An Examination of Unconscious Working Memory Flexibility using Continuous Flash Suppression

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Space For abstract (FONT 10)

Introduction

Until recently, unconscious information processing has been theoretically throttled to a 'low level' automatic cognitive process (Dehaene & Changeux, 2011; Wokke, van Gaal, Scholte, Ridderinkhof & Lamme, 2011). Within the last decade the zeitgeist has shifted as new research expands upon the boundaries of unconscious cognition (Dehaene & Naccache, 2000). Since we only consciously experience a fraction of the available perceptual information, our natural inclination is to deny its existence. The mounting body of research implicating higher cognitive processes beyond the conscious realm has made the fields inattention futile (Squire & Dede, 2015). This new research interest is promising, as the conscious experience has major clinical implications.

Before examining this recent research it is critical to explicitly state what is meant by 'consciousness'. The term is plagued by vagueness, it is important to separate its transitive and intransitive use (Hohwy, 2009). When used intransitively, it refers to a state of consciousness, in other words 'wakefulness' (Dehaene & Changeux, 2011). On the other hand, the transitive use, and the main focus of the scientific study of consciousness, refers to access or specific processing of information. It is vital for researchers to not conflate selective attention with conscious access (Dehaene & Naccache, 2000; Koch & Tsuchiya, 2007). Selective attention refers to the filtering, isolation and amplification of a particular sensory experience. In contrast, conscious access is when a particular sensory experience 'takes possession of the mind'. These two concepts are frequently, and incorrectly, combined due to their coincidental nature. Dehaene and Changeux (2011) emphasize that selection can occur without conscious processing and in simple paradigms conscious access may occur independently from selection. In the majority of instances, selective attention can be seen as a gatekeeper that decides what amount and type of information reaches conscious processing. Even though these two concepts are highly intertwined the
fundamental dissociability forms the theoretical necessity to separate them (Hohwy, 2012).

Dehaene and Changeux (2011) explain an armada of paradigms to contrast conscious and unconscious stimuli in an attempt to isolate the physiological properties of conscious access. These paradigms utilize either subliminal or preconscious stimuli. Subliminal presentations use a stimulus that is undetectable even with focused attention. In contrast, preconscious stimuli are potentially visible, yet due to temporary inattention or distraction there is a lack of conscious experience. Techniques for preconscious presentation include inattentional blindness, attentional blink (AB) and psychological refractory period (PRP). The most common subliminal presentation paradigms are masking, binocular rivalry and continuous flash suppression (CFS). CFS utilizes masking and intraocular suppression to render stimuli completely invisible (Pan, Lin, Zhao & Soto, 2014; Tsuchiya & Koch, 2005; Wilke, Logothetis & Leopold, 2003). Strong dynamic noise, usually moving colorful Mondrian-like images, is presented to the dominant visual field. This allows stimuli presented to the other eye to be suppressed from conscious awareness for relatively long periods of time.

Kouider and Dehaene (2007) review various studies examining depth of processing, particularly in low-level versus high-level semantic processing. Nonconscious low-level processing is largely acknowledged, yet the controversy surrounds high-level processing and to what extent it proliferates. Currently, the debate centers on whether subliminal priming reflects action-triggers or authentic semantic activation from primes. There is not decisive evidence leading in direct favor to either of these hypotheses. Multiple researchers have used subliminal and preconscious techniques to examine the domains of unconscious duration and flexibility. Subliminal priming has been shown to decrease rapidly with time, ceasing detectability after 500ms (Dehaene & Changeux, 2011; Soto & Silvanto, 2014; van Gaal, Lamme & Ridderinkhof, 2010). Dupoux, Gardelle and Kouider (2008) used a masked speech priming paradigm in which the prime to target inter stimulus interval was manipulated. The results showed priming longevity to exceed 456ms, yet the longer inter stimulus interval (608ms) did not breach significance. Greenwald, Draine and Abrams (1996) state semantic priming longevity is even shorter, specifically the inter stimulus interval cannot exceed 100ms. Durability of unconscious perceptual information has been shown to last from 4-15 seconds (Bergström & Eriksson, 2014; Hesselmann, Hebart & Malach, 2011; Soto, Mäntylä & Silvanto, 2011).

A recent shift has placed emphasis on the role of working memory without awareness, also known as unconscious working memory (Bergström & Eriksson, 2014; Dutta, Shah, Silvanto & Soto, 2014; Pan, Lin, Zhao & Soto, 2014; Soto, Mäntylä & Silvanto, 2011; Soto & Silvanto, 2014). Classic working memory theories have presumed conscious awareness as an essential aspect (Squire & Dede, 2015). Soto, Mäntylä and Silvanto (2011) presented findings challenging the assumption that working memory operates on conscious representations. This was accomplished
using a subliminal masking paradigm in which subjects were presented with a masked orientation of a Gabor cube followed by delay and a test of orientation. Instructions encouraged the participants to hold the cue in memory even without awareness. Following the forced choice cue discrimination task, a perceptual awareness scale was used as a subjective measurement of conscious awareness. The first experiment showed statistically significant discrimination performance on non-conscious trials. The second experiment added a congruent or incongruent Gabor cube as a distractor. The results did not differ from the first experiment, suggesting that unconscious stimuli can be maintained online even in the presence of a similar distractor. Subsequently, masked distractors were added and this did not alter the significant findings. The last experimental paradigm included the addition of another Gabor cube, thus participants were expected to unconsciously maintain two Gabor cube orientations. As with the previous experiments the results remained above chance, indicating unconscious working memory has the capacity to hold more then one item at a time. Collectively, these experiments revealed non-conscious visual working memory to possess the ability of maintenance, encoding and goal orientated discrimination.

Pan, Lin, Zhao and Soto (2014) utilized continuous flash suppression to show working memory perceptual selection mechanisms correctly discriminating without visual conscious awareness. Continuous flash suppression (CFS), as aforementioned, is a paradigm in which stimulus presented to one eye can be rendered fully invisible by presenting strong dynamic noise to the other eye (Wilke, Logothetis & Leopold, 2003). Importantly, the results indicated top down processing of visual stimuli without awareness of the guiding cues or perceptual imputs. Finally, adding further support to the previous research Bergström and Eriksson (2014) used the attentional blink phenomenon to render stimuli unconscious. The results indicated non-consciously presented perceptual information can last in full strength for at least 15 seconds and be utilized in a working memory task. Due to the length, type of task and use of distractors working memory is the only viable candidate facilitating correct task responses. In unison, these studies challenge the previously held expectation of conscious awareness mediating working memory.

Previous research has demonstrated the flexibility of unconscious cognition in various types of cognition, such as allowing subliminal extraction of semantics in diverse categories, subliminal stimuli biasing motor responses and enhancing motivation (Dehaene & Changeux, 2011). Van Gaal, Ridderinkhof, Fahrenfort, Scholte and Lamme (2008) published results indicating inhibitory control could be initiated via non-conscious ‘stop’ signals, which in turn interrupted or lengthened motor response times. A later study, by the same research group, explicitly attempted to test whether unconscious stimuli can activate cognitive control processes in a directed and flexible fashion, as commonly seen consciously (Wokke, van Gaal, Scholte, Ridderinkhof & Lamme, 2011). Participants underwent a masking paradigm in which the unconscious prime was associated with a ‘GO’ or ‘No-Go’ response. The task acted by forcing stimulus-response associations to update in a
dynamic and flexible basis on every trail. Results showed participants significantly inhibited their responses more often when a non-conscious ‘No-Go’ stimulus was present rather then a ‘GO’ prime, preceding a No-Go target. This result was absent in the Go target trails, yet ‘No-Go’ primes significantly slowed down the reaction time, in comparison to ‘Go’ primes. The authors provide these results, along with neurological correlates, as evidence for unconscious response inhibition therefore demonstrating unconscious cognition as sharing some of the flexible attributes of its conscious counterpart.

The purpose of the current study is to examine the flexibility of unconscious working memory, specifically in object and spatial discrimination. This was accomplished using continuous flash suppression within a simple working memory paradigm. Conscious awareness was determined via a modified perceptual awareness scale. Previous research has found subjective and objective measures to be in close agreement, therefore an objective measure will not be used (Dehaene & Changeux, 2011). The first aim of the study is to confirm the previous findings on working memory without conscious awareness. The second, and distinguishing novel, aim is examining working memory flexibility to alternating spatial and object discriminating instructions. This was an attempt to gauge the ‘completeness’ of non-conscious perceptual selection mechanisms within working memory. In essence there are two novel concepts to examine. Is unconscious working memory able to actively adapt to instructions? Also, is it able to differentiate objects and/or locations?

**Methods**

**Participants**

Multidisciplinary college students of all ages (m = 23.5) were used to conduct this study. The sample initially consisted of 13 males (62%) and 8 females (38%). Within this sample two participants were excluded for not following instructions and another due to inadequacies in suppression. These exclusions made the sample fall to a total of 18; 11 males (61%) and 7 females (39%). Participants were selected through convenience and online recruitment. Compensation for participation was 100sek (10.8e) per hour; the typical total amount was 300sek for three hours of experimentation. There were no ethical concerns. Informed consent was signed prior to experimentation. Exclusionary factors included epilepsy, left eye dominance and non-corrected impaired sight.

**Stimuli & Procedure**

A true experimental design was used. The division of groups was based on order of recruitment, therefore acting as random allocation. The two groups differed merely for the purposes of counterbalancing. Due to this counterbalancing act the groups have a fundamentally identical procedure yet the order of blocks is altered. The experiment consisted of four interleaving blocks, two spatial and two object blocks,
each lasting around thirty minutes. Time length of blocks slightly differed on an individual basis depending on swiftness of responses. Every participant was tested in the same room within the Integrative Medical Biology Department of Umeå University.

Upon arrival subjects were immediately tested for right eye dominance. Following successful completion of this task they were instructed to fill out and read the necessary forms. After signed consent the instructions were verbally explained and participants were encouraged to ask questions. Critically it was emphasized to discriminate for either types of objects (total = 6) or spatial locations (total = 4) during the forced choice masking task. This included emphasis of ‘going with your gut’ for unconscious responses and the 50% chance likelihood of match or no match.

Preceding the practice trial subjects were instructed to alternate closing each eye in an attempt to check that the visual fields had equivalence. The practice trial followed an identical experimental design yet with an added response screen. Duration was optimally shortened to blank trials, which lasted little over ten minutes. The experimenter checked responses, via the response screen, during the practice trail to ensure the participants fully understood the procedure. After the trail questions were again encouraged, along with directed questions regarding efficacy of suppression.

The design of each block consisted of blank control trials, blank unconscious trials and blank conscious trials (total = blank). Randomly generated flashing (at a frequency of 10Hz) Mondrian-like images were utilized for unconscious and control trials. The unconscious trials utilized the principles of CFS, while the control trials simply consisted of flashing mondrians (Tsuchiya & Koch, 2005). A specifically designed CFS devise consisting of a mirror stereoscope pointing at a computer screen was used for flash suppression. To promote stable binocular alignment each stimulus was surrounded by a checkered frame with a centered black fixation cross. The computer (windows blank) was running eprime (version blank) to display stimuli. In the unconscious trials contrast of the presented object was increased incrementally.

Following stimuli presentation a masked delay was used to suppress after image effects. The mask included an overlay of each stimuli combined in all of the four spatial locations. After which a forced choice match (1) no-match (2) condition was presented. Finally the PAS scale was utilized to measure subjective visual experience. The PAS scale was modified from four steps of visual experience into three steps to alleviate confusion (Bergström & Eriksson, 2014). They were as follows; no experience (1), vague experience (2) and clear experience (3). The eprime script logged responses as well as reaction times. Measuring reaction times allowed for additional analysis into the effects of unconscious stimuli presentation.
Only after the participant, along with the experimenter, were both fully satisfied with procedural knowledge and understanding of the later, could the subject begin the experimental protocol. Verbal instructions were repeated to take breaks, not blink during presentation along with the 50% chance likelihood between match and no match. Following these instructions the subject could begin the experiment.

**POSSIBLE TIMELINE FIGURE (depending on time constraints)**

*Statistical Analysis*

Reaction time outliers were dealt with on a trial-by-trial basis, 250ms was the lower bound cutoff while three standard deviations from the mean indicated the upper bound. Only trails within that range were considered for analysis, upper bounds were determined on a condition specific basis. All statistics was computed using SPSS version 22. Only non-conscious trials with a PAS=1 and conscious trials PAS=3 were included. D’ (Dprime) was computed as a performance measure, this data was used for a one sample T-test. Reaction times of hits in comparison to control trials were analyzed using a paired T-test. These inferential tests were repeated, in a separate manner, on data files filtering for both spatial and object information match and trails from the last half of each block. Before running inferential statistics descriptive and normality tests were run on the corresponding variables. In the case of variables with non-normal distributions the nonparametric equivalent will be used.

**Results:**

*One sample T-test of D’*

The first step of the statistical analysis was to determine which scale variables contained parametric qualities. Normality tests revealed all variables to be non-normal; DMSd_obj_Pas1, DMSd_obj_Pas3, DMSd_spa_Pas1, DMSd_spa_Pas3. Yet further inspection on boxplots revealed an extreme outlier on the unconscious variables (Pas1). Following exclusion of Subject 5, normality tests indicted variables DMSd_spa_Pas1 and DMSd_obj_Pas1 to contain parametric qualities. The D’ mean for unconscious spatial and object information was slightly higher then the comparison point for D’ (0), 0.06 (SD=0.22) and 0.03 (SD=0.12) respectively. The 95% confidence limits show that the populations mean difference for spatial encoding lies from -0.06 to 0.17, while the 95% confidence limits for object encoding lies from -0.03 to 0.09. A one sample T-test found there to be no significance in the D’ for unconscious spatial information (t(16) = 1.04, p = .3). Another one sample T-test also found a lack of significance for object information (t(16) = 1, p = .33). As expected significant results for D’ were obtained on conscious trails utilizing a Wilcoxon signed-rank test, for both spatial and object significance was bellow .000.

*Paired T-test of unconscious reaction times Hits in comparison to control trials*

Boxplots revealed subject 11 to be an extreme outlier for both unconscious spatial and object reaction times. Furthermore subject 1 had the same qualities in the
unconscious spatial variable therefore each subject was excluded only for the unconscious variables in which they possessed extreme qualities. Following these exclusions normality tests revealed all necessary variables to have parametric qualities (DMSRT_Hit_spa_Pas1, DMSRT_Hit_obj_Pas1 & DMSRT_baseline_Pas1). The mean score for unconscious spatial reaction times was 1642 ms (SD=568.3), while the baseline reaction times (with Sub 1 & 11 excluded) were slightly higher at 1778.3 ms (SD=609.2). Even though these mean scores differed slightly, a paired sample T-test showed that there was no significant difference between reaction times of unconscious spatial and baseline trials ($t$(15) = -1.6, $p = .17$). The mean for unconscious object reaction times was 1854 ms (SD=564.3), which was slightly slower then the baseline reaction times (with Sub 11 excluded) at 1821.9 ms (SD=616.7). Yet again, a paired sample T-test showed no significant difference of reaction times between the variables ($t$(16) = .44, $p = .67$).

Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>df</th>
<th>t</th>
<th>p</th>
<th>LL</th>
<th>UL</th>
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<tbody>
<tr>
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<td>0.12</td>
<td>16</td>
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<tr>
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<td>0.22</td>
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<td>-320.8</td>
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Analysis of both spatial & object match

One sample T-test of $D'$ in unconscious both match condition

As with the previous data set, subject 5 was excluded, for both the spatial and object condition, as an extreme outlier. Following this exclusion, unconscious $D'$ data for both spatial and object instructions possessed parametric qualities. The $D'$ mean for unconscious spatial information was slightly lower then the comparison point for $D'$ at -0.04 (SD=0.29), while the unconscious object information was slightly higher at 0.05 (SD=0.24). Even when only examining $D'$ for the both match condition, spatial and object information showed non-significant results, ($t$(16) = -0.49, $p = .63$) & ($t$(16) = .87, $p = .4$) respectively.

Paired T-test of unconscious reaction times Hits (ONLY in both-match) in comparison to control trials

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Boxplots revealed subject 11 to be an extreme outlier in both unconscious reaction time conditions, therefore this subject’s data was excluded. Normality tests revealed all variables (BRT_Hit_obj_Pas1, BRT_Hit_spa_Pas1 & DMSbaseline_RT_Pas1) to have parametric qualities. The mean score for unconscious spatial reaction times was 1726.7 ms (SD=591.4), while the baseline reaction times were slightly higher at 1821.9 ms (SD=616.7). In comparison, the mean for unconscious object reaction times was 1833.4 ms (SD=598.7), which was slightly slower then the baseline reaction times at 1821.9 ms (SD=616.7). Neither spatial nor object reaction times differed significantly in comparison to baseline reaction times, ($t$(16) = -0.12, $p = .25$) and ($t$(16) = 0.14, $p = .89$) respectively.

Table 2
Summary of statistics of D’ and reaction times in both-match data set

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>df</th>
<th>t</th>
<th>p</th>
<th>LL</th>
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<td>-1.2</td>
<td>0.25</td>
<td>-263</td>
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Analysis of last half blocks
One sample T-test of D’ at the end half of each block
Yet again, boxplots revealed subject five to be an extreme outlier for both spatial and object conditions. Normality tests determined unconscious D’ data for both conditions to possess parametric qualities, following the exclusion of subject five. The D’ mean for unconscious spatial information was higher then the comparison point for D’ at 0.05 (SD=0.27), while the unconscious object information was slightly lower at -0.003 (SD=0.17). (REVERSE THEN LAST 2 data sets; sample size issues?!?!?) A one sample T-test showed that neither spatial nor object D’ differed significantly, ($t$(16) = .74, $p = .47$) and ($t$(16) = -.07, $p = .94$) respectively.

Paired T-test of unconscious reaction times Hits (ONLY at the end half of blocks) in comparison to control trials
Boxplots revealed subject 11 to be an extreme outlier for only the object condition, therefore this data was excluded from object reaction time analysis. Following this exclusion all variable had parametric qualities (HalfRT_Hit_spa_Pas1, HalfRT_Hit_obj_Pas1 & HalfRT_baseline_Pas1). The mean score for unconscious spatial reaction times was 1837.8 ms (SD=801.3), while the baseline reaction times were slightly less at 1826.5 ms (SD=635.2). Unconscious object reaction times were 1785.9 ms (SD=531.9), which was also slightly slower then the corresponding baseline reaction times of 1760.4 ms (SD=587.6). Neither spatial nor object reaction...
times differed significantly in comparison to baseline reaction times, \((t(17) = .09, p = .93)\) and \((t(16) = .33, p = .75)\) respectively.

Table 3

*Summary of statistics of \(D'\) and reaction times in end-half of block data set*

<table>
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<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>df</th>
<th>(t)</th>
<th>(p)</th>
<th>95% CI</th>
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</thead>
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<td>0.74</td>
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<td>0.93</td>
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References: