

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

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

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

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43 1. Introduction

44

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

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

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

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

90 Another way to evaluate the contributions of early versus late visual structures is to
91 examine interocular transfer (Fig. 1) (Blake, Overton, & Lema-Stern, 1981). Different stages
92 of the retina-geniculate-striate pathway differ in the proportion of neurons that respond to a
93 stimulus presented to one eye versus both eyes. Monocular signals from the left and right eyes
94 remain segregated in the lateral geniculate nucleus (LGN) and begin to coalesce at the level of
95 V1 – though there are still a number of V1 neurons that respond to stimulation from only one
96 eye (Adams, Sincich, & Horton, 2007). Almost all neurons beyond V1 are binocular (Zeki,
97 1978). On the basis of this known anatomy, one can draw certain inferences from results
98 obtained in an interocular transfer experiment. If stimulus information is processed more
99 efficiently when it is presented in a monocular (to the same eye) compared to a dichoptic (to
100 different eyes) manner, then one can infer that early structures (such as the retina, LGN, and
101 V1) are largely responsible for this processing. Alternatively, if there is no discernible
102 difference in how a stimulus is processed when it is presented monocularly versus
103 dichoptically, then one can infer that later visual structures are equally responsible for this
104 processing.

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

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

131

132 2. Methods

133 2.1 Overview

134

135 Participants first completed tests of handedness, visual acuity, eye dominance, and binocular
136 fusion. Following this, each participant completed a threshold task to establish the minimum

137 luminance contrast necessary for the prime to break CFS. After this threshold was established,
138 participants completed the priming task with the stimuli adjusted to a luminance contrast lower
139 than this threshold value. Last, the threshold task was repeated at the end of the session to verify
140 that threshold values did not change in a way that would suggest that the primes could have
141 been visible during the CFS condition in the main priming task. The entire experiment took
142 approximately one hour to complete. The study was approved by the La Trobe University
143 Human Ethics Committee and was carried out in accordance with the Declaration of Helsinki.
144 All participants provided written informed consent.

145 146 **2.2 Participants**

147
148 Thirty-five right-handed participants completed the **entire study** ($M_{age} = 25.17$ years, age-range
149 = 18-56, 16 males). We verified that all participants had at least 20/40 vision in each eye using
150 the Snellen Eye Chart (Snellen, 1862). Eye dominance was established using the Miles test
151 (Miles, 1930). For this test, the participants touched their thumbs and index fingers together to
152 form a diamond shape viewing aperture and looked at a target on the wall. They then slowly
153 moved their hands closer to their face while keeping the target in view between their fingers.
154 The eye still looking through the aperture was deemed the dominant eye. We also screened for
155 binocular dysfunction using the *framing game* (Laycock et al., 2017; Peel et al., 2018). For this
156 test, participants extended their arm out in front of them and held a finger in front of a target
157 on the wall. First, they were told to focus their eyes on their finger and indicate whether or not
158 the target appeared to frame it (i.e. it became diplopic). They were then instructed to fixate on
159 the target and report whether or not their finger framed the object. Typical binocular fusion
160 abilities were assumed if framing occurred in both cases. Participants also had to be right
161 handed to be included in the study. Handedness was verified using the Edinburgh Handedness
162 Inventory (Oldfield, 1971).

163 164 **2.3 Stimuli and apparatus**

165
166 Craik-O'Brian-Cornsweet circles (Purves et al., 1999), similar to those used in one of our
167 previous studies (Laycock et al., 2017), were used in the present investigation. Two circle sizes
168 were presented: small (4°) and large (9°). These stimuli were generated using an in-house
169 program written in MATLAB (Math Works, Natick, Massachusetts, USA). The stimuli were
170 illusory: the centre appeared darker relative to the grey background even though both were
171 physically isoluminant (80.6 c/m^2). A standard CFS technique was used to suppress the stimuli
172 from awareness (Tsuchiya & Koch, 2005). We presented the dominant eye with 5 different
173 Mondrians (selected randomly from a sample of eight) at a frequency of 10-Hz (i.e. every 100
174 ms) while the non-dominant eye was presented with the prime for 200 ms (Figs. 2 and 3). The
175 visual stimuli were presented using E-Prime 2.0 software (Psychology Software Tools,
176 Sharpsburg, PA, United States) on a 17" LCD monitor (1280 x 1024 pixel resolution, 60-Hz
177 frame rate). Participants viewed the stimuli through a stereoscope while their head was placed
178 on a chin rest. The viewing distance was 57 cm.

179 180 **2.4 Procedures for the threshold task**

181
182 We presented participants with the small and large circles at different luminance contrasts
183 ranging from 2% (2.8 c/m^2) to 8% (10.4 c/m^2) in 1% increments under CFS (Fig. 2). The order
184 of trials was randomly generated by E-prime. At the end of each trial, participants responded
185 verbally with "Yes" when they had *any* inclination that they were aware of the masked stimulus
186 and "No" when they did not. **There were 5 trials for each contrast.** From this task, we calculated

187 the minimum luminance contrast necessary for the prime to break CFS for either the small or
 188 large circles on any trial. For example, if the large circle broke suppression at 5% (and no other
 189 lower value) and the small circle broke suppression at 4% (and no other lower value), then the
 190 threshold was deemed 4%. The stimuli were presented at a 1% decrement lower than the
 191 threshold value in the priming task that followed. The threshold task also served a second
 192 purpose, which was to verify the validity of a participant's reports. Ten catch trials without a
 193 stimulus were included in the task. Any participant reporting "Yes" during a catch trial prior
 194 to the priming task were excluded from proceeding with the study further. Three participants
 195 (other than the 35 in our final sample) were deemed ineligible to continue. None of the
 196 remaining participants reported seeing a stimulus in a catch trial when the threshold task was
 197 repeated after the priming task.

198

199 *2.5 Procedures for the priming task*

200

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

223

224 *2.6 Statistical Analyses*

225

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

230 Threshold values were analysed using a paired sample *t*-test to determine if they
 231 differed after compared to before the priming task. For the priming task, the mean reaction
 232 times from only the correct trials were entered into a three-way repeated-measures analysis of
 233 variance (ANOVA) with Visibility (no-CFS vs. CFS), Size Congruency (congruent vs.
 234 incongruent), and Eye (same eye vs. different eyes) as factors. Participant accuracy was not
 235 compared between conditions as these results were at ceiling levels of performance (Table 1).
 236 Effect sizes (partial eta-squared; η_p^2) obtained from the ANOVA are reported. Tukey's honest

237 significant difference (HSD) pair-wise comparison tests, which corrected for multiple
 238 comparisons, were carried out to examine further interactions and effects deemed significant
 239 by the ANOVA. In addition, Cohen's d effect sizes for pair-wise comparisons were calculated
 240 as the difference between the two means divided by their pooled standard deviation (Cohen,
 241 1988). Unless specified otherwise, all reported p values were corrected for multiple
 242 comparisons and were based on an alpha level of .05. In addition to null hypothesis statistical
 243 testing (NHST), we also performed Bayesian analyses. Bayes Factors (BF_{10}) were calculated
 244 to supplement all pairwise comparisons reported in the paper. They indicate the degree of
 245 support for the alternative (H_1) relative to the null (H_0) hypothesis. A BF_{10} greater than 3 was
 246 considered to provide substantial evidence for the alternative hypothesis, while a value less
 247 than .33 was considered to provide substantial evidence for the null hypothesis (Jeffreys, 1961).

248

249 3. Results

250

251 3.1 Threshold Task

252

253 A paired samples t -test demonstrated that the threshold values did not differ before ($M = 6.97$,
 254 $SD = 1.82$) compared to after ($M = 6.83$, $SD = 1.92$; $t_{(33)} = 1.304$, $p = .201$; $BF_{10} = 0.39$) the
 255 priming task, which confirms that the primes remained adequately suppressed from awareness
 256 throughout the entire testing session.

257

258 3.2 Priming Task

259

260 ANOVA revealed Visibility \times Size Congruency ($F_{(1, 34)} = 6.08$, $p = .019$, $\eta_p^2 = 0.152$) (Fig. 4A)
 261 and Eye \times Visibility ($F_{(1, 34)} = 17.10$, $p < .001$, $\eta_p^2 = 0.335$) (Fig. 4B) interactions. The three-
 262 way Eye \times Visibility \times Size Congruency interaction approached significance ($F_{(1, 34)} = 3.69$, p
 263 $= .063$, $\eta_p^2 = 0.098$) and all other interactions were not significant ($p \geq .785$). Tukey's pairwise
 264 comparisons revealed that the Visibility \times Size Congruency interaction was driven by priming
 265 effects in the no CFS ($p = .047$, $d = 0.25$, $BF_{10} = 18.45$) but not in the CFS ($p = .993$, $d = 0.03$,
 266 $BF_{10} = 0.23$) condition (Fig. 4A). These tests further revealed that the Eye \times Visibility
 267 interaction effect was driven by faster reaction times when responding to trials in which the
 268 prime and target were presented to the same eye compared to different eyes under CFS ($p =$
 269 $.004$, $d = 0.36$, $BF_{10} = 91.25$) (Fig. 4B). The same facilitation effect was not observed when
 270 comparing the same eye versus different eye conditions in the no CFS condition ($p = .974$, $d =$
 271 0.03 , $BF_{10} = 0.21$) (Fig. 4B). From the analyses so far, one cannot make any inferences as to
 272 whether or not the small and large primes exerted differential effects on priming. A re-analyses
 273 of the data using a four-way ANOVA with an additional factor of Prime Size (Small vs. Large)
 274 did not reveal a main effect of this factor ($F_{(1, 34)} = 0.053$, $p = .819$, $\eta_p^2 = 0.002$) nor any
 275 interaction with it ($p \geq .232$). However, our sample size may have been insufficient to properly
 276 examine this given the tendency of effect sizes to diminish as a function of more complex
 277 interactions.

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279

280 4. Discussion

281

282 We used CFS in conjunction with an interocular transfer paradigm to (a) evaluate if size
 283 information can be processed subconsciously and (b) assess the contributions of early versus
 284 late visual structures in size perception. In line with our first of two competing hypotheses,

285 processing information for the purposes of size perception seems to require awareness of the
286 stimulus and rely on late visual structures. Interestingly, we also observed an overall decrease
287 in reaction times to the target when the preceding prime was presented to the same compared
288 to the different eye under CFS. We speculate that this last finding could reflect the importance
289 of early visual processes in suppressing stimuli from awareness under CFS.

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

299 As discussed in the Introduction, V1 is important for size perception. The evidence
300 comes from fMRI studies demonstrating that activity in V1 reflects the perceived rather than
301 the retinal size of images (Sperandio, Chouinard, & Goodale, 2012; Schwarzkopf, & Rees,
302 2013; Pooresmaeli, Arrighi, Blagt, & Morrone, 2013; Murray, Boyaci, & Kersten, 2006).
303 Evidence also comes from a transcranial magnetic stimulation (TMS) study by Costa et al.
304 (2015). The authors of this study demonstrated that TMS applied to the early visual cortex
305 disrupted their participants' ability to make size judgements. However, V1 cannot act alone
306 (Sperandio & Chouinard, 2015; Chouinard & Ivanowich, 2014). Contemporary models of
307 consciousness and object recognition are in agreement that low and high level cortical regions
308 communicate with each other via reciprocal bidirectional connections for perception to occur
309 (Dehaene & Changeux, 2011; Lamme & Roelfsema, 2000; Bar, 2003). Another important
310 area within this wider distribution of cortical regions is the lateral occipital complex (LOC),
311 which is released from fMRI-adaptation when the physical size of stimuli varies compared to
312 when it does not (Grill-Spector et al., 1999; Grill-Spector, Kourtzi, & Kanwisher, 2001). In
313 agreement with these findings, Chouinard et al. (2008) demonstrated that applying TMS to this
314 area diminishes people's ability to discriminate between the physical **sizes** of different objects.
315 When considered together, these fMRI and TMS findings demonstrate that both V1 and LOC
316 are important and necessary for size perception, but neither are sufficient to process size alone.
317 Further studies could examine how **the** two areas interact with each other.

318 The **lack** of priming effects observed in the CFS condition is consistent with our
319 previous research demonstrating that perceptual size discrimination is not facilitated when the
320 prime is rendered subliminal with visual masking (Peel et al., 2018), which is an alternative
321 technique to render stimuli perceptually invisible (Kouider & Dehaene, 2007). **In the present**
322 **investigation, we wanted to verify if similar findings could occur using a different suppression**
323 **technique, such as CFS. This is an important consideration given that different suppression**
324 **methods yield different patterns of neural activation to subliminal stimuli (Fogelson et al.,**
325 **2014) – suggesting that the mechanisms of suppression differ. In addition, a number of**
326 **psychophysics studies demonstrate different outcomes from experiments using different**
327 **suppression techniques (Pereman & Lamy, 2014; Izatt, Dubois, Faivre, & Koch, 2014; Faivre,**
328 **Berthet, & Kouider, 2012; Kimchi, Devyatko, Sabary, 2018; Sayim, Manassi, & Herzog, 2014)**
329 **while other studies demonstrate convergence (Cox, Sperandio, Laycock, & Chouinard, 2018).**
330 **Similar conclusions arising from experiments using different suppression techniques increase**
331 **validity and confidence in the results, while the opposite does not. We are unaware of any other**
332 **CFS studies that have examined size priming effects – although there exists one study from our**
333 **group that examined size *aftereffects*. Laycock et al. (2017) presented stimuli similar to those**
334 **used in the present study but for a much longer period of time (3,000 ms) to produce aftereffects**

335 under conditions with and without CFS. Similar to our findings, size aftereffects were present
336 in the latter but not the former condition. This convergence underscores the importance of
337 awareness for shaping size perception.

338 Interestingly, there was a monocular facilitation effect under CFS, regardless of the
339 congruency in size between the prime and target. We speculate that this reflects the high
340 demands placed on processing the Mondrians and the subsequent neuronal fatigue experienced
341 from processing information from the eye receiving these highly salient stimuli. In the different
342 eyes condition, the target appeared to the eye that had just received the Mondrians. It could be
343 the case that the neural channels that processed information from that eye were fatigued after
344 the presentation of the highly salient Mondrians, and hence any stimulus presented afterwards
345 to that eye would be processed less efficiently, especially at a reduced luminance contrast. In
346 the same eye condition, on the other hand, the target appeared in the same eye that received the
347 prime and not the Mondrians. The neural channels that processed the prime may have been less
348 taxed given that this stimulus had a much lower saliency than the Mondrians. Hence, it is
349 possible that the neural channels processing information from that eye were not as fatigued and
350 therefore any stimulus presented afterwards to that eye could be processed more efficiently.
351 This interpretation of monocular channel fatigue is in line with a study by Kim, Kim, and Blake
352 (2017). The authors presented stimuli under CFS for prolonged periods of time. In doing this,
353 they demonstrated that images presented to the eye that was over-stimulated with the flashing
354 Mondrians were less likely to be seen in a subsequent binocular rivalry task. Thus, it would
355 seem that suppression during CFS entails competition between monocular channels (Blake,
356 1989; Tong, 2001) rather than the suppression of higher levels of visual processing (Logothetis,
357 Leopold, & Sheinberg, 1996).

358 Nonetheless, there are some methodological issues to consider. To ensure that stimuli
359 were reliably suppressed during CFS, the visibility of the stimuli under different luminance
360 contrasts were first examined in the threshold task to choose the one that would ensure that the
361 stimuli would not be seen in the priming task in a reliable manner. The individual differences
362 in contrast sensitivity found in previous studies and the present one demonstrate the importance
363 of using this individualised approach (Zadbood, Lee, & Blake, 2011). Alternatively, some
364 studies use a different approach to address this issue in which they ask participants after each
365 trial during the main experiment whether they saw or had an inkling of seeing the masked
366 stimulus (for review, see Sterzer, Stein, Ludwig, Rothkirch, & Hesselmann, 2014; Yang et al.,
367 2014). Performing the threshold procedures as we did before and after the primary task
368 achieved the same purpose, namely verifying the perceptual invisibility of the masked stimulus,
369 while allowing participants to focus their attention on the one task. Asking participants after
370 every trial if they saw the prime is akin to a dual task. We would be asking them not only to
371 make decisions about the size of the target but also to pay attention to the visibility of the prime
372 and maintain this in memory for future recall when the trial is over. How the two interact is
373 unknown but it is conceivably not conducive for isolating a process of interest (e.g. size
374 perception). Indeed, a number of studies demonstrate interference in dual task paradigms
375 whereby one task inhibits performance of the other and vice versa (e.g. Kahneman, 1973;
376 Pashler, 1994; Karatekin, Couperus, & Marcus, 2004; Szameitat, Vanloo, & Muller, 2016). We
377 did not want to introduce such interference.

378 Superimposing the prime over the flashing Mondrians to create a blended image is an
379 alternative approach to making a stimulus visible in CFS experiments (Kang, Blake &
380 Woodman, 2011; Jiang, Castello, & He, 2007; Engelen, Zhan, Sack, & de Gelder, 2018; Gayet,
381 Paffen, Belopolsky, Theeuwes, & Van der Stigchel, 2016). The advantage of such an approach
382 is that the flashing Mondrians are in both the masked and unmasked conditions – arguably
383 providing a better control over a number of visual and attentional variables. However, this was
384 not possible for us to do. The illusory nature of our Craik-O’Brian Cornsweet stimuli are known

385 to be driven by the luminance gradation of their boundaries over a grey background (Purves et
386 al., 1999). These illusory effects would disappear had we superimposed these stimuli over
387 flashing Mondrians.

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

402

403 **5. Conclusions**

404

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

409

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411

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414 conflict of interest.

415 **Figure legends**

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

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

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

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

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458 **References**

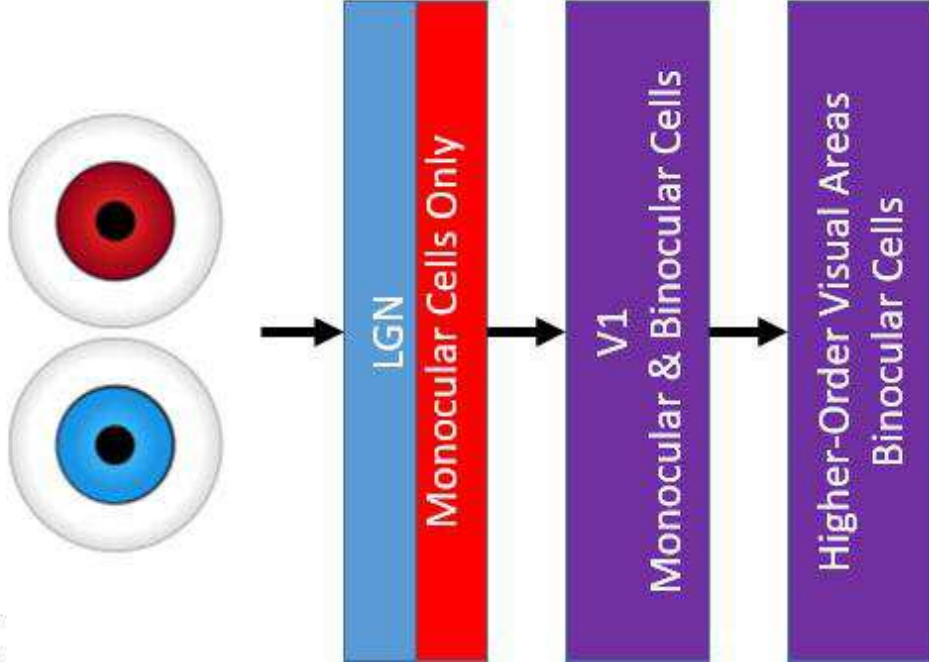
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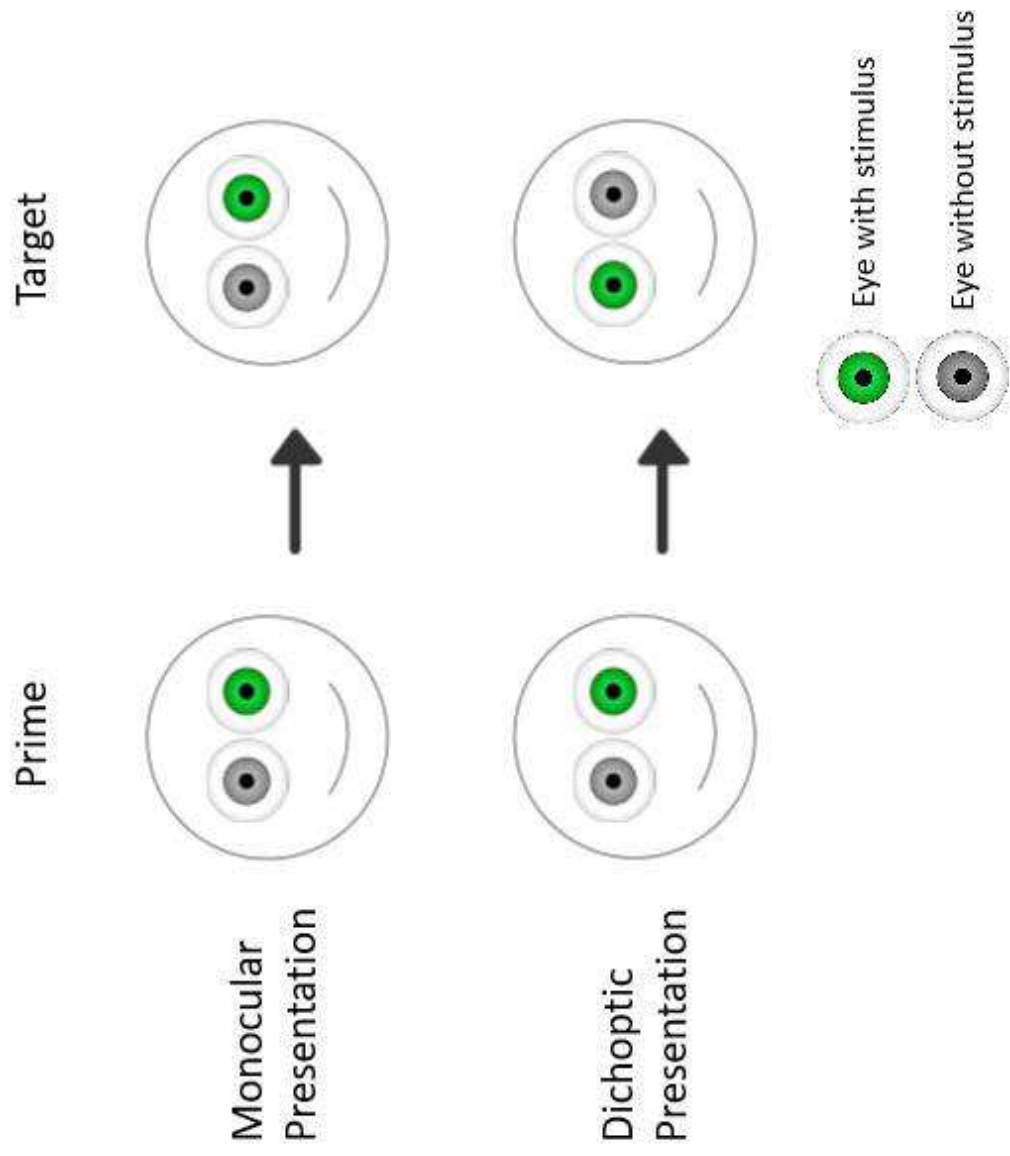
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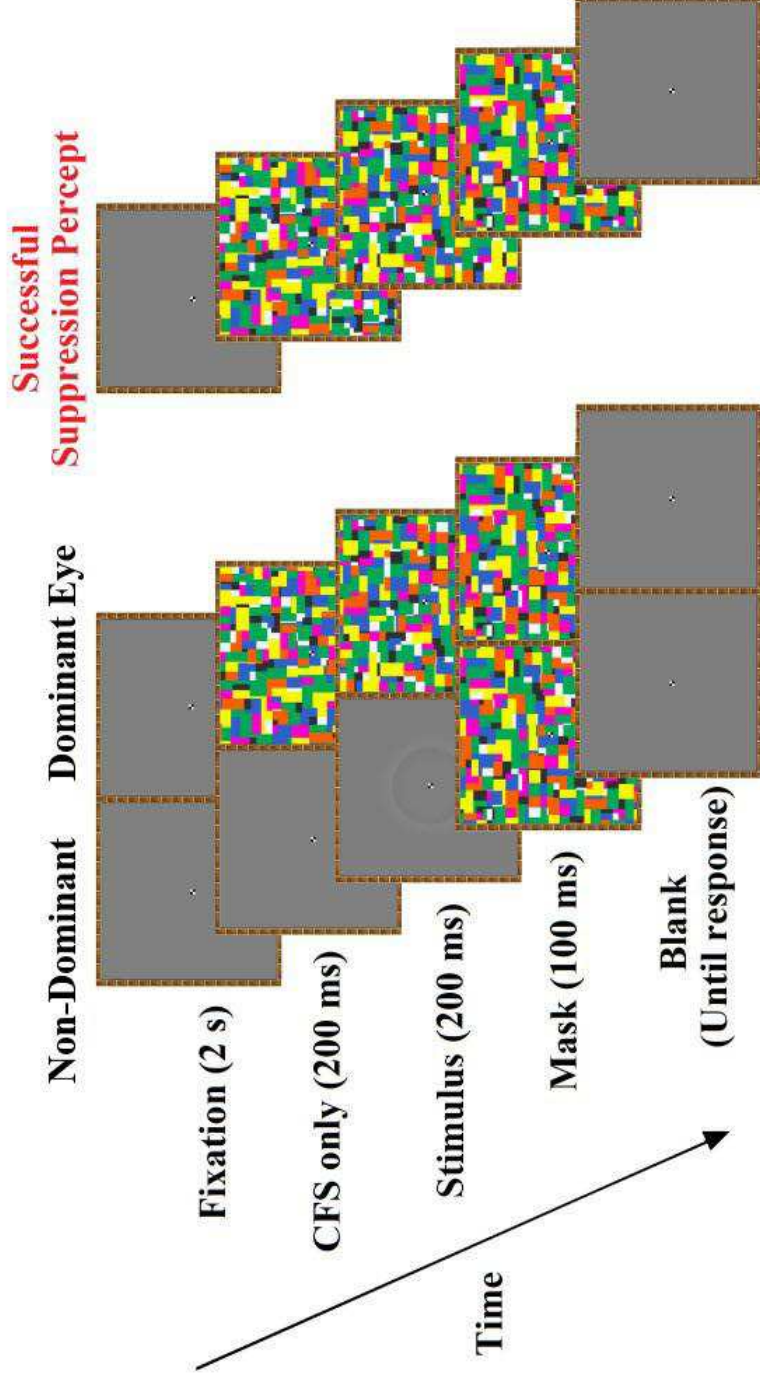
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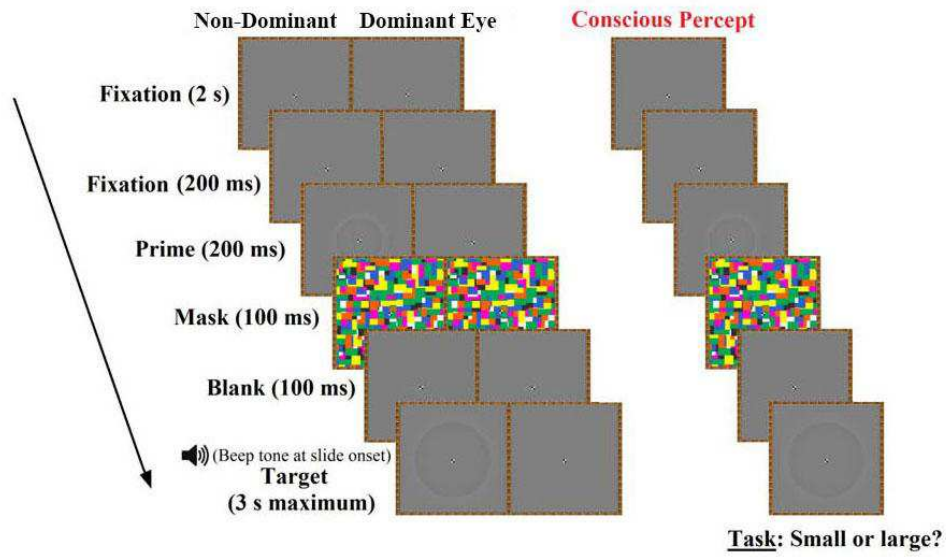


Trial Presentation and Temporal Sequence for the Prime Threshold Measure

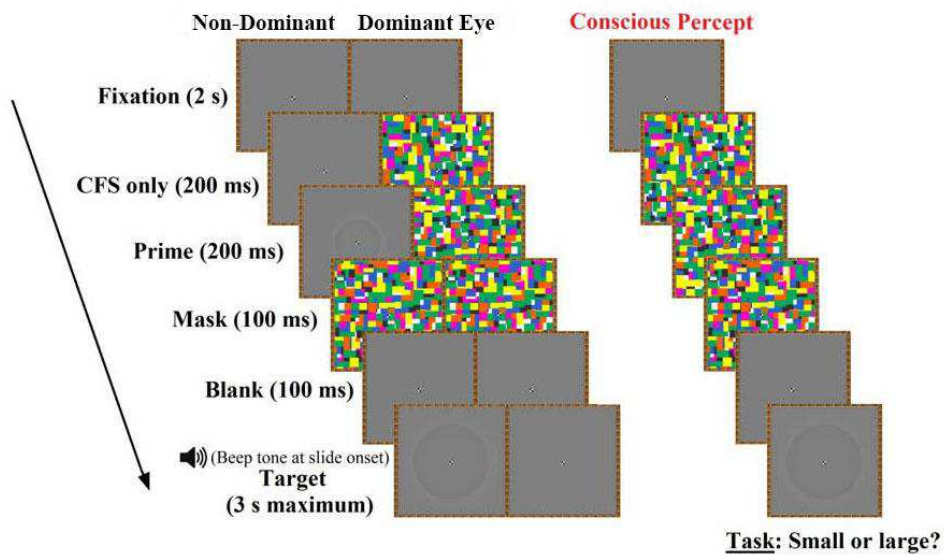


Presentation and Temporal Sequence for Repetition Priming Trials

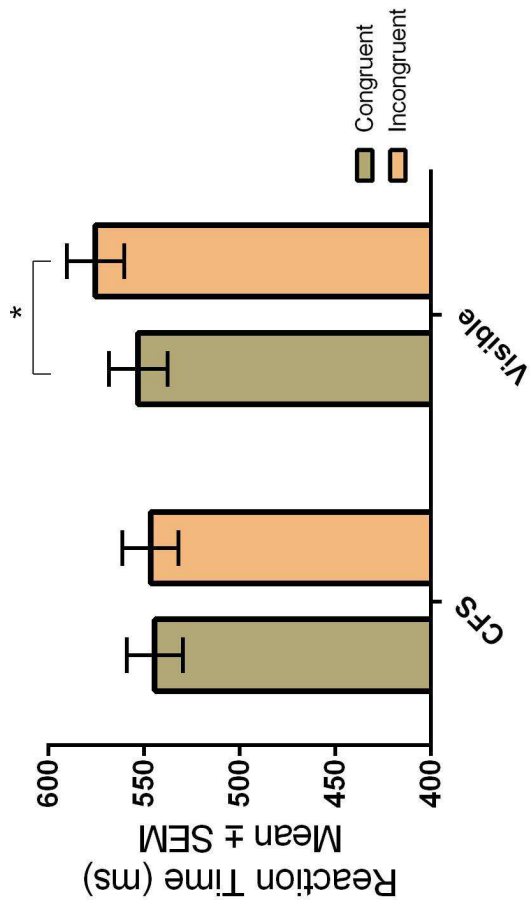
A No-CFS Priming Condition



B CFS Priming Condition



A Visibility x Congruency Interaction



B Eye x Visibility Interaction

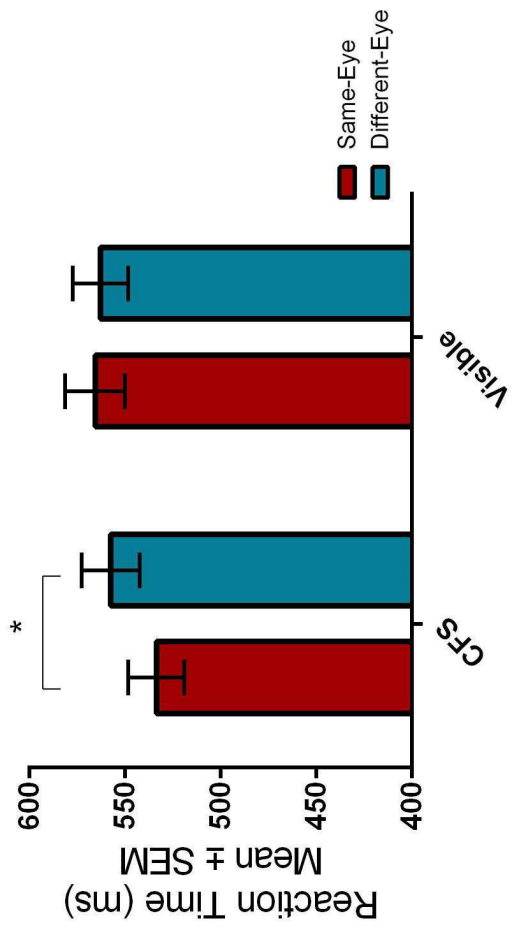


Table 1. Reaction time (ms) and accuracy (%) means and SDs for the different conditions.

<i>Condition</i>	<i>Reaction time M (SD)</i>	<i>Accuracy M (SD)</i>
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.