A global attentional scope setting prioritizes faces for conscious detection

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The scope of visual attention is known to affect conscious object perception, with recent studies showing that a global attentional scope boosts holistic face processing, relative to a local scope. Here we show that attentional scope settings can also modulate the availability of information for conscious visual awareness. In an initial experiment, we show that adopting a global attentional scope accelerates conscious detection of initially invisible faces, presented under continuous flash suppression (CFS). Furthermore, face detection time was not modulated by attentional scope in a nonrivalrous control condition, which emulated the experience of CFS without inducing binocular rivalry. In a follow-up experiment, we report an exact replication of the original effect, as well as data suggesting that this effect is specific to upright faces, and is abolished when using both inverted faces and images of houses in an otherwise identical task. Thus, attentional scope settings can modulate the availability of information to conscious awareness, fundamentally altering the contents of our subjective visual experience.

Introduction

Attention serves to amplify subsets of sensory inputs, for example, by dynamically modulating its scope (Eriksen & St. James, 1986; Müller, Bartelt, Donner, Villringer, & Brandt, 2003). With a global scope, attentional resources are spread over a large region of the visual field, enhancing the bandwidth of information processing at the expense of representing each input with lower resolution. Conversely, with a local scope, attention can "zoom in," increasing selectivity and precision for a smaller region of the visual field (Eriksen & St. James, 1986; Müller et al., 2003), at the expense of other aspects in the scene. The ability to shift fluidly between global and local attentional scopes is critical for task performance, especially given that some stimuli are processed more efficiently depending on the attentional scope setting. For instance, perception of faces is more efficient when observers adopt a global attentional scope, relative to a local scope (Hills & Lewis, 2009; Macrae & Lewis, 2002), which extends to learning and memory for faces (Lewis, Mills, Hills, & Weston, 2009). Additionally, adopting a global scope has also been shown to increase the magnitude of the composite face effect, a measure of holistic face perception (Gao, Flevaris, Robertson, & Bentin, 2011; Maurer, Le Grand, & Mondloch, 2002; Young, Hellawell, & Hay, 1987).

While these previous experiments demonstrate that attentional scope settings can modify conscious visual processing (Gao et al., 2011; Hills & Lewis, 2009), in the present experiments, we asked whether such settings could operate even before a percept enters conscious awareness. With visual attention and conscious awareness being separable, but intimately related phenomena (Cohen, Cavanagh, Chun, & Nakayama, 2012; Koch & Tsuchiya, 2007; Wyart & Tallon-Baudry, 2008), it is expected that attentional processes should play a central role in shaping the contents of our

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subjective conscious experience. Moreover, there is also evidence to suggest that attention can operate without awareness (Chou & Yeh, 2012; Gayet, Van der Stigchel, & Paffen, 2014a; Jiang, Costello, Fang, Huang, & He, 2006). For instance, object-based attention can occur even when observers are unaware of the cued objects (Chou & Yeh, 2012; Egly, Driver, & Rafal, 1994) and symbolic visual cues that were suppressed from awareness could drive shifts in attention, as long as these trials were intermixed with other trials containing valid visible cues (Gayet et al., 2014a). Finally, Jiang and colleagues (2006) showed that invisible erotic images suppressed from awareness could also cue attention, if the observer's sexual orientation was compatible with the content of the image. These studies, along with many others, suggest that attention and conscious awareness are dissociable processes, and that attention can operate without awareness, perhaps even to influence unconscious object processing (Chou & Yeh, 2012; Goodhew, Dux, Lipp, & Visser, 2012; Goodhew, Pratt, Dux, & Ferber, 2013; Kentridge, Nijboer, & Heywood, 2008; Koch & Tsuchiya, 2007; Lin & Murray, 2013). Thus, we explored whether modulating the scope of attention will affect face perception before the percept of a face stimulus reaches conscious awareness.

A recently developed paradigm called breaking continuous flash suppression (b-CFS) has been used to investigate several factors that modulate the time it takes for initially invisible images to breach the threshold for conscious detection (Jiang, Costello, & He, 2007; Tsuchiya & Koch, 2005; Tsuchiya, Koch, Gilroy, & Blake, 2006). Continuous flash suppression is a variant of binocular rivalry, in which the stimulus of interest is presented to one eye and a dynamic, high-contrast mask (i.e., Mondrian mask) is presented to the other eye (Tsuchiya & Koch, 2005; Tsuchiya et al., 2006). The resulting interocular competition causes the stimulus of interest to be rendered initially invisible, until it eventually breaks from CFS and becomes available to conscious awareness (Jiang et al., 2007; for reviews, see Gayet, Van der Stigchel, & Paffen, 2014b; Lin & He, 2009). Previous studies have shown that CFS times are sensitive to manipulations of the saliency and familiarity of face images. For example, upright faces break from suppression faster than inverted faces (Jiang et al., 2007; Stein, Sterzer, & Peelen, 2012; Zhou, Zhang, Liu, Yang, & Qu, 2010); fearful faces break from suppression faster than neutral or happy faces (Yang, Zald, & Blake, 2007); faces presented with direct gaze break from suppression faster than faces with averted gaze (Chen & Yeh, 2012; Stein, Senju, Peelen, & Sterzer, 2011); familiar faces break from suppression faster than unfamiliar faces (Gobbini et al. 2013); and finally, faces of the observer's own age and race also break from suppression more quickly than other-age and other-race faces (Stein, End, & Sterzer, 2014). Taken together, these results suggest that the visual system prioritizes the detection of salient and familiar faces, and that information signaling such saliency and familiarity may be extracted prior to the face stimulus reaching conscious awareness. Moreover, endogenous or contextual factors can also influence the emergence of stimuli from CFS to awareness. For instance, when observers listened to a recording of a sentence, invisible faces with lip movements congruent with the sentence broke from CFS more quickly than faces with incongruent lip movements (Alsius & Munhall, 2013). Furthermore, internally generated expectations have been shown to reduce suppression time for congruent visual images (Pinto, van Gaal, de Lange, Lamme, & Seth, 2015; Stein & Peelen, 2015). Specifically, word cues (e.g., "face," "house," or "neutral") presented prior to b-CFS reduced suppression time for congruent images, while also increasing suppression times for incongruent images (Pinto et al., 2015). This finding holds for both high-level categories (e.g., chairs, cats, guitars, people), as well as low-level visual information (e.g., Gabor orientation; Stein & Peelen, 2015).

In the experiments reported here, we explored whether global/local attentional scope setting, a contextual or endogenous factor, could influence the detection of initially invisible face images. Given that a global attentional scope increases both the efficiency and strength of holistic face processing during visible viewing conditions (Gao et al., 2011; Hills & Lewis, 2009; Macrae & Lewis, 2002), and that attention can operate without awareness to influence object processing (Chou & Yeh, 2012), we predicted that a global attentional scope would speed the conscious detection of initially invisible faces, relative to an local scope. This prediction is further supported by studies showing that the extraction of global image features is possible without awareness (Kaunitz, Fracasso, Lingnau, & Melcher, 2013; Wang, Weng, & He, 2012). Specifically, intact illusory Kanisza figures break from suppression faster than their nonillusory, misaligned counterparts (Wang et al., 2012; but see Moors, Wagemans, van Ee, & de-Wit, 2015, for an alternative interpretation). By the same token, moving dot ensembles containing coherent radial motion were more accurately detected in CFS than dot ensembles containing random motion (Kaunitz et al., 2013). With respect to higher-level stimuli, pairs of objects positioned in typical arrangements (e.g., a mirror above a sink) emerged from CFS faster than the same objects positioned in atypical arrangements (Stein, Kaiser, & Peelen, 2015). Taken together, the results of these previous studies motivated our prediction that a global attentional scope setting would accelerate conscious awareness of otherwise invisible faces, relative to a local scope.

Experiment 1

To modulate an observer's attentional scope setting, we employed a Navon letter task (Gao et al., 2011; Macrae & Lewis, 2002; Navon, 1977; Stevenson, Sun, Hazlett, Cant, Barense & Ferber, 2016). Specifically, observers viewed hierarchical, composite letter images depicting a large global letter, comprised of smaller local letters. Prior to the start of each block, observers were presented with an on-screen cue (e.g., "Focus on the big [small] letter") directing them to attend either to the global or local letter(s) in the Navon images. In a single trial, observers were sequentially presented with two Navon letters and judged whether the letters were the same or different, at either the global or local level. Past work has shown that this type of task modulates attentional scope settings, which can influence performance on a subsequent task (Gao et al., 2011; Macrae & Lewis, 2002; Stevenson et al., 2016). Thus, we interleaved Navon letter trials with the critical CFS trials in which a face image was presented to one eye and a dynamic Mondrian mask was presented to the other eye (see Figure 1A, B). We predicted that when observers attended to the global Navon letters, attentional scope would be biased to take a global setting, and thus speed the subsequent detection of invisible CFS faces, relative to when observers attended to the local Navon letters.

However, if such an effect were observed, an alternative explanation could be that of partial awareness (Kouider & Dupoux, 2004). Specifically, it could be the case that attentional scope does not modulate the suppression time for faces per se, but rather accelerates feature detection, as images begin to partially emerge from CFS. To address this issue, past b-CFS studies have employed a nonrivalrous control task (Jiang et al., 2007; but see Stein, Hebart, & Sterzer, 2011; Stein & Sterzer, 2014) in which the stimulus-of-interest and the Mondrian are presented to both eyes. The contrast of the face image gradually increases, eventually becoming visible for detection (see Figure 1C). This type of control task mimics the appearance and task demands of b-CFS without inducing interocular competition. Thus, if adopting a global attentional scope speeds response times to any visual onset, then we might expect to see the same differences mirrored in this control task. Conversely, if attentional scope operates without awareness to resolve the visual ambiguity present in the b-CFS condition, then we would expect to see differences only in the rivalrous b-CFS condition, and not in the nonrivalrous control task, which only involves simple detection.

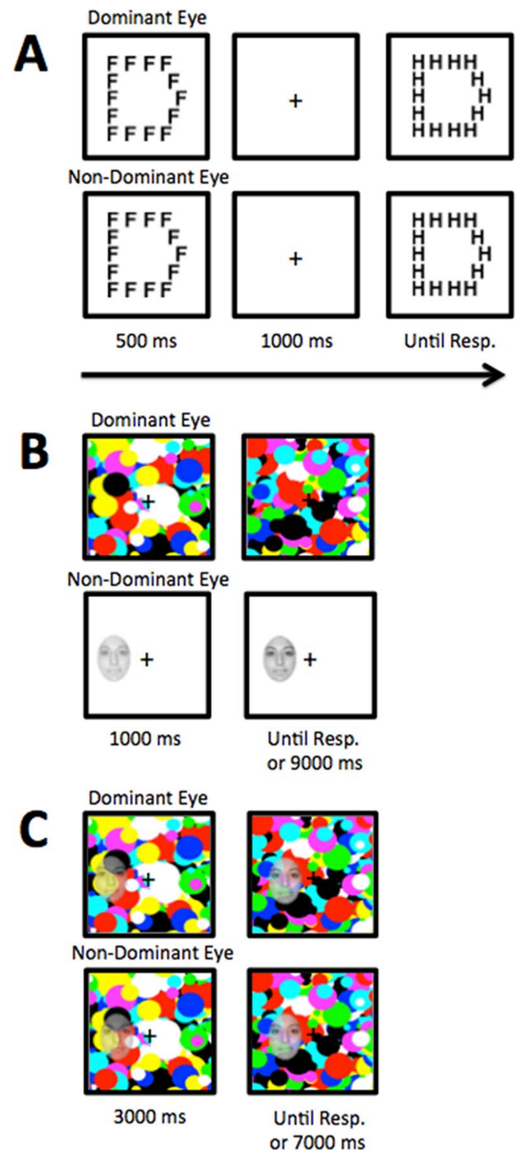

Figure 1. Trial schematics. (A) Navon trial: Two hierarchical Navon letters were presented sequentially. Observers respond to indicate whether the first letter was the same as or different from the second letter based on attention to either the global or local letter. Here, the global letters are the same, while the local letters are different. (B) CFS upright face trial: Mondrian images presented to the dominant eye are updated at a rate of approximately 10 Hz. The face image appears to either the left or right of fixation. Face images are initially invisible, and then break into awareness. Participants respond to indicate if the face is to the left or right of fixation. (C) Nonrivalrous control trial: Both the face and Mondrian are presented to both eyes, which does not induce interocular competition.

Method

Participants

Fifteen individuals (11 female, four male; 12 right-handed; nine right-eye dominant) with a mean age of 19.8 years (range: 17–24 years) participated in Experiment 1. Three participants reported having a diagnosis of astigmatism and had difficulty maintaining stable binocular fusion and these individuals were excluded from further analysis. The remaining 12 participants reported normal or corrected-to-normal visual acuity and normal color vision. Participants provided written informed consent in accordance with the Declaration of Helsinki and received partial course credit as compensation. Procedures were approved by the University of Toronto Research Ethics Board. Participants were assessed for eye dominance using the Miles method (Miles, 1929, 1930).

Stimuli and apparatus

Stimuli were presented using MATLAB (MathWorks, Natick, MA) with the Psychophysics Toolbox (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997) on a 36×27 cm CRT monitor with a resolution of 1280×960 pixels and a refresh rate of 75 Hz. Viewing distance was held constant at 30 cm and head position was secured with a chinrest. To allow for presentation of separate images to each eye, stimuli were viewed through a monitor-mounted four-mirror stereoscope (ScreenScope; ASC Scientific, Carlsbad, CA).

All stimuli were presented on a uniform white background and were contained within a black frame subtending approximately $10.7° \times 10.7°$ of visual angle to facilitate stable binocular fusion. Navon composite letter stimuli consisted of large global letters comprised of smaller local letters. Sixteen unique Navon letter images were created by combining the letters D, E, F, and H (black Helvetica bold font) in all possible global-to-local combinations. Each local letter subtended approximately $1.5° \times 1.8°$ of visual angle, while each global letter subtended approximately $10° \times 10°$ of visual angle. Face stimuli consisted of 10 unique images of Caucasian faces (five female, five male) with neutral expressions selected from the Center for Vital Longevity Face Database (Minear & Park, 2004). Faces were presented in grayscale and cropped using an oval mask subtending approximately $2.1° \times 2.6°$ visual angle. Mondrians were generated using MATLAB by randomly overlaying colored circles of various sizes (see Stein, Hebart et al., 2011). Each Mondrian image subtended approximately $10.7° \times 10.7°$ of visual angle to fit into the black frame as described above.

Design and procedure

Experiment 1 employed a fully within-subject 2×2 design with factors of attentional scope (global vs. local) and trial type (CFS vs. control). All experimental manipulations were blocked (for a total of four blocks) with block order counterbalanced between observers, with the restriction that the two global blocks and the two local blocks were consecutively presented. Within each block, observers were always presented with three Navon letter trials in a row, followed by one CFS or control trial. As such, there were three times as many Navon trials as CFS or control trials in order to maximize the strength of the attentional scope manipulation. In total, each block consisted of 90 Navon letter trials and 30 CFS or control trials.

Prior to the start of each block, the positions of the stereoscope mirrors were calibrated for each observer to ensure stable binocular fusion. Calibration began with the presentation of a blue frame ($10.7° \times 10.7°$ of visual angle) to one eye and a gray square ($8.7° \times 8.7°$ of visual angle) to the other eye. Observers adjusted the position of the stereoscope mirrors until the square fit perfectly within the blue frame. Next, observers were presented with a random-dot stereogram. Upon proper stereoscope calibration, observers would perceive a three-dimensional square projected outward from the screen. The block would begin when observers successfully reported seeing the three-dimensional square (see Mudrik, Breska, Lamy, & Deouell, 2011). All blocks began with a cue (e.g., "Focus on the big [small] letter") directing observers to attend either to the global or local letter(s) in the Navon images.

On Navon letter trials, identical stimuli were presented to each eye; thus, all Navon displays were fully visible and did not induce interocular competition. Navon letter trials began with a 500 ms central fixation cross, followed by removal of the cross and the central presentation of a single, randomly selected Navon letter for 500 ms. After a 1000-ms interstimulus interval, a second Navon letter was presented centrally until response. The second Navon letter could be either same or different from the initially presented letter at the attended level (global or local). Observers responded with middle and index fingers of their left hand on the S and D keys to indicate if the two letters were same or different, respectively. The letters at both the attended and unattended levels were the same on 50% of all trials (see Figure 1A).

CFS trials began with a 500 ms central fixation cross, followed by the presentation of Mondrian masks to the dominant eye, and a face image to the nondominant eye. A new Mondrian image was presented every 100 ms, resulting in a flicker of approximately 10 Hz. The face image was randomly presented to either the left or right of fixation and the center of the face image deviated approximately 2° of visual angle from fixation. The face image smoothly increased in contrast from 0%–100% for the first 1000 ms, and then remained at full contrast until response, or up to a limit of 10,000 ms (i.e., 1000 ms of increasing contrast, plus 9000-ms of full contrast if no response is made). This initial gradual increase in contrast is to facilitate suppression of the stimulus-of-interest and is typical in CFS experiments. Observers responded with the index and middle fingers of their right hand on the left and right arrow keys to indicate the position of the face (see Figure 1B). Initially, observers do not consciously perceive the face; thus, they are unable to report its location. After the face breaks from CFS, observers make a speeded response to report the location of the face; thus, response time (RT) on the b-CFS task can be used as an estimate of suppression time.

Control trials began with a 500-ms fixation cross, followed by presentation of both the Mondrian and face stimuli to both eyes (presentation of identical images to both eyes does not induce interocular competition). While the presentation of the Mondrians was identical to CFS trials, the face image faded in at a slower rate and did not reach full contrast. Specifically, face images increased in contrast from 0%–30% for the first 3000 ms, then remained at 30% contrast until response, or up to a limit of 10,000 ms. This slower contrast ramp was chosen to match the typically reported suppression times for faces (Jiang et al., 2007; Stein, Hebart, & Sterzer, 2011). On control trials, the observers' task was identical to the CFS trials (see Figure 1C).

Results and discussion

Navon letter task

Since we used the Navon letter task to manipulate attentional scope (with different predictions for global versus local scope settings), it was important to design the Navon task to produce ceiling-level performance, such that the results of the CFS and control tasks would not be confounded with difficulty on the Navon task. We achieved this aim, as observers performed very well, averaging 97% correct overall (see Appendix 1 for descriptive statistics for all Navon letter conditions). Furthermore, accuracy for matching Navon letters did not differ between the global and local blocks, $t(11) = 0.49$, $p = 0.63$, $d = 0.14$, nor did RT, $t(11) = 0.53$, $p = 0.61$, $d = 0.15$.

CFS and control tasks

Accuracy was calculated as the proportion of trials in which observers correctly reported the location of the face image (left or right) within 10,000 ms of trial onset. RTs for correct trials that were greater than 2.5 standard deviations than the mean were excluded for each observer and for each condition. Furthermore, RTs were log transformed to correct for the positive skew of the RT distribution. All statistical analyses were conducted on log(RT), while all figures and tables display raw RT values to facilitate interpretability. Performing the same statistical analyses on the raw RT values does not qualitatively change the results and thus will not be discussed further. Accuracy and RT for the CFS and control tasks were analyzed using a 2×2 repeated measures analysis of variance (ANOVA) with factors of attentional scope (global vs. local) and trial type (CFS vs. control; see Table 1 for descriptive statistics).

	Accuracy		Detection time (ms)	
Condition	Mean	*SEM*	Mean	*SEM*
Global, CFS	0.95	0.02	2327	341
Local, CFS	0.89	0.05	2859	436
Global, control	0.99	0.01	2796	147
Local, control	0.97	0.01	2867	154

Table 1. Descriptive statistics for all conditions in Experiment 1. Statistical analyses were conducted on log(RT) values, while the raw RT values are presented here to enhance interpretability.

Accuracy was found to be uniformly at ceiling across all conditions (>89%). Furthermore, the ANOVA revealed no significant main effects or interaction for accuracy (all $ps > 0.05$). For RTs, suppression time in the CFS trials were not different from detection times in the control trials, which resulted in a nonsignificant main effect of trial type, $F(1, 11) = 2.89$, $p = 0.12$, $\eta^2_p = 0.20$. Overall, responses were numerically faster in blocks in which observers attended to the global Navon letters, relative to the local Navon letters, which resulted in a trending main effect of attentional scope, $F(1, 11) = 4.47$, $p = 0.058$, $\eta^2_p = 0.29$. Critically, these main effects were qualified by a significant Trial Type × Attentional Scope interaction, $F(1, 11) = 4.99$, $p < 0.05$, $\eta^2_p = 0.31$. Consistent with our predictions, follow-up paired t tests revealed that faces broke from CFS more quickly in the global condition, relative to the local condition, $t(11) = 2.42$, $p < 0.05$, $d = 0.70$. Importantly, this difference between attentional scope conditions was not observed in the nonrivalrous control condition, $t(11) = 0.59$, $p = 0.57$, $d = 0.17$. These results support our hypothesis that a global attentional scope setting can facilitate the conscious detection of initially invisible faces (see Figure 2).

Experiment 2

In Experiment 2, we investigated whether the facilitation of conscious face detection by a global attentional scope was indeed specific to faces, providing further support of the results of the first experiment. In Experiment 1, our data suggested that modulation of face suppression time in b-CFS was owing to the specific attentional scope of the observers and not due to a

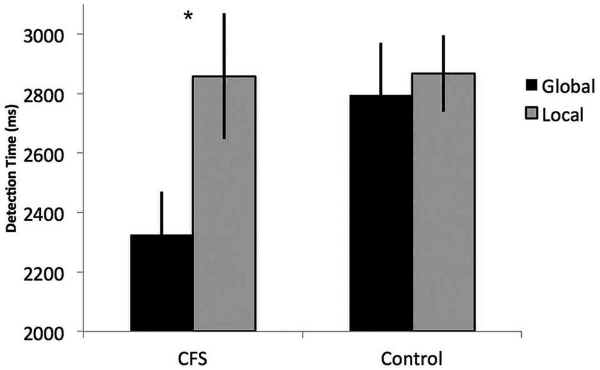

Figure 2. Results of Experiment 1. Under a global attentional scope, faces break from CFS faster, relative to a local scope (* = $p < 0.05$). Attentional scope does not modulate face detection in the nonrivalrous control condition. Error bars represent 1 *SEM* calculated from within-subject variability (c.f., Cousineau, 2005). Statistical analyses were conducted on log(RT) values, while the raw RT values are presented here to facilitate interpretability.

difference in detecting visual onsets in general, evidenced by the null effect in the nonrivalrous control condition (coupled with the significant interaction). However, Stein, Hebart, and Sterzer (2011) and Stein and Sterzer (2014) have recently argued that this type of control condition does not necessarily measure the same decision processes as b-CFS by showing that RT distributions are more variable for b-CFS, relative to control. Furthermore, posttest interviews reveal that most observers are able to subjectively distinguish between these two conditions.

Based solely on the data from Experiment 1, it could also be the case that a global attentional setting aids in the conscious detection of any type of object that is initially CF-suppressed, and that the effect under consideration is category-general (i.e., not face-specific). Related to this issue, past studies have shown that the face and body inversion effects in b-CFS tasks are indeed specific to images of human faces and bodies, respectively. For instance, Zhou, Zhang, et al. (2010) showed that while upright faces break from suppression faster than inverted faces, upright and inverted house images did not differ in CFS breaking time. Similarly, Stein and colleagues (2012) have shown that both upright faces and bodies break from suppression more quickly than their inverted counterparts, but the same effect is not observed for images of chairs. Given the above findings, the notion that the face inversion effect is thought to be driven by holistic processing (Farah, Tanaka, & Drain, 1995), and that under visible viewing conditions a global attentional scope strengthens holistic face processes (Gao et al., 2011), we predicted that the effect we observed in Experiment 1 would be specific to upright faces.

To explicitly test this prediction, in Experiment 2 we used the same b-CFS condition with upright face images, as in Experiment 1, but included two additional b-CFS control conditions with images of inverted faces and upright houses in place of the nonrivalrous control condition. For upright faces, we expected to replicate the results of Experiment 1 in that a global attentional scope would reduce suppression time, relative to a local scope. Importantly, if such an effect were specific to upright faces, then we would expect to see either no effect for the other two stimulus classes, or the opposite effect. Indeed, it could be the case that adopting a local attentional scope would aid in detection of initially invisible inverted faces or upright houses, as many categories of nonface/nonbody objects are processed in a parts-based manner (Gauthier & Tarr, 1997; Gauthier, Williams, Tarr, & Tanaka, 1998; Maurer et al., 2002).

Method

Participants

A new sample of 32 individuals (23 female, nine male; 29 right-handed; 19 right-eye dominant) with a mean age of 20.5 years (range: 18–32 years) participated in Experiment 2. All participants reported normal or corrected-to-normal visual acuity and normal color vision. Participants provided written informed consent in accordance with the Declaration of Helsinki and received partial course credit as compensation. Procedures were approved by the University of Toronto Research Ethics Board.

Stimuli and apparatus

All details regarding stimulus presentation, the Navon letter trials, and the b-CFS trials with faces were identical to Experiment 1. In Experiment 2, the nonrivalrous control condition was replaced with two additional b-CFS control conditions, consisting of images of inverted faces and upright houses (see Figure 3). Inverted face images were generated by rotating the 10 unique upright face identities by 180° in orientation. Ten unique images of houses were retrieved from the internet through a Google image search, converted to grayscale, and enclosed in an oval mask subtending approximately 2.1° × 2.6° of visual angle. All other details of the b-CFS control conditions were identical to those in the b-CFS upright face condition in Experiment 1.

Design and procedure

Past CFS studies have reported that suppression time typically decreases throughout the course of an experimental session (Heyman & Moors, 2014; Stein, Hebart, & Sterzer, 2011). We confirmed this observation in a pilot experiment in which observers completed 120 b-CFS trials in a single experimental session and

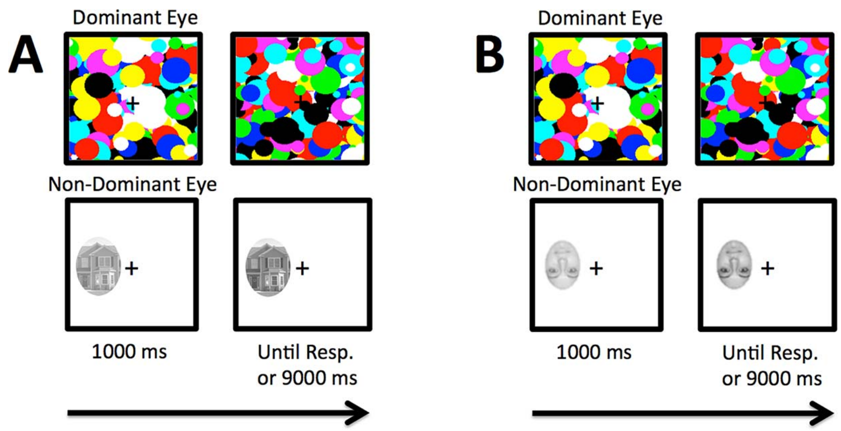

Figure 3. Trial schematics. (A) CFS upright house trial: Mondrian images presented to the dominant eye are updated at a rate of approximately 10 Hz. The house image appears to either the left or right of fixation. House images are initially invisible, and then break into awareness. Participants respond to indicate if the house is to the left or right of fixation. (B) CFS inverted face trial: Face images from the upright face condition are rotated 180° in orientation and presented in an otherwise identical b-CFS task.

the suppressive strength of CFS decreased until stimuli broke almost instantaneously in the final 30 trials. Such a phenomenon is likely due to the visual system adapting to CFS with repeated exposure. Thus, because Experiment 2 involved running three b-CFS conditions (rather than just one, as in Experiment 1), we ran one of our manipulations as a between-subjects factor in order to maintain a reasonable level of CFS strength throughout a given experimental session. Specifically, Experiment 2 employed a mixed 2 × 3 design with a within-subject factor of attentional scope (global vs. local) and a between-subjects factor of object type (upright face vs. inverted face vs. upright house). Ten observers were randomly assigned to each of the upright face or house conditions, while 12 observers were assigned to the inverted face condition. In contrast to Experiment 1, we also ran an additional 30 Navon letter trials and 10 b-CFS trials per block for a total of 120 Navon and 40 b-CFS trials in each condition/block. All other design and procedural details were identical to those used in Experiment 1.

Results and discussion

Navon letter task

As in Experiment 1, observers performed well on the Navon letter task averaging 98.2% correct overall. Furthermore, accuracy for matching Navon letters did not differ between the global and local blocks, $t(31) = 1.32$, $p = 0.20$, $d = 0.23$, nor did RT, $t(31) = 1.08$, $p = 0.29$, $d = 0.19$.

CFS tasks

For the b-CFS task, accuracy and RT were subject to the same calculation and preprocessing procedures as in Experiment 1. Both accuracy and RT from the b-CFS task were analyzed using a 2 × 3 mixed ANOVA with a within-subject factor of attentional scope (global vs. local) and a between-subjects factor of object type (upright face vs. inverted face vs. upright house; see Table 2 for descriptive statistics).

For accuracy, the ANOVA revealed no significant main effects or interaction (all ps > 0.05) suggesting that observers' ability to report the object positions was uniform across conditions. For RTs, the ANOVA revealed a significant main effect of object type, $F(2, 29) = 3.63$, $p < 0.05$, $\eta^2_p = 0.20$; no significant main effect of attentional scope, $F(1, 29) = 0.35$, $p = 0.56$, $\eta^2_p = 0.01$; and no Scope × Object Type interaction, $F(2, 29) = 0.91$, $p = 0.41$, $\eta^2_p = 0.06$. We explored the main effect of object type using two orthogonal contrasts. Specifically, we found that faces broke from suppression faster than houses, $F(1, 29) = 6.93$, $p < 0.05$, $\eta^2_p = 0.19$, while upright and inverted faces did not differ in suppression time, $F(1, 29) = 0.2$, $p = 0.66$, $\eta^2_p = 0.01$. While this result may seem inconsistent with past studies (Jiang et al., 2007; Stein, Hebart, & Sterzer, 2011, 2012; Zhou, Zhang et al., 2010), it is likely that large individual differences in suppression time strongly reduced power to detect between-subjects differences with b-CFS, and face inversion was run as a between-subjects manipulation, for practical reasons (see Experiment 2, Design and procedure, and General discussion).

In the present experiment, we included house images primarily to examine if attentional scope would modulate suppression time for nonface objects. It did not, but it is important to note that the main effect of object type could be driven by differences in low-level visual properties, which have been shown to exert strong influences on b-CFS results and should be interpreted with caution (Heyman & Moors, 2014;

Condition	Accuracy Mean	Accuracy *SEM*	Detection time (ms) Mean	Detection time (ms) *SEM*
Global, upright face	0.88	0.06	1940	183
Local, upright face	0.87	0.05	2124	176
Global, inverted face	0.90	0.07	1849	168
Local, inverted face	0.89	0.08	1714	161
Global, house	0.87	0.03	3241	193
Local, house	0.80	0.05	3203	195

Table 2. Descriptive statistics for all conditions in Experiment 2. Statistical analyses were conducted on log(RT) values, while the raw RT values are presented here to facilitate interpretability.

Yang & Blake, 2012). Thus we ran a reduced 2 × 2 mixed ANOVA with a within-subject factor of scope (global vs. local) and a between-subjects factor of face orientation (upright face vs. inverted face), to examine results that would not be confounded by low-level stimulus properties. The analysis revealed nonsignificant main effects of orientation, $F(1, 20) = 0.31$, $p = 0.58$, $\eta^2_p = 0.02$, and scope, $F(1, 20) = 0.12$, $p = 0.69$, $\eta^2_p = 0.01$, which were qualified by a trending Scope × Orientation interaction, $F(1, 20) = 3.91$, $p = 0.06$, $\eta^2_p = 0.16$.

Finally, we proceeded with planned follow-up paired *t* tests comparing suppression time between global and local conditions, within each level of object type. Importantly, we found that when observers attended to the global Navon letters, upright faces broke from CFS more quickly than when observers attended to the local letters, $t(9) = 2.54$, $p < 0.05$, $d = 0.80$. This result replicates the findings of Experiment 1 and provides further support that a global attentional scope can facilitate conscious awareness of initially invisible upright faces. Critically, attentional scope did not modulate the speed at which inverted faces, $t(11) = 0.95$, $p = 0.36$, $d = 0.28$, or upright houses broke from CFS, $t(9) = 0.42$, $p = 0.68$, $d = 0.13$. These results, combined with the trending Scope × Face Orientation interaction from the reduced ANOVA, suggest that a global attentional scope facilitates conscious detection of invisible upright faces, relative to inverted faces. Additionally, we find no evidence suggesting that attentional scope modulates suppression times for images of upright houses (see Figure 4).

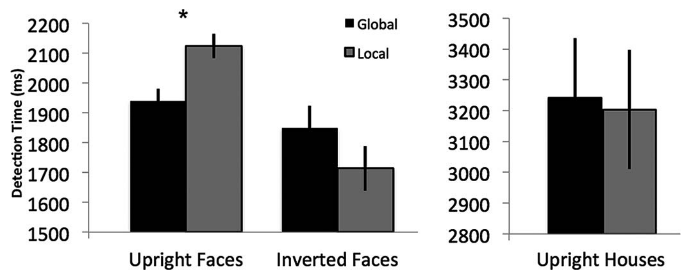

Figure 4. Results of Experiment 2. For upright faces, adopting a global attentional scope accelerates conscious detection, relative to a local scope (* = $p < 0.05$). This finding is an exact replication of the effect found in Experiment 1. Conversely, attentional scope does not modulate conscious detection of CF-suppressed inverted faces or houses. Error bars represent 1 *SEM* calculated from within-subject variability (c.f., Cousineau, 2005). Statistical analyses were conducted on log(RT) values, while the raw RT values are presented here to facilitate interpretability.

General discussion

The present study was designed to test whether attentional scope settings could operate without awareness to facilitate conscious detection of initially invisible images. To this end, we manipulated observers' attentional scopes to assume either a global or local setting using a Navon letter task (Gao et al., 2011; Macrae & Lewis, 2002; Navon, 1977; Stevenson et al., 2016) and then subsequently presented invisible CF-suppressed faces and measured the speed at which these images broke from suppression and became available to conscious awareness. Across two experiments, we provide evidence that a global scope of attention can accelerate the conscious detection of upright faces, relative to a local scope. These findings demonstrate that endogenous attentional scope settings can gate the processing of incoming visual input, fundamentally altering the contents of subjective conscious experience. Furthermore, these results are in line with previous research showing that contextual or endogenous factors can facilitate conscious detection of congruent stimuli (Alsius & Munhall, 2013; Gayet, Van der Stigchel, & Paffen, 2014a; Lupyan & Ward, 2013; Pinto et al., 2015; Salomon, Lim, Herbelin, Hesselmann, & Blanke, 2013; Stein et al., 2015). For instance, when observers listened to a sentence, invisible faces with lip movements congruent with the sentence broke from CFS more quickly than faces with incongruent lip movements (Alsius & Munhall, 2013). Similar multisensory contextual effects have been reported in that an observer's hand position (palm facing up or down) causes an image of a congruent hand (same position as real hand) to break from suppression and reach awareness more quickly than an incongruent hand image (Salomon et al., 2013). Using traditional binocular rivalry, it has also been shown that congruent olfactory (Zhou, Jiang, He, & Chen, 2010) and tactile (Lunghi & Alais, 2013; Lunghi, Binda, & Morrone, 2010) stimulation prolongs the dominance of simultaneously presented congruent visual stimuli. For example, a concurrent rose scent prolonged visual dominance of an image of a rose, and the dominance time of visual gratings was lengthened by the concurrent haptic exploration of a tactile grating of the same orientation (Lunghi & Alais, 2013; Lunghi et al., 2010). Using strictly visual stimuli, it has also been recently demonstrated that word cues can induce expectations that reduce CFS time for congruent images, while also increasing suppression times for incongruent images (Pinto et al., 2015; Stein et al., 2015). These effects have been reported for face and house images (Pinto et al., 2015), as well as a variety of high-level stimulus categories (Stein et al., 2015). Thus, our results add to the growing body of evidence showing that contextual and endogenous factors strongly influence the contents of visual experience by modulating conscious detection of initially invisible stimuli.

To address the possibility that adopting a global attentional scope might speed response times to any visual onset, in Experiment 1 we employed a nonrivalrous control condition, commonly utilized in previous studies to mimic the appearance and task demands of b-CFS without inducing interocular competition (Jiang et al., 2007). Specifically, if CFS times were actually equal across conditions, but observers simply reacted faster to the emergence of face images when adopting a global scope, then differences between global and local attentional scope conditions should also be observed in the nonrivalrous control condition. In contrast, our results showed that detection times were similar between global and local scope conditions in the control task, thus arguing against this alternative explanation.

However, while nonrivalrous control tasks are commonplace in the b-CFS literature (e.g., Jiang et al., 2007; Mudrik et al., 2011; Alsius & Munhall, 2013), their validity has recently been questioned on the grounds that their RT distributions are significantly less variable then those of the b-CFS conditions they are intended to emulate. Thus, in Experiment 2, we removed this condition and utilized two b-CFS control conditions. Specifically, we investigated whether modulation of suppression time by attentional scope setting is specific to upright faces by presenting images of inverted faces and upright houses in otherwise identical b-CFS conditions. We replicated the finding that upright faces broke from suppression faster under a global scope, relative to a local scope, and we did not observe this difference for inverted faces or upright houses. Furthermore, the degree to which attentional scope modulated suppression time was greater for upright faces than inverted faces. However, as we did not observe an Attentional Scope × Object Type interaction including houses, we cannot conclude that the effect is stronger for upright faces than houses. Additionally, the between-subjects variability of the attentional scope effect was much greater with houses than faces (see Figure 4). This suggests that many participants did show either a benefit or cost of global attentional scope on house suppression times, despite the lack of a reliable condition-level difference. Future research is needed to explore the sources of these individual differences.

Unlike most previous b-CFS experiments involving face inversion, we did not find that upright faces broke from suppression faster than their inverted counterparts with our between-subjects design (Jiang et al., 2007; Stein, Hebart, & Sterzer, 2011, 2012; Zhou, Zhang et al., 2010). The likely explanation is that due to large individual differences in CFS time, the b-CFS paradigm is most conducive to detecting within-subject differences, where individual differences can be partitioned out and separated from error variance. Indeed, all previous studies reporting b-CFS face inversion effects included face orientation as a within-subject factor. For practical concerns, we ran face orientation as a between-subjects factor (see Experiment 2, Design and procedure), thus limiting our power to detect an inversion effect. However, we do not see our work as inconsistent with past studies. Indeed, our goal was not to replicate the b-CFS face inversion effect, but to examine whether attentional scope can modulate suppression time. Thus, we designed our experiments to always include attentional scope as the within-subject factor, maximizing our power to detect the contrast of interest.

Relevant to our findings, Zhou, Zhang et al. (2010) have reported that upright faces break from CFS faster than inverted faces, but the same inversion effects are not observed with house images. Other studies have also found inversion effects with images of both faces and human bodies in b-CFS, while also reporting no inversion effect with images of chairs (Stein et al., 2012). Given that inversion is thought to disrupt holistic processes (Farah et al., 1995), and that a global attentional scope increases the magnitude of holistic face processing (Gao et al., 2011), our results are consistent with these past studies. Our findings are also consistent with the idea that holistic or integrative processing is possible without conscious awareness, which is explicitly predicted by the unconscious binding hypothesis (Lin & He, 2009). While many current theories of conscious awareness assert that integration is one of the hallmarks of subjective conscious experience (Baars, 2005; Dehaene & Naccache, 2001; Tononi & Edelman, 1998; Tononi & Koch, 2008), the unconscious binding hypothesis posits that multiple sensory inputs that are separated both spatially and temporally can be bound into coherent perceptual units, even when such inputs are presented without awareness. This view is supported by several recent studies; for instance, Mudrik and colleagues (2011) have demonstrated that relationships between foreground objects and background scenes can be processed without awareness (Mudrik & Koch, 2013; for a review, see Mudrik, Faivre, & Koch, 2014). Furthermore, intact Kanizsa figures, which integrate to form illusory contours, break from suppression faster than nonintact figures (Wang et al., 2012, but see Moors et al., 2015). With respect to more complex stimuli, as stated previously, upright faces break from suppression faster than inverted faces, with inversion known to disrupt holistic processing (Jiang et al., 2007; Stein et al., 2012; Zhou, Zhang et al., 2010). Finally, pairs of objects positioned in typical arrangements (e.g., a mirror above a sink) emerged from CFS faster than the same objects positioned in atypical arrangements (Stein et al., 2015). Taken together, these studies demonstrate that integrative processing of multiple visual inputs reduces suppression time, and supports the idea that binding is possible without awareness (Lin & He, 2009; Mudrik et al., 2014). Given these past results, it is tempting to conclude that our global attentional scope manipulation increased the holistic processing of unconsciously presented faces, which resulted in shorter CFS times. Although our data are consistent with this interpretation, recent papers have questioned the degree to which differences in b-CFS times can be used to draw conclusions regarding unconscious processing (Stein, Hebart et al., 2011; Stein & Sterzer, 2014). While many early b-CFS papers did arrive at such conclusions, it is now argued that CFS tasks must involve indefinite suppression of the stimulus-of-interest for such conclusions to be made (Sterzer, Stein, Ludwig, Rothkirch, & Hesselmann, 2014; Stein, Thoma, & Sterzer, 2015). Thus, a potential avenue for future research would be to first manipulate attentional scope and then measure the neural response to faces rendered permanently invisible, which would allow for stronger conclusions on how attentional scope affects unconscious processing.

To what extent are our effects driven by a processing bias towards low-level physical properties of the stimuli? Between the global and local conditions, we presented identical images, thus any pairwise comparisons between these conditions are not confounded by low-level stimulus differences. While there are certainly large differences in low-level properties between faces and houses, we also manipulated face orientation through inversion, thereby holding low-level properties constant for this factor. Thus, our finding that attentional scope modulates suppression times for upright, but not inverted faces shows that these effects likely result from processing in later stages of the visual hierarchy. Related to these issues, there is a rich literature investigating the link between attentional scope and the processing of spatial frequency information. Classical work has shown that a global attentional scope facilitates processing of low spatial frequency information (Shulman, Sullivan, Gish, & Sakoda, 1986; Shulman & Wilson, 1987). More recent work suggests that holistic face perception seems to also rely heavily on such information (Goffaux & Rossion, 2006), and that perhaps the effect of Navon letter processing on face perception is simply a perceptual aftereffect of adapting to the high spatial frequency content of the initially presented Navon letter images (Hills & Lewis, 2009). Thus, in our experiments, it is possible that exposure to Navon letters asymmetrically biases processing toward the lower spatial frequencies, thus facilitating conscious access to images with higher power at these frequencies. Our results do not preclude this explanation, nor is it inconsistent with our conclusions. Specifically, if global/local attentional scope is better characterized as simply a bias toward one end of the spatial frequency spectrum, then such biases that are acquired during exposure to Navon letters can also operate without awareness to boost congruent information into conscious awareness. This interpretation could be tested in the future by examining the effect of directly manipulating the spatial frequency content of priming images on the subsequent presentation of invisible target images. Such studies might also help to generalize the current results from faces to other categories of stimuli, depending on spatial frequency content. Related to the current discussion, Stein and colleagues (2015) have shown that endogenous expectations can boost perceptual sensitivity for congruent stimuli. Specifically, a predictive word cue (e.g., "horizontal") decreased contrast sensitivity thresholds for subsequently presented Gabor patches of a consistent orientation, which could be the mechanism for the facilitative effects of expectations on CFS times. Based on this finding, a global attentional scope might modulate suppression time by increasing perceptual sensitivity, but primarily for low spatial frequency images. Thus, another avenue for future research would be to manipulate attentional scope, and then examine contrast sensitivity thresholds at various spatial frequencies.

In conclusion, our results demonstrate that attentional scope settings can modulate the availability of information to conscious awareness. More specifically, adopting a global attentional scope can facilitate the conscious detection of upright face images, relative to a local scope. Furthermore, this effect is unlikely to be explained by general detection speed, and is also not observed when faces are inverted or replaced with images of upright houses. This work highlights the importance of how dynamic, endogenous attentional states can influence the content and quality of subjective visual experience.

Keywords: attentional scope, visual attention, face perception, conscious detection, visual awareness, continuous flash suppression

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