Perceptual size discrimination requires awareness and late visual areas: a continuous flash suppression and interocular transfer study.

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We applied continuous flash suppression (CFS) during an interocular transfer paradigm to evaluate the importance of awareness and the contribution of early versus late visual structures in size recognition. Specifically, we tested if size judgements of a visible target could be influenced by a congruent or incongruent prime presented to the same or different eye. Without CFS, participants categorised a target as "small" or "large" more quickly when it was preceded by a congruent prime – regardless of whether the prime and target were presented to the same or different eye. Interocular transfer enabled us to infer that the observed priming was mediated by late visual areas. In contrast, there was no priming under CFS, which underscores the importance of awareness. We conclude that awareness and late visual structures are important for size perception and that any subconscious processing of the stimulus has minimal effect on size recognition.

Keywords: Size perception, consciousness, perceptual discrimination, continuous flash suppression (CFS), priming, interocular transfer.

1. Introduction

Continuous flash suppression (CFS) is a technique used to examine perceptual processes outside of awareness (Tsuchiya & Koch, 2005). Its principles derive from binocular rivalry and it involves presenting different images to each eye in a dichoptic fashion (Moors, Stein, Wagemans, & van Ee, 2015). To explain, binocular rivalry occurs when each eye is presented with conflicting images. The two images compete for awareness rather than merge to form a composite percept. Typically, the participant's percept alternates between seeing one image and then the other (Blake & Logothetis, 2002). CFS allows the opportunity to suppress one of the images from awareness for a prolonged period of time in a more controlled manner (Tsuchiya & Koch, 2005). This is achieved by presenting a series of colourful Mondrian images in rapid succession to one eye while a stimulus of interest is presented to the other at a reduced saliency. The highly salient Mondrians enter awareness immediately while the stimulus of interest at a reduced saliency does not.

CFS is sometimes applied during a priming paradigm (Yang, Brascamp, Kang, & Blake, 2014). In these paradigms, a visible target is presented after the presentation of either a visible (no CFS) or subliminal (CFS) prime. Normally, under conditions without CFS, responses are faster when the prime is congruent than when it is incongruent to the target (Schmidt, Haberkamp, & Schmidt, 2011). It then follows that if a prime is presented under CFS and it still influences the participant's response to a target, then one can infer that the prime has been processed subconsciously. Numerous studies demonstrate that primes presented under CFS can influence target classifications across a range of stimulus categories (for a review, see Yang, Brascamp, Kang, & Blake, 2014).

Previous functional magnetic resonance imaging (fMRI) studies demonstrate reduced stimulus-specific processing in higher visual areas relative to the primary visual cortex (V1) (Fogelson et al., 2014; Yuval-Greenberg & Heeger, 2013; Bahmani et al., 2014; but see also Watanabe et al., 2011 for opposing demonstrations). Notably, Fogelson et al. (2014) used multivoxel pattern analysis (MVPA) to ensure that the reported fMRI activation reflected the processing of the masked stimulus specifically. The authors of this study demonstrated that fMRI signals from V1 and not from any other visual area could be decoded successfully to differentiate stimuli that were faces versus those that were tools – suggesting that CFS corrupts processing in higher order visual areas to a much higher degree than V1.

This possibility has implications for understanding the mechanisms of size perception. Activation in V1 has been shown with fMRI to reflect the perceived rather than the retinal size of images (Sperandio, Chouinard, & Goodale, 2012; Schwarzkopf, & Rees, 2013; Pooresmaeili, Arrighi, Blagt, & Morrone, 2013; Murray, Boyaci, & Kersten, 2006), which implies that this area has an important role in size perception. In addition, damage to V1 results in cortical blindness, which implies that this area is necessary for the conscious awareness of stimuli (e.g. Sperandio & Chouinard, 2015; Leopold, 2012). However, processing in V1, like all other brain areas, depends on receiving input from other regions, which includes feedback from higher order areas for successful size perception (Sperandio & Chouinard, 2015; Chouinard & Ivanowich, 2014; Chouinard, Whitwell, & Goodale, 2009). The importance of this feedback can vary depending on the stimulus and task demands (Chouinard et al., 2008). If it is the case that CFS preserves stimulus-specific processing in V1 but not in higher order visual areas (Fogelson et al., 2014; Yuval-Greenberg & Heeger, 2013), then the presence of response priming during CFS could provide an indirect demonstration that size processing in V1 does not require top-down modulation while its absence would imply that it does.

Another way to evaluate the contributions of early versus late visual structures is to examine interocular transfer (Fig. 1) (Blake, Overton, & Lema-Stern, 1981). Different stages of the retina-geniculate-striate pathway differ in the proportion of neurons that respond to a stimulus presented to one eye versus both eyes. Monocular signals from the left and right eyes remain segregated in the lateral geniculate nucleus (LGN) and begin to coalesce at the level of V1 – though there are still a number of V1 neurons that respond to stimulation from only one eye (Adams, Sincich, & Horton, 2007). Almost all neurons beyond V1 are binocular (Zeki, 1978). On the basis of this known anatomy, one can draw certain inferences from results obtained in an interocular transfer experiment. If stimulus information is processed more efficiently when it is presented in a monocular (to the same eye) compared to a dichoptic (to different eyes) manner, then one can infer that early structures (such as the retina, LGN, and V1) are largely responsible for this processing. Alternatively, if there is no discernible difference in how a stimulus is processed when it is presented monocularly versus dichoptically, then one can infer that later visual structures are equally responsible for this processing.

To illustrate how this paradigm works further, Song, Schwarzkopf, and Rees (2011) examined how early versus late visual areas modulate size perception in the Ebbinghaus and Ponzo illusions using a mirror stereoscope. The stereoscope allowed the authors to present the illusion background (e.g. the rings of circles in the Ebbinghaus illusion) and target (e.g. the central circle in the Ebbinghaus illusion) either to the same or different eye. Illusion strength was stronger when both the background and target were presented to the same eye in the Ebbinghaus illusion, demonstrating that processing in early visual structures are important for this illusion. Conversely, illusion strength was as powerful in the dichoptic compared to the monocular condition in the Ponzo illusion, demonstrating that this illusion relies more strongly on higher-order areas populated by binocular neurons where information from each eye is combined. From these results, one can infer that the contributions of early versus late visual areas in size perception change depending on context.

In the present investigation, we presented a prime with or without CFS followed by a visible target. The prime was presented either monocularly (same eye condition) or dichoptically (different eye condition) relative to the target (Fig. 1). Participants decided whether the target corresponded to a small or large circle, which either had the same or different size as the preceding prime. The design enabled us to (a) evaluate if size information can be processed subconsciously and (b) assess the contributions of early versus late visual structures. We had two competing hypotheses. If processing information for the purposes of size perception requires awareness of the stimulus as well as late visual structures, then we would predict (a) priming in the no CFS but not in the CFS condition and (b) no differences in priming between the same eye and different eye conditions. Alternatively, if processing of information for the purposes of size perception does not require awareness of the stimulus and is largely mediated by early visual structures, then we would predict (a) priming in both the no CFS and CFS conditions and (b) larger priming effects in the same eye compared to the different eye condition. Our findings are better aligned with the first hypothesis.

2. Methods

2.1 Overview

Participants first completed tests of handedness, visual acuity, eye dominance, and binocular fusion. Following this, each participant completed a threshold task to establish the minimum luminance contrast necessary for the prime to break CFS. After this threshold was established, participants completed the priming task with the stimuli adjusted to a luminance contrast lower than this threshold value. Last, the threshold task was repeated at the end of the session to verify that threshold values did not change in a way that would suggest that the primes could have been visible during the CFS condition in the main priming task. The entire experiment took approximately one hour to complete. The study was approved by the La Trobe University Human Ethics Committee and was carried out in accordance with the Declaration of Helsinki. All participants provided written informed consent.

2.2 Participants

Thirty-five right-handed participants completed the entire study (M_{age} = 25.17 years, age-range = 18-56, 16 males). We verified that all participants had at least 20/40 vision in each eye using the Snellen Eye Chart (Snellen, 1862). Eye dominance was established using the Miles test (Miles, 1930). For this test, the participants touched their thumbs and index fingers together to form a diamond shape viewing aperture and looked at a target on the wall. They then slowly moved their hands closer to their face while keeping the target in view between their fingers. The eye still looking through the aperture was deemed the dominant eye. We also screened for binocular dysfunction using the *framing game* (Laycock et al., 2017; Peel et al., 2018). For this test, participants extended their arm out in front of them and held a finger in front of a target on the wall. First, they were told to focus their eyes on their finger and indicate whether or not the target appeared to frame it (i.e. it became diplopic). They were then instructed to fixate on the target and report whether or not their finger framed the object. Typical binocular fusion abilities were assumed if framing occurred in both cases. Participants also had to be right handed to be included in the study. Handedness was verified using the Edinburgh Handedness Inventory (Oldfield, 1971).

2.3 Stimuli and apparatus

Craik-O'Brian-Cornsweet circles (Purves et al., 1999), similar to those used in one of our previous studies (Laycock et al., 2017), were used in the present investigation. Two circle sizes were presented: small (4°) and large (9°). These stimuli were generated using an in-house program written in MATLAB (Math Works, Natick, Massachusetts, USA). The stimuli were illusory: the centre appeared darker relative to the grey background even though both were physically isoluminant (80.6 c/m2). A standard CFS technique was used to suppress the stimuli from awareness (Tsuchiya & Koch, 2005). We presented the dominant eye with 5 different Mondrians (selected randomly from a sample of eight) at a frequency of 10-Hz (i.e. every 100 ms) while the non-dominant eye was presented with the prime for 200 ms (Figs. 2 and 3). The visual stimuli were presented using E-Prime 2.0 software (Psychology Software Tools, Sharpsburg, PA, United States) on a 17" LCD monitor (1280 x 1024 pixel resolution, 60-Hz frame rate). Participants viewed the stimuli through a stereoscope while their head was placed on a chin rest. The viewing distance was 57 cm.

2.4 Procedures for the threshold task

We presented participants with the small and large circles at different luminance contrasts ranging from 2% (2.8 c/m^2) to 8% (10.4 c/m^2) in 1% increments under CFS (Fig. 2). The order of trials was randomly generated by E-prime. At the end of each trial, participants responded verbally with "Yes" when they had *any* inclination that they were aware of the masked stimulus and "No" when they did not. There were 5 trials for each contrast. From this task, we calculated the minimum luminance contrast necessary for the prime to break CFS for either the small or large circles on any trial. For example, if the large circle broke suppression at 5% (and no other lower value) and the small circle broke suppression at 4% (and no other lower value), then the threshold was deemed 4%. The stimuli were presented at a 1% decrement lower than the threshold value in the priming task that followed. The threshold task also served a second purpose, which was to verify the validity of a participant's reports. Ten catch trials without a stimulus were included in the task. Any participant reporting "Yes" during a catch trial prior to the priming task were excluded from proceeding with the study further. Three participants (other than the 35 in our final sample) were deemed ineligible to continue. None of the remaining participants reported seeing a stimulus in a catch trial when the threshold task was repeated after the priming task.

2.5 Procedures for the priming task

Fig. 3 shows the temporal sequence of events for a trial in both the no CFS (Fig. 3A) and CFS (Fig. 3B) conditions. Each trial began with the participant maintaining central fixation over a blank screen for 2,000 ms. Next, we either continued to present a blank image with fixation (no CFS condition) (Fig. 3A) or 4 Mondrians (chosen randomly from a set of 8) at a frequency of 10 Hz (CFS condition) (Fig. 3B) to the dominant eye for 400 ms. The prime appeared in the non-dominant eye for 200 ms after a delay of 200 ms from the appearance of the first Mondrian. This delay served to draw attention to the Mondrians in the CFS condition. Afterwards, before the presentation of the target, a final Mondrian was presented for 100 ms to both eyes followed by a blank image for 100 ms. The final Mondrian served to eliminate any possible afterimages of the prime and the subsequent blank image served to attenuate any forward masking on the target (Stein & Sterzer, 2011). The target was presented at the same luminance contrast as the prime to either the non-dominant (same eye condition) or dominant (different eye condition) eye. The size of the target either matched (congruent condition) or did not match (incongruent condition) the size of the prime. The presentation of the target was always accompanied by a brief auditory alerting cue. Participants manually categorised the target as either small or large via a serial response box as fast and as accurately as possible. The target remained on the screen for 3 s or until a response was made. E-prime randomly generated the order of the trials – presenting each condition 40 times in an intermixed fashion for a grand total of 640 trials. Seven break periods were evenly dispersed throughout the procedures. Participants got acquainted with the procedures with a brief practice before performing the actual task. The practice consisted of 10 trials classifying small and large visible circles. The practice circles remained on the screen until a response was made.

2.6 Statistical Analyses

We analysed the data using the Statistical Package for Social Sciences (SPSS) version 23 (IBM Corporation; Armonk, New York, USA), JASP software version 0.8 (University of Amsterdam, Amsterdam, The Netherlands), and GraphPad Prism version 6 (GraphPad Software Inc.; La Jolla, California, USA).

Threshold values were analysed using a paired sample *t*-test to determine if they differed after compared to before the priming task. For the priming task, the mean reaction times from only the correct trials were entered into a three-way repeated-measures analysis of variance (ANOVA) with Visibility (no-CFS vs. CFS), Size Congruency (congruent vs. incongruent), and Eye (same eye vs. different eyes) as factors. Participant accuracy was not compared between conditions as these results were at ceiling levels of performance (Table 1). Effect sizes (partial eta-squared; η_p^2) obtained from the ANOVA are reported. Tukey's honest significant difference (HSD) pair-wise comparison tests, which corrected for multiple comparisons, were carried out to examine further interactions and effects deemed significant by the ANOVA. In addition, Cohen's *d* effect sizes for pair-wise comparisons were calculated as the difference between the two means divided by their pooled standard deviation (Cohen, 1988). Unless specified otherwise, all reported *p* values were corrected for multiple comparisons and were based on an alpha level of .05. In addition to null hypothesis statistical testing (NHST), we also performed Bayesian analyses. Bayes Factors (BF_{10}) were calculated to supplement all pairwise comparisons reported in the paper. They indicate the degree of support for the alternative (H_1) relative to the null (H_0) hypothesis. A BF_{10} greater than 3 was considered to provide substantial evidence for the alternative hypothesis, while a value less than .33 was considered to provide substantial evidence for the null hypothesis (Jeffreys, 1961).

3. Results

3.1 Threshold Task

A paired samples *t*-test demonstrated that the threshold values did not differ before ($M = 6.97$, $SD = 1.82$) compared to after ($M = 6.83$, $SD = 1.92$; $t_{(33)} = 1.304$, $p = .201$; $BF_{10} = 0.39$) the priming task, which confirms that the primes remained adequately suppressed from awareness throughout the entire testing session.

3.2 Priming Task

ANOVA revealed Visibility × Size Congruency ($F_{(1,\,34)} = 6.08$, $p = .019$, $\eta_p^2 = 0.152$) (Fig. 4A) and Eye × Visibility ($F_{(1,\,34)} = 17.10$, $p < .001$, $\eta_p^2 = 0.335$) (Fig. 4B) interactions. The three-way Eye × Visibility × Size Congruency interaction approached significance ($F_{(1,\,34)} = 3.69$, $p = .063$, $\eta_p^2 = 0.098$) and all other interactions were not significant ($p \geq .785$). Tukey's pairwise comparisons revealed that the Visibility × Size Congruency interaction was driven by priming effects in the no CFS ($p = .047$, $d = 0.25$, $BF_{10} = 18.45$) but not in the CFS ($p = .993$, $d = 0.03$, $BF_{10} = 0.23$) condition (Fig. 4A). These tests further revealed that the Eye × Visibility interaction effect was driven by faster reaction times when responding to trials in which the prime and target were presented to the same eye compared to different eyes under CFS ($p = .004$, $d = 0.36$, $BF_{10} = 91.25$) (Fig. 4B). The same facilitation effect was not observed when comparing the same eye versus different eye conditions in the no CFS condition ($p = .974$, $d = 0.03$, $BF_{10} = 0.21$) (Fig. 4B). From the analyses so far, one cannot make any inferences as to whether or not the small and large primes exerted differential effects on priming. A re-analyses of the data using a four-way ANOVA with an additional factor of Prime Size (Small vs. Large) did not reveal a main effect of this factor ($F_{(1,\,34)} = 0.053$, $p = .819$, $\eta_p^2 = 0.002$) nor any interaction with it ($p \geq .232$). However, our sample size may have been insufficient to properly examine this given the tendency of effect sizes to diminish as a function of more complex interactions.

4. Discussion

We used CFS in conjunction with an interocular transfer paradigm to (a) evaluate if size information can be processed subconsciously and (b) assess the contributions of early versus late visual structures in size perception. In line with our first of two competing hypotheses, processing information for the purposes of size perception seems to require awareness of the stimulus and rely on late visual structures. Interestingly, we also observed an overall decrease in reaction times to the target when the proceeding prime was presented to the same compared to the different eye under CFS. We speculate that this last finding could reflect the importance of early visual processes in suppressing stimuli from awareness under CFS.

Two results derived from the present investigation suggest that size perception is likely mediated by later visual areas in the cortex. First, we observed complete interocular transfer of size information in the no CFS condition, as evidenced by a lack of a difference between monocular and dichoptic presentations. This finding indicates that the perception of size, at least in the absence of contextual cues, is mediated by cortical areas that are populated by binocular neurons, where signals from each eye are combined and the eye of origin is lost. Second, size response priming occurred when the primes were visible but not when they were suppressed with CFS. This finding suggests that top-down mechanisms associated with awareness are critical for processing information for size perception.

As discussed in the Introduction, V1 is important for size perception. The evidence comes from fMRI studies demonstrating that activity in V1 reflects the perceived rather than the retinal size of images (Sperandio, Chouinard, & Goodale, 2012; Schwarzkopf, & Rees, 2013; Pooresmaeili, Arrighi, Blagt, & Morrone, 2013; Murray, Boyaci, & Kersten, 2006). Evidence also comes from a transcranial magnetic stimulation (TMS) study by Costa et al. (2015). The authors of this study demonstrated that TMS applied to the early visual cortex disrupted their participants' ability to make size judgements. However, V1 cannot act alone (Sperandio & Chouinard, 2015; Chouinard & Ivanowich, 2014). Contemporary models of consciousness and object recognition are in agreement that low and high level cortical regions communicate with each other via reciprocal bidirectional connections for perception to occur (Dehaene & Changeux, 2011; Lamme & Roeslfsema, 2000; Bar, 2003). Another important area within this wider distribution of cortical regions is the lateral occipital complex (LOC), which is released from fMRI-adaptation when the physical size of stimuli varies compared to when it does not (Grill-Spector et al., 1999; Grill-Spector, Kourtzi, & Kanwisher, 2001). In agreement with these findings, Chouinard et al. (2008) demonstrated that applying TMS to this area diminishes people's ability to discriminate between the physical sizes of different objects. When considered together, these fMRI and TMS findings demonstrate that both V1 and LOC are important and necessary for size perception, but neither are sufficient to process size alone. Further studies could examine how the two areas interact with each other.

The lack of priming effects observed in the CFS condition is consistent with our previous research demonstrating that perceptual size discrimination is not facilitated when the prime is rendered subliminal with visual masking (Peel et al., 2018), which is an alternative technique to render stimuli perceptually invisible (Kouider & Dehaene, 2007). In the present investigation, we wanted to verify if similar findings could occur using a different suppression technique, such as CFS. This is an important consideration given that different suppression methods yield different patterns of neural activation to subliminal stimuli (Fogelson et al., 2014) – suggesting that the mechanisms of suppression differ. In addition, a number of psychophysics studies demonstrate different outcomes from experiments using different suppression techniques (Pereman & Lamy, 2014; Izatt, Dubois, Faivre, & Koch, 2014; Faivre, Berthet, & Kouider, 2012; Kimchi, Devyatko, Sabary, 2018; Sayim, Manassi, & Herzog, 2014) while other studies demonstrate convergence (Cox, Sperandio, Laycock, & Chouinard, 2018). Similar conclusions arising from experiments using different suppression techniques increase validity and confidence in the results, while the opposite does not. We are unaware of any other CFS studies that have examined size priming effects – although there exists one study from our group that examined size *aftereffects*. Laycock et al. (2017) presented stimuli similar to those used in the present study but for a much longer period of time (3,000 ms) to produce aftereffects under conditions with and without CFS. Similar to our findings, size aftereffects were present in the latter but not the former condition. This convergence underscores the importance of awareness for shaping size perception.

Interestingly, there was a monocular facilitation effect under CFS, regardless of the congruency in size between the prime and target. We speculate that this reflects the high demands placed on processing the Mondrians and the subsequent neuronal fatigue experienced from processing information from the eye receiving these highly salient stimuli. In the different eyes condition, the target appeared to the eye that had just received the Mondrians. It could be the case that the neural channels that processed information from that eye were fatigued after the presentation of the highly salient Mondrians, and hence any stimulus presented afterwards to that eye would be processed less efficiently, especially at a reduced luminance contrast. In the same eye condition, on the other hand, the target appeared in the same eye that received the prime and not the Mondrians. The neural channels that processed the prime may have been less taxed given that this stimulus had a much lower saliency than the Mondrians. Hence, it is possible that the neural channels processing information from that eye were not as fatigued and therefore any stimulus presented afterwards to that eye could be processed more efficiently. This interpretation of monocular channel fatigue is in line with a study by Kim, Kim, and Blake (2017). The authors presented stimuli under CFS for prolonged periods of time. In doing this, they demonstrated that images presented to the eye that was over-stimulated with the flashing Mondrians were less likely to be seen in a subsequent binocular rivalry task. Thus, it would seem that suppression during CFS entails competition between monocular channels (Blake, 1989; Tong, 2001) rather than the suppression of higher levels of visual processing (Logothetis, Leopold, & Sheinberg, 1996).

Nonetheless, there are some methodological issues to consider. To ensure that stimuli were reliably suppressed during CFS, the visibility of the stimuli under different luminance contrasts were first examined in the threshold task to choose the one that would ensure that the stimuli would not be seen in the priming task in a reliable manner. The individual differences in contrast sensitivity found in previous studies and the present one demonstrate the importance of using this individualised approach (Zadbood, Lee, & Blake, 2011). Alternatively, some studies use a different approach to address this issue in which they ask participants after each trial during the main experiment whether they saw or had an inkling of seeing the masked stimulus (for review, see Sterzer, Stein, Ludwig, Rothkirch, & Hesselmann, 2014; Yang et al., 2014). Performing the threshold procedures as we did before and after the primary task achieved the same purpose, namely verifying the perceptual invisibility of the masked stimulus, while allowing participants to focus their attention on the one task. Asking participants after every trial if they saw the prime is akin to a dual task. We would be asking them not only to make decisions about the size of the target but also to pay attention to the visibility of the prime and maintain this in memory for future recall when the trial is over. How the two interact is unknown but it is conceivably not conducive for isolating a process of interest (e.g. size perception). Indeed, a number of studies demonstrate interference in dual task paradigms whereby one task inhibits performance of the other and vice versa (e.g. Kahneman, 1973; Pashler, 1994; Karatekin, Couperus, & Marcus, 2004; Szameitat, Vanloo, & Muller, 2016). We did not want to introduce such interference.

Superimposing the prime over the flashing Mondrians to create a blended image is an alternative approach to making a stimulus visible in CFS experiments (Kang, Blake & Woodman, 2011; Jiang, Castello, & He, 2007; Engelen, Zhan, Sack, & de Gelder, 2018; Gayet, Paffen, Belopolsky, Theeuwes, & Van der Stigchel, 2016). The advantage of such an approach is that the flashing Mondrians are in both the masked and unmasked conditions – arguably providing a better control over a number of visual and attentional variables. However, this was not possible for us to do. The illusory nature of our Craik-O'Brian Cornsweet stimuli are known to be driven by the luminance gradation of their boundaries over a grey background (Purves et al., 1999). These illusory effects would disappear had we superimposed these stimuli over flashing Mondrians.

Another point to consider is whether or not the introduction of a 200 ms gap between prime offset and target onset was suboptimal for detecting priming under CFS. This gap was introduced because we were concerned that not presenting a mask between the two stimuli would create an afterimage of the prime, which would have introduced a confound to the study. Clearly, this gap was not an issue for the no-CFS condition. Priming was significant. However, this gap could be a greater concern in the CFS condition, whereby the signal of the prime is conceivably weaker and dissipates faster. However, other CFS studies using similar gaps have demonstrated significant effects on other tasks (e.g. Nakashima & Sugita, 2018; Stein & Sterzer, 2011) – suggesting that priming effects can still persist for that amount of time under CFS. Further, if this were an issue, it is conceivable that there would still be some statistical evidence for residual effects. For example, effect sizes would diminish but still be present and the reported BF_{10} would be within the inconclusive range between .33 and 3 in the CFS condition. Instead, the reported effect size was negligible ($d = 0.03$) and the reported BF_{10} was substantially in favour of the null hypothesis ($BF_{10} = 0.23$).

5. Conclusions

To summarise, we demonstrate that the size discrimination of a target is not facilitated when primes are suppressed under CFS. This finding, along with the observation of interocular transfer in the no CFS condition, highlights the importance of regions beyond early visual areas in processing size information for the purposes of perception.

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Figure legends

Figure 1. An illustrative explanation of the interocular transfer paradigm. As indicated in Panel A, different stages of the retina-geniculate-striate pathway differ in the proportion of neurons that respond to a stimulus presented to one eye versus both eyes. Monocular signals from the left (red) and right (blue) eyes remain segregated in the lateral geniculate nucleus (LGN) and begin to coalesce (purple) at the level of the primary visual cortex (V1). Neurons are largely binocular beyond V1. One can determine if processing is mediated by early or late visual structures by presenting primes and targets to either the same or different eye (Panel B). If the effects are comparable in both cases, then one can infer that later visual processing is more important. If the effects are stronger in the monocular than the dichoptic conditions, then one can infer that early visual processing is more important.

Figure 2. Threshold task. This figure depicts the sequence of events in the threshold task. Each trial began with 2 s of fixation followed by the presentation of 4 flashing (10 Hz) Mondrians to the dominant eye for 400 ms. During this time, a stimulus was presented to the non-dominant eye for 200 ms after a 200 ms delay. Afterwards, a final Mondrian was presented to both eyes for 100 ms. Participants were then tasked to verbally say ‘yes’ or ‘no’ as to whether or not they had any inclination of seeing the stimulus.

Figure 3. Priming task. In the no CFS condition (A), a trial began with 2.2 s of central fixation, followed by a prime that was presented to the non-dominant eye for 200 ms, followed by a Mondrian that was presented to both eyes for 100 ms, followed by a blank image that was presented for 100 ms, followed by a target that was presented to either the non-dominant (same eye condition) or dominant (different eye condition) eye. The target remained on the screen for a maximum of 3 s or until the participant made a manual response indicating whether it was small or large. An auditory alerting cue was always presented at target onset. This particular example corresponds to the no CFS, incongruent size, same eye condition. In the CFS condition (B), the events were similar except that the prime presented to the non-dominant eye was rendered perceptually invisible by the presentation of 4 flashing Mondrians in the dominant eye for 400 ms at 10 Hz. This particular example corresponds to the CFS, incongruent size, same eye condition.

Figure 4. Results. The figure depicts the two interaction effects that were significant from the ANOVA. Panel A displays the Visibility × Congruency interaction, which demonstrates the presence of priming in the no CFS but not the CFS condition. Panel B displays the Eye × Visibility interaction, which demonstrates complete interocular transfer of size cues in the visible condition. In contrast, there was a facilitation effect in the monocular condition in the CFS condition. Asterisks (*) denote significant effects at $p < 0.05$ after corrections for multiple comparisons were applied.

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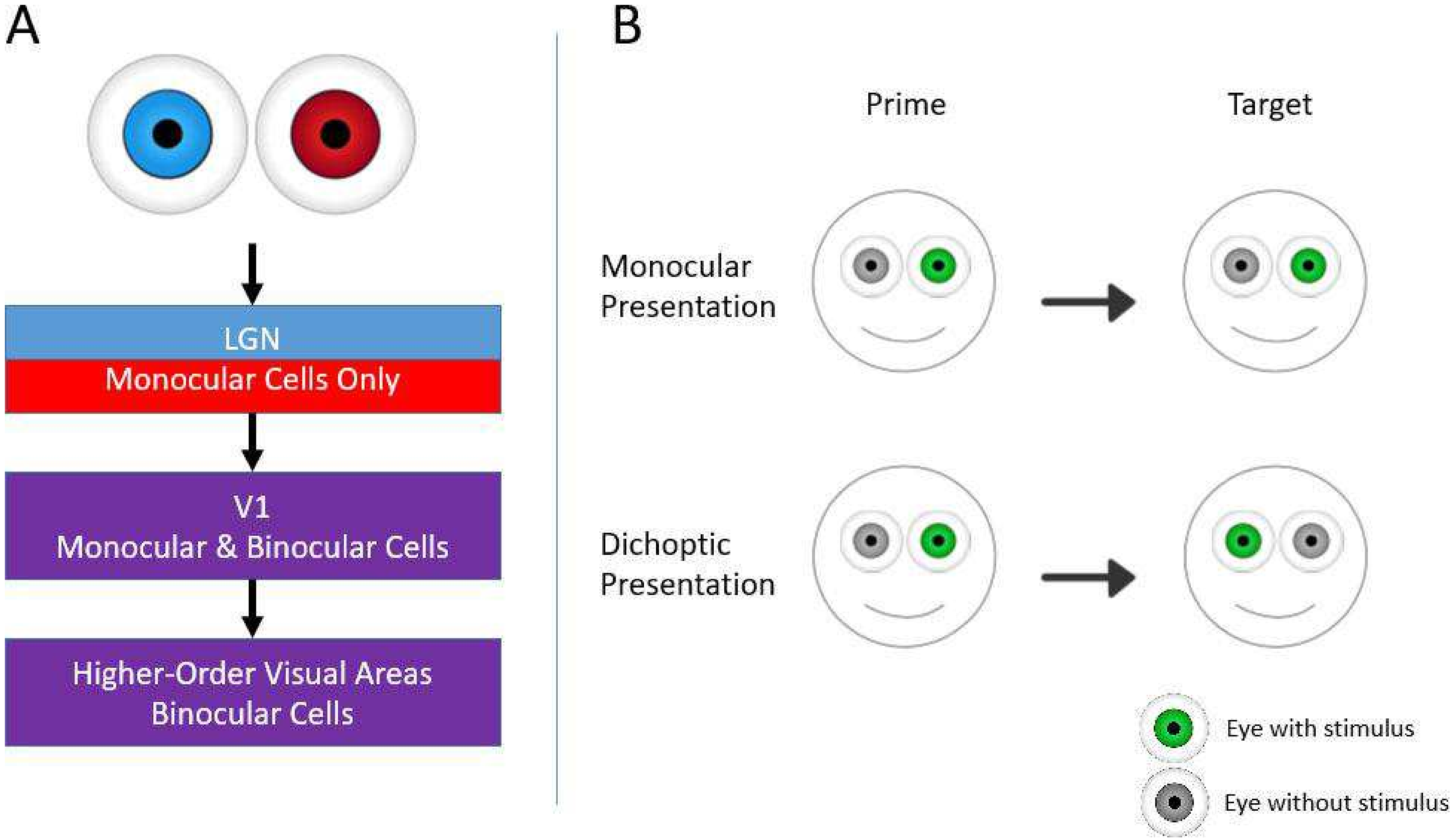
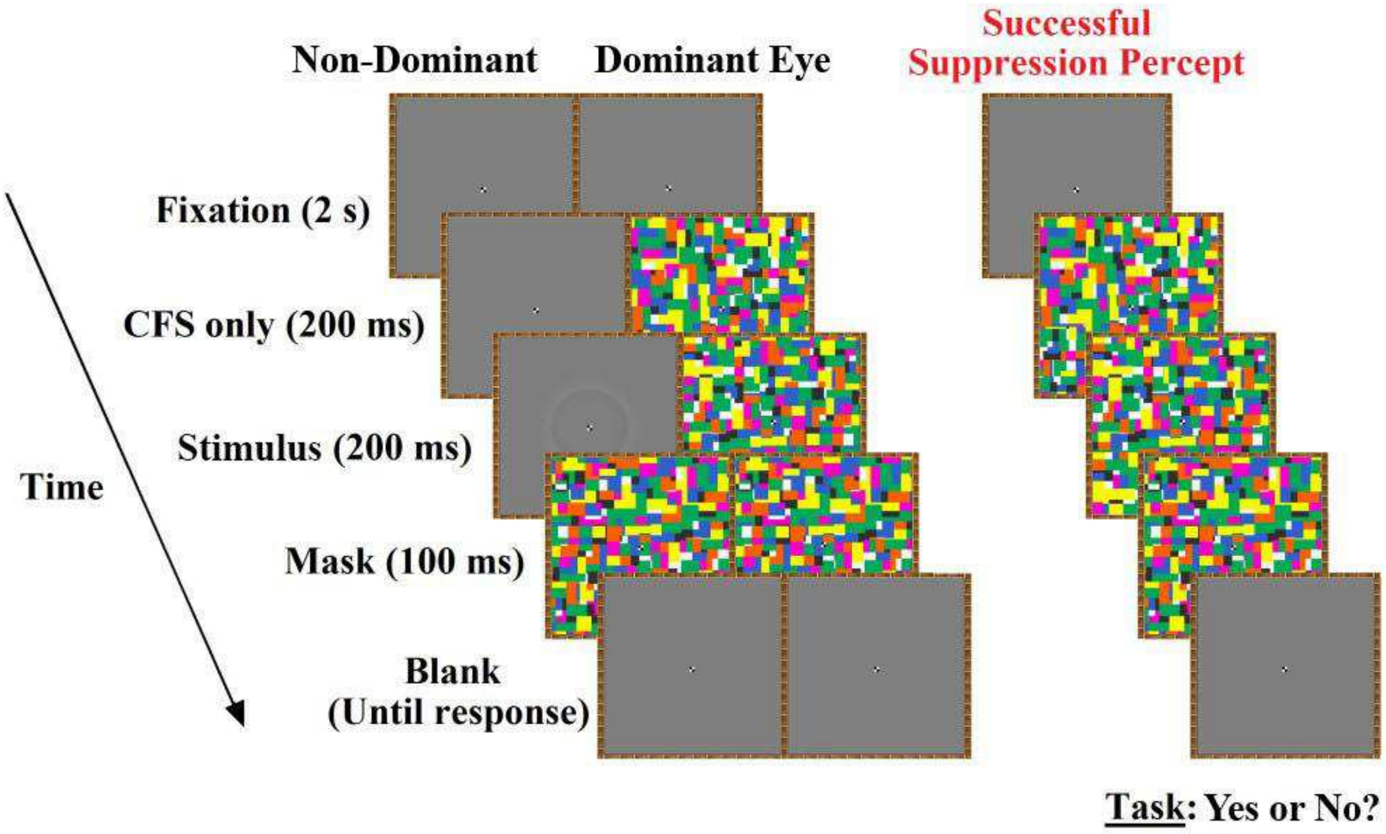
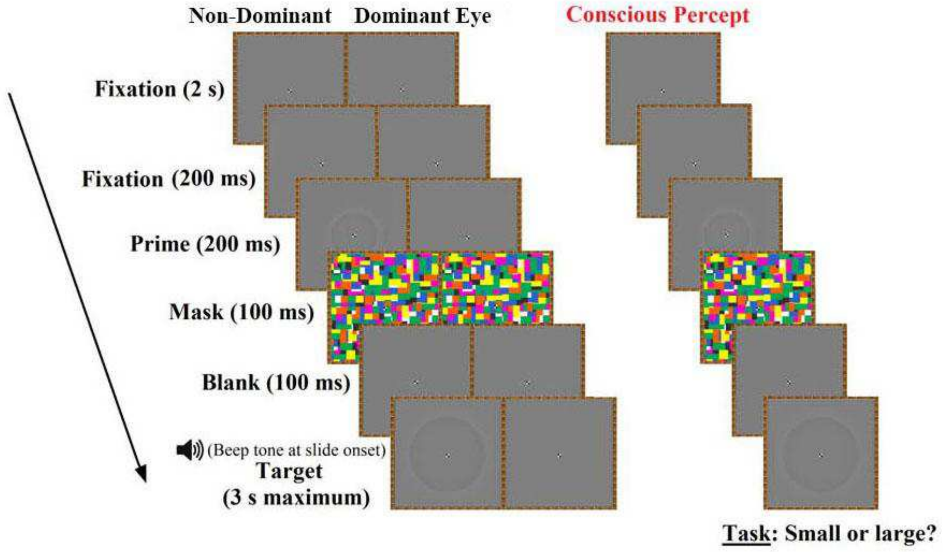

A
LGN
Monocular Cells Only
V1
Monocular & Binocular Cells
Higher-Order Visual Areas
Binocular Cells
B
Prime
Target
Monocular Presentation
Dichoptic Presentation
Eye with stimulus
Eye without stimulus

Trial Presentation and Temporal Sequence for the Prime Threshold Measure

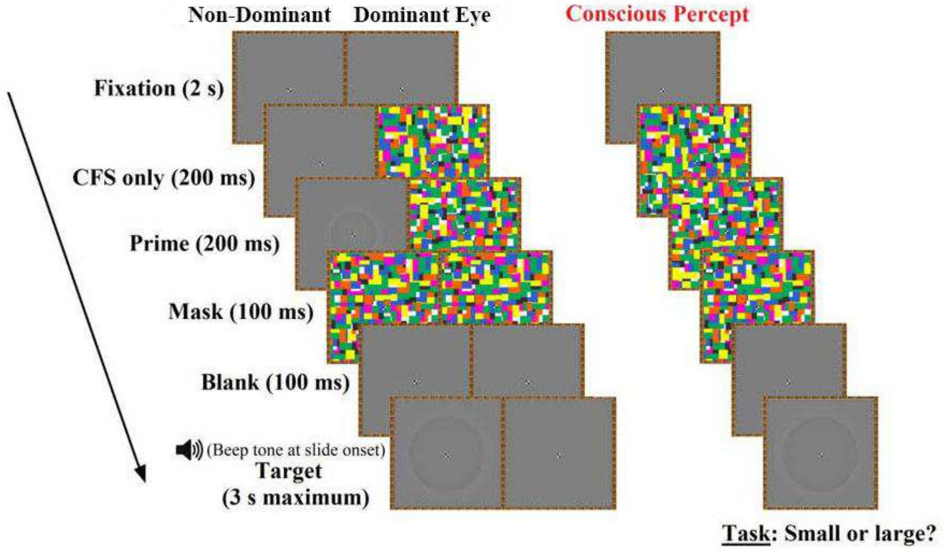


Presentation and Temporal Sequence for Repitition Priming Trials

A No-CFS Priming Condition



B CFS Priming Condition



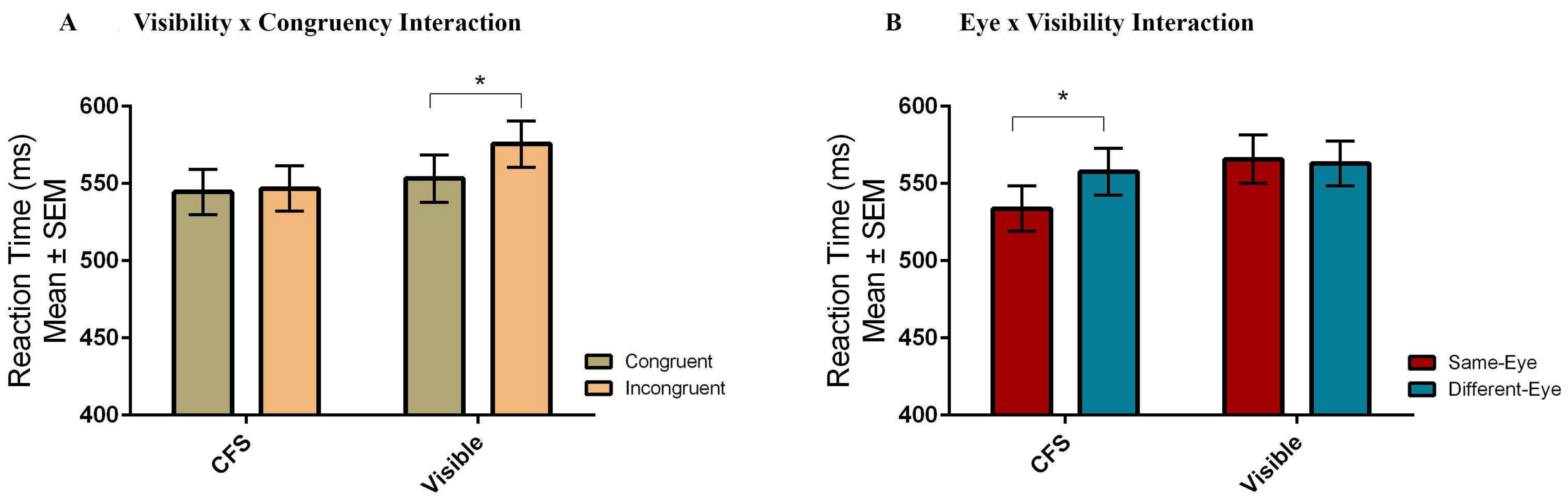

A
Visibility x Congruency Interaction
Reaction Time (ms)
Mean ± SEM
600
550
500
450
400
*
CFS
Visible
Congruent
Incongruent
B
Eye x Visibility Interaction
Reaction Time (ms)
Mean ± SEM
600
550
500
450
400
*
CFS
Visible
Same-Eye
Different-Eye

Table 1. Reaction time (ms) and accuracy (%) means and SDs for the different conditions.

Condition	*Reaction time M (SD)*	*Accuracy M (SD)*
Same eye, CFS, incongruent size	536.10 (88.62)	99.17 (0.02)
Same eye, CFS, congruent size	531.47 (84.77)	99.13 (0.02)
Same eye, no CFS, incongruent size	575.05 (96.26)	97.80 (0.03)
Same eye, no CFS, congruent size	556.48 (94.15)	99.20 (0.02)
Different eye , CFS, incongruent size	557.53 (88.02)	99.35 (0.02)
Different eye , CFS, congruent size	557.81 (91.93)	99.11 (0.02)
Different eye , no CFS, incongruent size	575.97 (88.01)	98.29 (0.02)
Different eye , no CFS, congruent size	550.10 (89.62)	99.40 (0.02)

Reaction time measures include accurate trials only.