findings as it shows that the diminished T2 accuracy at Lag2 seems to be because of the AB effect which has documented robust subliminal effects. As a side note, AB effects are usually depicted with more than two lags (e.g. Lag1), which shows the lag1-sparring effect. The lag1-sparring effect is an important factor in explaining the cause of AB effects (Martens & Wyble, 2010), but is not relevant for this study's purposes. Thus, any excessive lags were omitted to make the experiment less time consuming and instead enable more trials per subject.

The second sub goal of showing a subliminal behavioral effect was also confirmed. All of the three memory storage lengths had significantly higher T2│T1 accuracy when no perceptual experience was reported than what chance would have predicted. This result is aligned with other AB studies showing subliminal priming effects (Sergent, Baillet, & Dehaene, 2005; Pesciarelli et al., 2007; Harris & Little, 2010; Kouider & Dehaene, 2007).

The main goal was to explore how subliminal memory traces diminished over time by looking at subliminal behavioral effects. The results deviated from the expected outcome. The behavioral effects were expected to decline over time, from which the intention was to extrapolate the curve for a hypothetical end to the memory trace. Instead, the ANOVA demonstrated that the behavioral effects were not significantly different over time. There was thus no curve to extrapolate from. The results could however be used to extrapolate a straight line continuing over time indefinite. Thence, the only conclusion to be drawn is that subliminally encoded memory traces seem to last at least 7000ms. This result is by itself intriguing because 7000ms is much more than the 500ms generally accepted (Dehaene & Changeux, 2011).

It should be noted that the initial ANOVA demonstrated that T2 RT was, while T2 accuracy was not, significantly different over time. The inconsistency was surprising as the expectation was to find that both T2 accuracy and T2 RT would be consistent. Based on the following observations a hypothesis was formed. First, when reviewing the T2 RT over time it was clear that the 150ms trials were longer than the other lengths, which is odd since it was expected to be shortest. Second, a similar pattern was found in the T2 accuracy over time, where the accuracy was lower for the 150ms trials (though not significantly) than the other lengths when it was expected to be the highest. Third, verbal feedback reports from subjects indicated surprise and temporary tumult and the abruptness of the 150ms trials. Taken together, these observations led to the hypothesis that the abrupt ending of 150ms, compared to the much longer and more numerous trials with longer lengths, caused the result to deviate from expectations. To test the new hypothesis another ANOVA was done, but this time all 150ms trials were excluded. The results demonstrated that neither T2 accuracy nor T2 RT was significantly different over time. The deviating results were therefore attributed to the experimental design, and not a psychological process. These findings uniformly support the previous interpretation that memory traces seem to be able to last for at least 7000ms as both measures are consistent.

It is also worth mentioning that the use of subjective measures of consciousness can cause overestimations that are difficult to detect. However, precautions in the form of methods and instructions were taken to prevent/limit overestimation or other biases. There are other factors that commonly effect priming results (see subsection Depth of Unconscious Processing). The factors that could have affected this study are category size, target repetitions, and number of trials. If the category size (in this case T2) is small it can add to priming effects, if there are many target repetitions it can also facilitate priming effects, and if the number of trials are many it can have an negative impact on priming effects (fatigue, loss of attention), but it can also reduce noise and thus produce more stable priming effects (Van den Bussche, Van den Noortgate, & Reynvoet, 2009). Before commenting on them it should be made clear that these factors are especially important when trying to find a 'pure' semantic effect. Something this study is not concerned with, as its primary concern is subliminally encoded memory traces, whatever the kind, which affects behavior. Additionally, these factors might be causing relatively more biases when objective measures are used since the subliminal effect is much weaker than with less conservative measures. That being said, the category size and target repetitions probably facilitated the behavior effects. However, the behavioral effects were strong, and the facilitation effects did probably not affect the outcome to any larger extent. As for the number of trials, some subjects reported slight fatigue at the end of the experiment, while others were reportedly entertained throughout. The number of trials chosen was needed to accumulate usable and trustworthy data. It is difficult to know in which way direction the number of trials affected the behavioral effects. All in all, there probably was a facilitation effect, but it is not likely that it would have changed the outcome to any significant extent. Especially considering the fact that this study was not concerned with a purely semantic effect. Even though the experimental paradigms validity is increased by the sub goals it is unfortunate that many subjects had to be excluded from the statistical analysis. More studies are needed to confirm the subliminal memory findings, but it is nevertheless reasonable to interpret the results as an indication of the strength of subliminally encoded memory traces.

Theoretical Implications

The results of this study have some theoretical implications on the capabilities of unconscious compared to conscious processing. In Tsuchiya & Koch (2009) working memory is categorized as requiring top-down attention and necessarily giving rise to consciousness (see table 1.). It is not something that is discussed in detail, but it is worth commenting on anyway. The storage length of 7000ms is more than what is commonly attributed to iconic memory (<1000ms), and thus the information must have been stored in working memory. Since it was encoded and stored in working memory without conscious awareness it seems reasonable to assume that working memory does not necessarily give rise to consciousness. Furthermore, the AB method hinges on suppression of attention, and yet information was stored in working memory. Additionally, Baars & Franklin's (2003) claim that consciousness is necessary for WM is not supported by the subliminal memory findings. That is, since subliminally encoded and stored information in WM should not be possible, but that clearly is what these findings imply. However, when reviewing their model of WM and consciousness (see figure 3.) it becomes clear that their strong position is based on their definition of consciousness. As they define unconscious (without accurate reportability and qualitative content) it is reasonable to assume that there probably is no information stored. Although, by their definition how would one find out? I would also include their fringe consciousness (accurate reportability without qualitative content) as unconscious. Because that is exactly what the subliminal memory findings in this study are. When understanding their model as fringe conscious being equal to unconscious one can see that almost all, and most relevantly, both the visuospatial sketchpad and visual semantics are accessible during fringe consciousness/unconsciousness. Thus, it is clear that the views on unconscious access to WM are the same, whereas the definition of what constitutes a conscious and unconscious are not. On Baddeley & Andrade (2000) whom claimed that WM is necessary for consciousness there is little to add. That relationship could still very well allow for WM encoding and storage with and without consciousness.

As previously mentioned (see subsection Depth of Unconscious Processing) there are conflicting theoretical positions on consciousness and mental representations. For this commentary mental representations are reductively defined as information-carrying neuronal structures in the brain. As such, it is hard to see how there can be a mental representation R of anything without R being in some kind of memory. It could be argued that an R can have an immediate effect, by-passing memory formation, and then disappear. However, this is a controversial issue by itself, fortunately, an issue this study need not worry about since it involves longer memory traces. The results indicate that subliminally encoded memory traces can last for at least 7000ms, which implies the existence of unconscious mental representations. The information about T2 is a mental representation, which is subliminally encoded, stored, and later retrieved from memory. Therefore, it can be concluded that unconscious processing of mental representations do exist, and that the result of this study disproves theoretical positions claiming that all unconscious processes are non-representational. Dehaene (2007) places himself in between the two extreme positions on consciousness and mental representations. He argues that unconsciousness is associated with lower level processes, while consciousness is associated with higher level processes. One process that his global neuronal workspace theory (Kouider & Dehaene, 2007; Dehaene & Naccache, 2001) predict to be exclusively associated with consciousness is *"…the ability to maintain representations in an active state for a durable period of time in absence of stimulation…"* (Dehaene & Naccache, 2001, p. 9). Here an active state means that the information has been encoded in active neurons and is available to influence connected systems, and a durable period of time is taken to mean no more than 500ms (Dehaene & Changeoux, 2011). The empirical finding of this study clearly contradicts Dehaene's prediction. Mental representations were found to affect behavior 7000ms after stimulation, which implies that the mental representations were maintained in an active state for more than 500ms. Thus, it seems to be the case that consciousness cannot be necessary for durable information maintenance, and that the unconscious mind is capable of more complex levels of processing than traditionally assumed. That subliminal memory traces were strong at longer memory storage lengths is a slight support for previous controversial studies (Merikle & Smith, 2005; Yang, Xu, Du, Shi, & Fang, 2011).

Other recent findings also question the traditional view that the unconscious mind is limited to simple processing tasks. Such findings include unconscious understanding of semantic relations between parts of a visual scene (Mudrik, Breska, Lamy, & Deouell, 2011), unconscious flexibility (Stapel & Koomen, 2006), unconscious cognitive control (Lau & Passingham, 2007), and unconscious goal pursuit (Hassin, Bargh, & Zimerman, 2009). Therefore one can see the indication of unconscious durable information maintenance as a part of several recent indications that the traditional view of unconscious process capabilities might need to be revised. The true limit of unconsciousness in general seems to still be open for empirical investigations, and so is the limit for subliminally encoded memory traces. Although this study has merely begun to track the subliminal memory traces there is still reason for cautious optimism of future findings.

Experimental Improvements

The third sub goal was to evaluate the paradigm to find further improvements before implementing it in an fMRI experiment. Firstly, it is clear that the strength of the subliminally encoded memory traces were grossly underestimated in this study. For further studies the memory storage lengths needs to be increased. So that there, at least, will be a significant decline over time. Depending on how long the lengths will have to be the experimental paradigm might have to be revised to find an acceptable balance between trial lengths and number of trials. If it is a matter of seconds most of the current paradigm could be kept. However, if it would be a matter of minutes it could be necessary to make much more radical changes to the paradigm. Secondly, too many subjects had a poor balance between trials that were reported PAS=1 and PAS>1, which caused too many subjects to be excluded from the analysis. The most efficient solution for that problem would be to revise the initial calibration phase of

20 trials. One could for instance, instead of basing it on T1 performance, base it on a slightly more complex formula that more accurately depicts the wanted balance in conscious perception, and maybe increase the size of trials for more robust calibration. Possibly calculating the balance between amount of trials that are PAS=1 T2│T1, versus PAS>1 T2│T1, and have the adjustment be sensitive to skewed balance. Thirdly, it was verbally reported by many subjects that the letter D was easier to perceive. A possible solution could be to e.g. include zeros as distracters to not have the D's perceptually 'stick out' too much with its features. Fourthly, considering the robust behavioral measures it could be interesting to focus more strictly on subliminally encoded semantic memory traces in a future study. A simple modification to the category size (increasing number of letters), would take care of that effect, and at the same time minimizing the target repetitions if number of trials are kept constant. Fifthly, it could be plausible to incorporate a variant of a process-dissociation procedure into the experimental paradigm, which arguably could be more convincing when judging potential overestimations of subliminal behavioral effects. The downside would be that all trials would need to be divided into two blocks, which would demand a stable balance between perceptually aware trials and unaware trials.

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Corrigendum

After the final review of the thesis a programming error was detected during a post analysis, which in practice meant that the letter F never was presented as T2. However, a review of the subject's responses showed that the F was not underrepresented, and thus the statistical validity remains unaffected.