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Did you see it? Robust individual differences in the speed with which meaningful visual stimuli break suppression

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ABSTRACT

Perceptual conscious experiences result from non-conscious processes that precede them. We document a new characteristic of the cognitive system: the speed with which visual meaningful stimuli are prioritized to consciousness over competing noise in visual masking paradigms. In ten experiments ($N = 399$) we find that an individual's non-conscious visual prioritization speed (NVPS) is ubiquitous across a wide variety of stimuli, and generalizes across visual masks, suppression tasks, and time. We also find that variation in NVPS is unique, in that it cannot be explained by variation in general speed, perceptual decision thresholds, short-term visual memory, or three networks of attention (alerting, orienting and executive). Finally, we find that NVPS is correlated with subjective measures of sensitivity, as they are measured by the Highly Sensitive Person scale. We conclude by discussing the implications of variance in NVPS for understanding individual variance in behavior and the neural substrates of consciousness.

And then, you suddenly become aware: it might be of a child running into the road in front of your car, your friend walking on the other side of the street, or a large spider on your shoe. On the timeline that stretches between non-conscious processes and the conscious experiences that emerge from them, this paper focuses on the moment in which your visual conscious experiences begin: *just* when you become aware of the child, your friend or the spider. Before this moment visual processing is strictly non-conscious; after this point a mix of conscious and non-conscious processing ensues, influencing behavior, broadly defined.

Three prevalent theories describe the processes that precede conscious experiences. According to Global Neural Workspace, conscious experiences occur when activation in the occipito-temporal cortex reaches higher association cortices, in which it is amplified and broadcasted to the rest of the brain through long distance reverberation (e.g., Dehaene, Changeux, Naccache, & Sergent, 2006). Integrated Information Theory, on the other hand, argues that for sensory information to be consciously experienced it must be integrated with currently active information in the brain (Tononi, 2008; for reviews see Dehaene, Charles, King, & Marti, 2014; Tononi & Koch, 2015). Finally, Local Ignition theories suggest that a "local ignition", a stable recurrent pattern of neuronal activity, often in the relatively early perceptual layers of the cortex, is closely associated with conscious perception (Malach, 2007; Noy et al., 2015; Zeki, 2003).

These frameworks hold, then, that (i) the process of rendering information conscious takes time, and that (ii) only a (small) subset of the information that is processed by our brains becomes conscious (see, Cohen, Dennett, & Kanwisher, 2016; Dehaene et al., 2006; Libet, 2009; Sergent, Baillet, & Dehaene, 2005; Wu & Wolfe, 2018). These characterizations mean that the lay belief, which holds that when we open our eyes we instantaneously see everything that is in front of us, is doubly wrong. Conscious experiences are not immediate, and the process is selective.

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This limited nature of conscious experiences compared to our overall sensory processing implies that the brain prioritizes information for consciousness.[1] Indeed, in recent decades research of prioritization processes found that both low-level visual features such as contrast, and higher-level cognitive determinants such as expectations, motivations, and semantic content, influence prioritization (e.g., Abir, Sklar, Dotsch, Todorov, & Hassin, 2018; Balcetis, Dunning, & Granot, 2012; Sklar et al., 2012; Stein, Sterzer, & Peelen, 2012; Zeelenberg, Wagenmakers, & Rotteveel, 2006).

Here we begin exploring a here-to-fore neglected aspect of prioritization – individual variability. An examination of the major theories of consciousness quickly reveals that they are silent regarding individual differences. This silence implies that individual variation in prioritization is either non-existent or lies outside the scope of theories of consciousness. The existing empirical literature concurs: to the best of our knowledge, no published research examined general individual differences in prioritization.

In this paper we propose that there are meaningful differences in how quickly we become aware of visual stimuli (Non-conscious Visual Prioritization Speed; NVPS). We suggest that these differences are *general, ubiquitous and unique*. NVPS is *general* in that it characterizes performance in various tasks; NVPS is *ubiquitous* in that it can be found for many types of stimuli, and NVPS is *unique*, in the sense that it is largely independent of similar cognitive traits such as general speed of processing, perceptual decision threshold, attentional networks, and short-term memory.

Individual variability is a potent source for theoretical development which allows one to test possible links between phenomena within and across levels of analysis (Bolger, Zee, Rossignac-Milon, & Hassin, 2019). For example, examining individual variability helped establish the independent nature of attentional networks (e.g., Fan, McCandliss, Sommer, Raz, & Posner, 2002), and the degree to which different executive function tasks measure the same (vs. different) construct (thus leading to the identification of core executive functions; Miyake & Friedman, 2012). Individual variability is also a potent tool in identifying neural substrates of cognition (e.g., Kleinschmidt, Sterzer, & Rees, 2012) potentially leading to better understanding of both cognition and the brain (e.g., Wimmer & Shohamy, 2012).

1. The paradigms

The scientific study of consciousness within cognitive psychology and cognitive neuroscience relies heavily on masking paradigms that use visual noise to block percepts from breaking suppression. These techniques allow scientists to map brain networks and activation patterns that are associated with conscious vs. non-conscious perception (e.g., Dehaene et al., 2006; Kouider et al., 2013; Noguchi, Yokoyama, Suzuki, Kita, & Kakigi, 2012; Sterzer, Jalkanen, & Rees, 2009; Suzuki, Noguchi, & Kakigi, 2015). They also allow for an exploration of conscious vs. non-conscious processes (e.g., inhibitory control; van Gaal, Ridderinkhof, Fahrenfort, Scholte, & Lamme, 2008; face adaptation; Moradi, Koch, & Shimojo, 2005). Given the prevalence of masking in the literature, we begin the foray into individual differences using such paradigms.

The main paradigm we employ is breaking continuous flash suppression (bCFS; Tsuchiya & Koch, 2005). In bCFS, a stimulus is presented to one eye while a dynamic mask is presented to the other eye (see Fig. 1). Participants are asked to respond via key press when they become aware of (any part of) the target stimulus. This reaction time is our measure of participants' NVPS.

bCFS is particularly suited for assessing prioritization for two reasons (e.g., Nakamura & Kawabata, 2018; Yang, Zald, & Blake, 2007). First, it allows subliminal presentations that can last seconds, enabling lengthy non-conscious processing. Second, bCFS measures spontaneous emergence into awareness, focusing on the moment in which a previously non-conscious stimulus becomes conscious.[2] To examine the robustness within bCFS, we use two different types of masks in CFS studies – colorful Mondrians and grey-scale stimuli that contain unusually-shaped numbers (see Fig. 1 panels a and b).

Crucially, to examine generality we use a new long duration masking technique that we have recently introduced, Repeated Mask Suppression (RMS; Abir & Hassin, 2020). In RMS, a target stimulus is presented to both eyes, and it is temporally interleaved with a mask (see Fig. 1 panel c). The phenomenology of doing RMS is similar to that of CFS – initial experience of the masks is followed by the target stimulus (or parts of it) spontaneously emerging into consciousness. RMS has been used to replicate robust CFS findings (e.g., face inversion; face dimension; see Abir & Hassin, 2020). Naturally, the process that blocks consciousness in RMS is not binocular rivalry, but rather competition of visual stimuli over time.

It is important to note, that our choice to explore individual differences with the widely used paradigm of masking, allows us to examine only a narrow meaning of *prioritization*. Namely, prioritization of meaningful stimuli in the face of competing visual noise. Prioritizing in this narrow sense does not necessarily require a process that assigns values to non-conscious representations. Rather, it may be implemented in the architecture of the cognitive system or in early bias in the interplay between meaningful visual stimuli and noisy masks. This bias results in (or implements) priorities (consider, e.g., the various ways in which the visual system prioritizes information from the fovea over information from the periphery; or the lack of a centralized selecting process in *natural selection*). We further discuss these alternative instantiations of *prioritization* in the General Discussion.

2. Overview

Ten experiments document large, consistent and robust differences in NVPS that are stable at least over short periods of time (Experiment 7). We address *generality* by showing strong correlations between bCFS and bRMS: participants who are fast prioritizers in one paradigm are also fast when tested using the other (Experiment 3a) and between different types of masks in bCFS (Experiment 3b). We demonstrate *ubiquity* by examining a wide variety of stimuli, including words (Experiment 2), numbers (Experiment 5), faces (Experiments 3, 3b, 4 and 6), and emotional expressions (Experiment 1). The issue of *uniqueness*, that is – our claim that NVPS is largely independent from relevant cognitive traits, is addressed in multiple experiments establishing that NVPS cannot be explained by variation in conscious cognitive speed (Experiment 4), perceptual threshold (Experiment 5), visual short-term memory (Experiment 6), and the efficacy of alerting, orienting and executive attention (Experiment 7). Finally, we find that differences in NVPS are moderately correlated with self-reported differences in sensitivity in the richness of experience (Experiment 8). Based on these results we conclude that NVPS is a robust trait, that affords new possibilities to advance our understanding of non-conscious processes, consciousness, and the related brain mechanisms.

[1] The other logical possibility, that all contents of conscious experiences are stochastically determined, is unlikely given the adaptive advantage of allocating processing resources to stimuli that are important for one's current concerns.

[2] There are disagreements regarding the interpretation of breaking time differences (e.g., Gayet, Stein, & Peelen, 2019; Stein, Hebart, & Sterzer, 2011). Although these issues are less relevant to individual differences experiments, in which all participants respond to the same stimuli, we address them directly in multiple experiments by using more than one task (Experiment 3), and by testing the relationship between NVPS and (conscious) cognitive speed and perceptual threshold (Experiments 4 & 5).

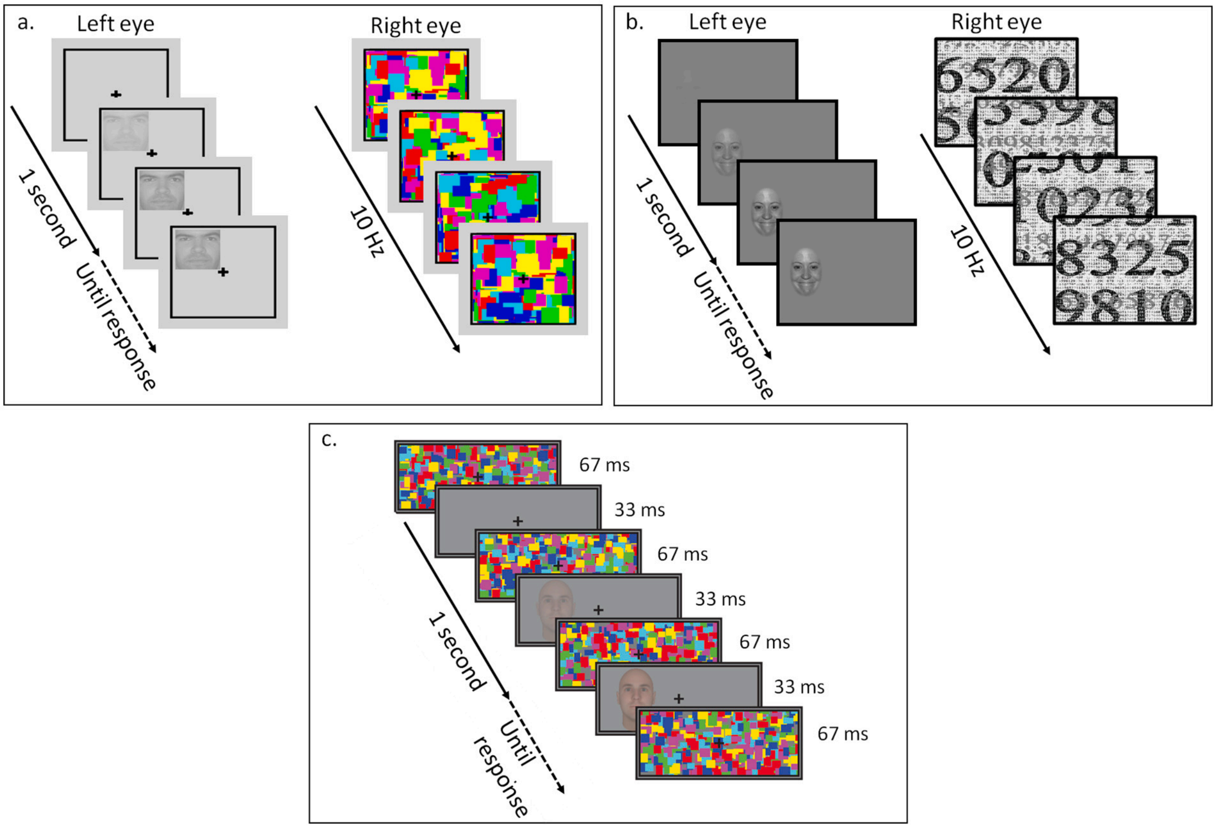

Fig. 1. (a). Example of bCFS. A static stimulus, fading in over time, is presented to the left eye, while colorful Mondrians are presented to the right eye. Presentation continues until participants indicate awareness. (b). Example of bCFS with grayscale numbers mask. (c). Example of bRMS. A static stimulus repeatedly presented (here, for 33 milliseconds) with each presentation followed by a longer presentation of a mask (67 milliseconds) that suppresses the target stimulus from awareness. Like in bCFS, The static stimulus fades in over time.

2.1. Experiment 1

Experiment 1 quantified individual variation in NVPS of emotional faces, a type of stimulus that has often been examined in bCFS (e.g., Yang et al., 2007).

2.1.1. Participants

Twenty Hebrew University students (15 female) participated in this experiment (see Expended Methods section below for details regarding sample size choices for all experiments).

2.1.2. Method

Participants responded to *happy*, *neutral* and *sad* faces in a bCFS task. To generate intraocular suppression, in each trial, an emotional face appeared randomly in one of the four corners of the display area of one eye while a dynamic Mondrian mask stimulus was presented over the entire display area in the other eye (for more details regarding the experimental procedure of all experiments see Expended Methods). Participants responded by pressing a key to indicate the corner at which the face appeared. Participants were instructed to respond as soon as they noticed any part of the face. On each trial, the duration between the start of stimulus presentation and the participant's response is the time it took the participant to become aware of and respond to the face. Therefore participants' reaction times (RT) serve as our measure for NVPS.

2.1.3. Results

Following standard procedure when analyzing bCFS results (e.g., Abir et al., 2018), six participants who did not correctly locate the target stimulus on at least 90% of trials were excluded from analysis[3](Sklar, 2021). Replicating previous results (Sterzer, Hilgenfeldt, Freudenberg, Bermpohl, & Adli, 2011), significant differences in response time of different emotional expressions emerged, $F_{2,26} = 24.40$, $P < 0.001$, $BF_{10} > 1000$. Neutral expressions (M = 1.76 s, SD = 0.43) entered consciousness sooner than Happy expressions (M = 1.96 s, SD = 0.57), and both entered consciousness sooner than Sad expressions (M = 2.20 s, SD = 0.64).

To examine our main hypothesis regarding individual variation in NVPS, we computed mean expression-specific RTs for each participant per each type of face, and examined their correlations across participants. The higher this correlation, the more individuals' visual prioritization speed varied consistently across expressions.

We found very strong correlations between participants' RTs (which index NVPS) for the different emotional expressions: $r = 0.93, p < 0.001$, $BF_{10} > 1000$, credible interval 0.72 to 0.98; $r = 0.97$, $p < 0.001$, $BF_{10} > 1000$, credible interval 0.85 to 0.99; and $r = 0.94$, $p < 0.001$, $BF_{10} > 1000$, credible interval 0.75 to 0.98; for happy-sad, happy-neutral and sad-neutral (See Fig. 2). Thus, individuals consistently vary in NVPS,

[3] The same exclusion rules – accuracy above 90% and mean reaction time not further than three standard deviations from the group mean – were used in all experiments. Where the second rule is not noted this is because no participants were excluded due to its applications.

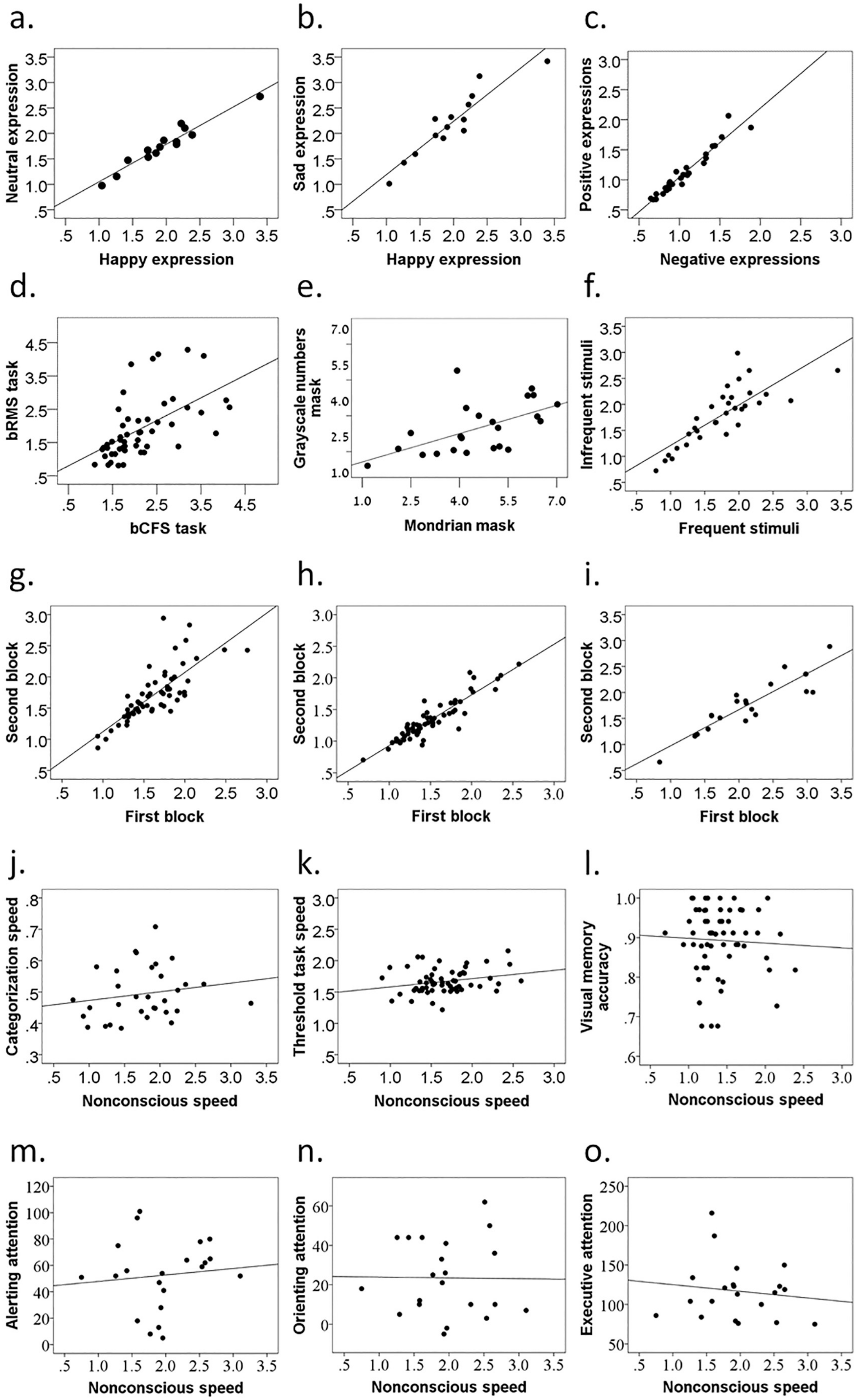

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Fig. 2. Results overview. Panels a-i, correlations between measures of NVPS in Experiment 1 (panels a-b), Experiments 2 (c), Experiment 3a (d), Experiment 3b (e), Experiment 4 (f), Experiment 5 (g), Experiment 6 (h) and Experiment 7 (i). Panels j-o, correlations between NVPS and measures of other traits (i.e., reducibility of NVPS to other traits) in Experiment 4 (j, speed on a categorization task), Experiment 5 (k, decision threshold), Experiment 6 (l, short term visual memory) and Experiment 7, (m-o, Alerting, Orienting and Executive attention). In all panels, lines represent linear least square best fit lines and speed values are in seconds, attentional effect measures (panels m-o) are in milliseconds.

over and above the mean differences in the speed of reaction to different emotional expressions (see Supplementary Analyses below for additional analyses).

2.2. Experiment 2

In Experiments 2a and 2b we examined individual variation in NVPS of written language in two previously published datasets (Sklar et al., 2012, Experiments 4a and 4b) in which this individual variance was not previously explored.

2.2.1. Participants

Twenty eight Hebrew University students (14 female) participated in Experiment 2a and 30 Hebrew University students (18 female) participated in Experiment 2b.

2.2.2. Method

We reanalyzed data from two previously published experiments (Sklar et al., 2012, Experiments 4a and 4b) in which participants performed bCFS with valenced phrases (e.g., *black eye*). Using pilot ratings, we categorized phrases as either positive or negative.

2.2.3. Results

Only participants who correctly located the target stimulus on at least 90% of trials (27 and 28 in Experiments 2a and 2b respectively) were analyzed. As previously reported (Sklar et al., 2012),

we found a significant difference between the RT of positive and negative phrases, $F_{1,26} = 6.90$, $p = 0.014$, $BF_{10} = 3.46$ and $F_{1,27} = 6.07$, $p = 0.02$, $BF_{10} = 2.65$ in Experiments 2a and 2b, respectively.

Crucially, when we averaged separately RTs for positive and negative stimuli within participant, and examined the correlation across participants, we found that the correlations between the prioritization speeds of positive and negative phrases were very high, $r = 0.97$, $p < 0.001$, $BF_{10} > 1000$, credible interval 0.91 to 0.98 in Experiment 2a and $r = 0.94$, $p < 0.001$, $BF_{10} > 1000$, credible interval 0.87 to 0.97 in Experiment 2b. Thus, the results show consistent individual variation in NVPS of written language, over and above the differences in RT generated by stimulus meaning.

2.3. Experiment 3a

Experiments 3a and 3b address the generality of NVPS across masks and paradigms. Experiment 3a examine whether individual variance in NVPS measured in a bCFS paradigm correlates with variability in NVPS as measured by a different long-duration suppression paradigm, bRMS. Importantly, the processes that underlie suppression in these two paradigms are different. In bCFS, it is binocular rivalry; in bRMS, it is competition over time. If the two estimates of NVPS are correlated to a large degree, it would suggest that prioritization cannot be exhaustively explained by variability in the effectiveness of either masking process.

2.3.1. Participants

Fifty three Hebrew University students (38 female) participated in this experiment.

2.3.2. Method

Participants completed a bCFS task and a breaking repeated masked suppression task (bRMS; Abir & Hassin, 2020). In RMS target stimuli are repeatedly presented briefly (34 milliseconds) with each presentation followed by a longer (67 milliseconds) presentation of a mask stimulus to suppress the target stimulus from awareness. Thus, while CFS relies on interocular suppression, RMS relies on backward and forward masking to achieve long-duration suppression.

In both tasks, participants were asked to detect target faces, which were masked using Mondrian masks. A manipulation of target face detectability through varying presentation contrast allowed us to test the possible influence of stimulus detectability. Each participant was exposed to six contrast levels, spaced logarithmically between 30% and 90% contrast in both the bCFS and bRMS tasks.

2.3.3. Results

Only participants who correctly located the target stimulus on at least 90% of trials in the maximum contrast level in both tasks and whose mean reaction time in both tasks did not differ by more than three standard deviations from the group mean (50 participants) were included in the analyses. As expected, there were significant main effects of stimulus detectability in both tasks ($F_{(5,245)} = 130.54$, $p < 0.001$, $BF_{10} > 1000$ and $F_{(5.245)} = 92.23$, $p < 0.001$, $BF_{10} > 1000$ in the bCFS and bRMS tasks respectively), with every level increase in contrast significantly reducing mean reaction time over the previous level in both tasks (all $F_{(1,49)} > 31$, $p < 0.001$, $BF_{10} > 1000$).

Crucially, for each of the contrast levels, NVPS performance in the bCFS and bRMS were significantly correlated ($r = 0.63$, $r = 0.5$, $r = 0.5$, $r = 0.43$, $r = 0.57$ and $r = 0.5$ in contrast levels 0.3–0.9 respectively, all $p < 0.001$, $BF_{10} > 100$ except contrast level 0.58 in which $r = 0.43$, $p = 0.002$, $BF_{10} = 17.98$) and these correlations did not significantly differ from each other (all $Z < 1.36$, $p > 0.085$). Overall, the correlation between NVPS averaged across all contrast levels between the bCFS and bRMS tasks was $r = 0.56$, $p < 0.001$, $BF_{10} > 1000$, credible interval 0.33 to 0.72. Thus, the results show strong evidence for generality of NVPS across the two suppression paradigms.

2.4. Experiment 3b

Experiment 3b examines another aspect of the generality of NVPS. Namely, whether individual variance in NVPS as it is measured using the commonly used Mondrian masks, correlates with individual variability in NVPS when measured with a different type of masking pattern (see Fig. 1 panel b).

2.4.1. Participants

Thirty-six Hebrew University students (29 female) participated in this experiment.

2.4.2. Method

Participants completed a bCFS task in which they were asked to detect in which of three possible locations (left, middle or right side of the display area) a target face appeared. Faces were binocularly masked using either dynamic Mondrian masks (50% of trials) or dynamic grayscale number patterns (50% of trials). Because pilot testing indicated that grayscale number patterns are more effective at masking faces, the presentation contrast for target faces was set higher in the grayscale numbers trials (presentation alpha 70%) than in the Mondrian mask trials (presentation alpha 50%).

2.4.3. Results

Only participants who correctly located the target stimulus on at least 90% of trials (24 participants) were included in the analyses.

Possibly due to the higher target presentation contrast, mean response times were significantly faster ($t_{23} = 7.22$, $p < 0.001$) for grayscale numbers masks (M = 2.72 s, SD = 1.04) than for Mondrian masks (Mean = 4.56 s, SD = 1.5). Critically however, despite different masking effectiveness, response times (i.e., NVPS) were strongly correlated between the two masking conditions ($r = 0.57$, $p < 0.001$, $BF_{10} = 13.95$, credible interval 0.19 to 0.77). Thus, the results show strong evidence for generality of NVPS across the two mask types.

2.5. Interim discussion

In Experiments 1-3b, we found reliable and strong individual variability in NVPS. This variability was consistent over both low-level factors (detectability; Experiment 3) and high-level factors (valance; Experiments 1and 2), and was strongly related between two suppression paradigms (Experiment 3a) and two mask types (Experiment 3b). Experiments 4–7 serve as a test of the ubiquity of NVPS across different stimulus categories and its stability over time. Additionally, they examine the uniqueness of NVPS, by estimating its correlations with other factors that might be theoretically related to it: general cognitive speed, attentional mechanisms and perceptual decision thresholds.

2.6. Experiment 4

Experiment 4 tested the hypothesis that NVPS is a result of general processing speed. To test general speed we used a simple, conscious, categorization task.

2.6.1. Participants

Forty two Hebrew University students (26 female) participated in this experiment.

2.6.2. Method

General processing speed was measured using reaction times in a simple categorization task, in which participants categorized pictures as either faces or houses. Next, participants completed the bCFS task with stimuli from the same categories. In both the bCFS and the conscious categorization task, the frequency of each stimulus category was varied between participants, with half of the participants exposed to faces on 80% of the trials, and the other half exposed to faces only on 20% of the trials. As in the previous experiments, participants' task in the bCFS task was determining the location of the target stimulus.

2.6.3. Results

Only participants who correctly located the target stimulus on at least 90% of trials (32 participants) were included in the analysis. There was a strong correlation between the processing speed of frequent and infrequent stimuli, $r = 0.86$, $p < 0.001$, $BF_{10} > 1000$, credible interval 0.71 to 0.93. NVPS of frequent and infrequent stimuli were also strongly correlated, $r = 0.80$, $p < 0.001$, $BF_{10} > 1000$, credible interval 0.59 to 0.89.

Crucially, however, categorization speed was not significantly correlated with NVPS, $r = 0.18$, $p = 0.32$, $BF_{10} = 0.35$, credible interval − 0.17 to 0.48. Thus, while both general processing speed and NVPS show consistent individual variations, there is no evidence that these individual differences are correlated. It appears, therefore, that conscious processing speed and NVPS do not share the same underlying processes.

2.7. Experiment 5

Experiment 5 examined whether NVPS may be explained in terms of decision thresholds – the amount of information an individual seeks to gather before reaching a perceptual decision.

2.7.1. Participants

Sixty three Hebrew University students (38 female) participated in this experiment.

2.7.2. Method

Participants completed two very similar tasks: (i) a bCFS task with masked arithmetic statements (e.g., 7–2–1 = 4; we used similar arithmetic stimuli previously in Sklar et al., 2012) and (ii) a decision threshold task in which the same stimuli and masks were presented to both eyes so that no interocular masking occurred. In both tasks participants were asked to press a key indicating whether the target was above or below fixation as soon as they saw the target. Importantly, in the threshold task the contrast (and therefore amount of information) of targets was linearly ramped up during the first three seconds of each trial (maximum 20% contrast). This task, then, allows us to approximate conscious decision threshold via measuring how quickly participants react to conscious targets. Participants with higher decision thresholds should be slower to decide, whereas participants with lower decision thresholds should be faster. Participants completed two blocks of bCFS followed by two blocks of the threshold task.

2.7.3. Results

Only participants who correctly located the target stimulus on at least 90% of trials and whose mean reaction time in the bCFS task did not differ by more than three standard deviations from the group mean (59 participants) were included in the analyses.

There were strong correlations between the NVPS in the two blocks of the bCFS task, $r = 0.78$, $p < 0.001$, $BF_{10} > 1000$, credible interval 0.638 to 0.857 and between the two block of decision thresholds task, $r = 0.74$, $p < 0.001$, $BF_{10} > 1000$, credible interval 0.581 to 0.831.

Crucially, there was a weak, and marginally significant, correlation between NVPS and decision thresholds, $r = 0.249$, $p = 0.059$, $BF_{10} = 0.95$, credible interval − 0.008 to 0.47. Moreover, when decision threshold variance was statistically controlled for, the partial correlation between NVPS in the two blocks of the bCFS task, $r = 0.78$, $p < 0.001$ was almost identical to the simple correlation.

Therefore, while some of the variance in performance in bCFS tasks may be due to individual differences in thresholds, individual variation in NVPS is robust even when accounting for conscious perceptual thresholds.

2.8. Experiment 6

To test the possibility that differences NVPS stem from differences in participants' ability to encode or retrieve stimuli in short term visual memory, in Experiment 6 we examined whether NVPS is associated with acuity of short-term visual memory in a previously published dataset (the combined data of Experiments 1 and 2 in Abir et al., 2018) in which individual variance in NVPS or its relation to short-term visual memory were not previously examined.

2.8.1. Participants

Sixty five Hebrew University students (47 female) participated in this experiment.

2.8.2. Method

Participants first completed an n-back task (n-1) on artificial faces, similar to those used in Experiment 3, in which they were asked to identify instances where the same face appeared in consecutive trials. Accuracy rates in this task serve as measures of acuity of visual short-term memory (Phillips, 1974). Participants then completed two blocks of bCFS with the same stimuli.

2.8.3. Results

Only participants who correctly located the target stimulus on at least 90% of trials and whose mean reaction time in the bCFS task did not differ by more than three standard deviations from the group mean (60 participants) were included in the analyses. The correlation between NVPS in the two blocks was high, $r = 0.92$, $p < 0.001$, $BF_{10} > 1000$, credible interval 0.86 to 0.95.

Crucially, Short-term visual memory was not significantly correlated with NVPS, $r = -0.05$, $p = 0.72$, $BF_{10} = 0.17$, credible interval − 0.29 to 0.20. Thus, NVPS cannot be explained by the short-term ability to encode and quickly use visual stimuli.

2.9. Experiment 7

Experiment 7 examined whether individual variation in NVPS relates to, and may therefore be explained by, individual variation in attentional capacities.

2.9.1. Participants

Twenty seven Hebrew University students (13 female) participated in this experiment.

2.9.2. Method

Cognitive and neuroscientific evidence documents three distinct attentional functions – alerting, orienting and executive attention – that are supported by separate brain networks (Petersen & Posner, 2012; Posner, 2011; Posner & Petersen, 1990). To measure these three attentional functions, we used the Attention Networks Test (ANT), a widely used behavioral task that estimates individual variation for all three functions (Fan et al., 2002). In the ANT, participants respond to the direction of a central arrow, which is preceded on some trials by either an alertness cue, or a cue predicting its location. On some trials, the arrow is surrounded by either congruent or incongruent flanking arrows. Differences between reaction times in the different conditions of the task represent the effectiveness of alerting or orienting attention, as well as executive attention (indexed by the effect of conflicting flankers). Importantly, the executive component of the ANT has been previously linked to working memory capacity, fluid and crystallized intelligence (Redick & Engle, 2006; Tillman, Bohlin, Sørensen, & Lundervold, 2009; Tourva, Spanoudis, & Demetriou, 2016).

Participants completed, in the following order, (i) one block of bCFS task with pictures of faces in varying orientations; (ii) the ANT task which lasted approximately 20 min, (iii) a second block of bCFS and (iv) the Landolt C visual acuity measure from the adaptive Freiburg Vision Test (Bach, 1996). The time difference between the two bCFS blocks additionally allows us to test whether individual variation in NVPS is stable across such a time gap.

2.9.3. Results

Only participants who correctly located the target stimulus on at least 90% of trials in the bCFS task (21 participants) were included in the analysis. NVPS was highly correlated between the two bCFS blocks, $r = 0.905$, $p < 0.001$, $BF_{10} > 1000$, credible interval 0.74 to 0.96, indicating that NVPS is stable over the 20 min time gap between the two bCFS blocks.

There were significant main effects for alerting (Mean = 52.62 milliseconds, SD = 26.78, $t_{20} = 9.0$), orienting (Mean = 23.52 milliseconds, SD = 19.0, $t_{20} = 5.67$) and executive attention (Mean = 117.0 milliseconds, SD = 36.24, $t_{20} = 14.8$). Orienting attention was not significantly correlated with either alerting ($r = 0.13$, $p = 0.57$) or executive attention ($r = 0.26$, $p = 0.26$). Alerting and executive attention were significantly ($r = 0.52$, $p = 0.016$).

Crucially, NVPS was not significantly correlated with any of the attentional functions, $r = 0.105$, $p = 0.65$, $BF_{10} = 0.297$, credible interval − 0.32 to 0.48; $r = -0.012$, $p = 0.96$, $BF_{10} = 0.27$, credible interval − 0.41 to 0.39 and $r = -0.134$, $p = 0.56$, $BF_{10} = 0.32$, credible interval − 0.50 to 0.27 for alerting, orienting and executive attention, respectively.

NVPS was also not correlated with participants' acuity averaged across eyes, $r = -0.025$, $p = 0.92$, $BF_{10} = 0.28$, credible interval − 0.43 to 0.39 as well as the acuity difference between the dominant and non-dominant eye, $r = 0.053$, $p = 0.825$, $BF_{10} = 0.28$, credible interval − 0.37 to 0.45.

Thus, NVPS was not related to, and therefore cannot be explained by, individual variation in attention or visual acuity.

2.10. Experiment 8

In Experiment 8, we examined whether differences in NVPS are echoed in people's conscious, everyday life experience. Per unit of time, people with faster NVPS are likely to experience more percepts than people with slow NVPS. This may suggest that people with fast (vs. slow) NVPS tend to consciously experience more of their surroundings.

To examine correlates of NVPS we used the short version of the Highly Sensitive Person Scale (HSP; Aron, Aron, & Jagiellowicz, 2012).[4] The HSP measures a personal tendency, that may be partly determined genetically, towards general increased sensitivity – a basic tendency for observing and noting more (i.e., processing more cues) at the cost of acting slower (Aron et al., 2012). HSP scores correlate with better performance in visual search (Gerstenberg, 2012), stronger neural activation in high-level visual processing areas when detecting small differences in visual scenes (Jagiellowicz et al., 2011) and with increase in both negative and positive emotional reactivity (Acevedo et al., 2014; Jagiellowicz, Aron, & Aron, 2016; Pluess et al., 2018).

In light of the nature of HSP we hypothesized a negative correlation between HSPS and NVPS, such that more sensitive individuals will have faster NVPS.

2.10.1. Participants

Ninety two Hebrew University students (54 female) who had previously participated in relevant bCFS experiments (experiments 3, 4 or 6 from Abir et al., 2018 or a follow up experiment using the same face stimuli) who were reached and willing to provide additional data are included in this experiment.

2.10.2. Method

The HSP is a self-reported measure of the experience of perceptual sensitivity that has been linked to greater neural responses in higher order visual areas (e.g., Jagiellowicz et al., 2011), increased experience of non-ordinary states of consciousness under sensory deprivation (Jonsson, Grim, & Kjellgren, 2014; Kjellgren, Lindahl, & Norlander, 2009) as well as an overall increase in subjective reporting of health symptoms and stress (e.g., Benham, 2006; Grimen & Diseth, 2016). In order to gather a large enough sample to achieve statistical power that would allow us to identify correlations with self-report measures, we attempted to contact all participants who completed bCFS tasks in our lab during the 18 months prior to data collection. To reduce potential error variance due to differences between the bCFS tasks, we focused on bCFS tasks in which faces or scrambled face images were used as stimuli. These participants had been part of one of experiments 3, 4 or 6 from Abir et al., 2018 or a follow up experiment using the same face stimuli.

2.10.3. Results

Of the 152 participants we attempted to contact, 92 (60.5%) were reached and were willing to answer additional questions, 84 of whom had correctly located the target stimulus on at least 90% of trials in the bCFS task and were included in the analysis.

As expected, there was a significant correlation between NVPS and self-reported sensitivity, $r = -0.27$, $p = 0.014$, $BF_{10} = 2.69$, credible interval − 0.45 to −0.055. This result holds even if we exclude one NVPS item that may be measuring visual perception rather directly ("I seem to

[4] Several measures relevant for other projects were additionally gathered; see Expanded Methods.

be aware of subtleties in my environment"; $r = -0.3$, $p = 0.006$, $BF_{10} = 5.86$, credible interval − 0.48 to −0.088).

These correlations establish that participants with short NVPS have higher HSPS scores (see Fig. 3), suggesting that differences in NVPS may lead to differences in how one consciously experiences the world.

3. General discussion

Our findings paint a picture of a highly robust cognitive characteristic. NVPS is general, ubiquitous and unique: It affects performance in various tasks, for a large variety of stimuli, and it cannot be explained by cognitive characteristics such as general speed, perceptual threshold, short-term visual memory, or three different attentional networks. NVPS is also stable over short periods of time, and it correlates with HSPS, which measures self-reports of sensitivity of processing.

Before we discuss the broader implications of our findings, we turn to address potential limitations.

3.1. The nature of NVPS

The current examination of NVPS is limited to masking paradigms, and may hence reflect a masking-specific characteristic. As we note in the introduction, prioritization as we examine it here does not necessarily assume prioritizing processes that assign value to non-conscious representations. Rather, it may be implemented in a systematic sensory, perceptual, or cognitive bias. It is therefore conceivable that the results we report here mainly (or solely) reflect duration-dependent biases in consciously perceiving meaningful visual objects in the face of visual masking. This, in turn, may help explain the lack of correlation with control experiments that do not include visual competition (Experiments 4–7).

The correlation between bCFS and bRMS (Experiment 3a) suggests that NVPS as it is measured here is not limited to binocular or temporal masking. The correlation between two types of masks (Experiment 3b) suggests that NVPS is not limited to Mondrian masks. The moderate correlation with the short version of the HSPS (and the version without the potentially visual item; Experiment 8) suggests that NVPS is associated with more central aspects of sensitivity. This is but preliminary evidence that bears on the nature of prioritization. Mapping the more central vs. uniquely masking-related characteristics of NVPS as it is measured here is a challenge for future research (Harris, Sklar, & Hassin, 2020). The history of psychology teaches us that it is likely that both low- and high-level processes are at play.

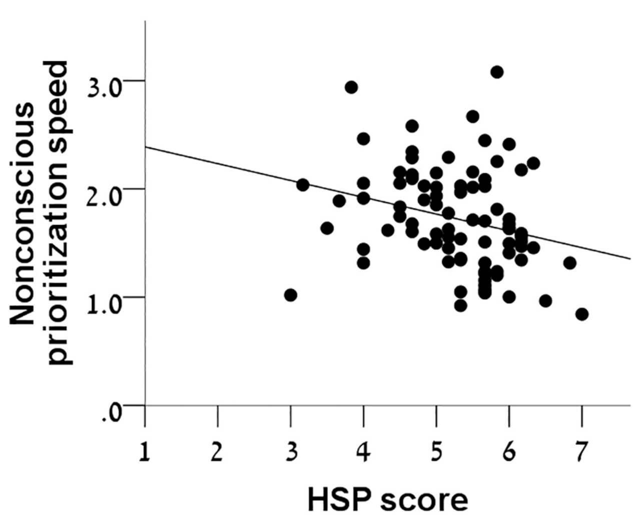

Fig. 3. Results of Experiment 8. Correlation between Highly Sensitive Person (HSP) scale scores and NVPS (in seconds). The line is linear least square best fit.

3.2. Consciousness

Notably, much of the consciousness literature relies on masking paradigms. Global Neuronal Workspace (e.g., Dehaene et al., 2006) and local ignition (e.g., Malach, 2007; Noy et al., 2015; Zeki, 2003) explicitly rely on differences between masked and non-masked stimuli to infer the neuronal mechanisms underlying consciousness, and the axioms of Information Integration Theory (Tononi & Koch, 2015) seem to take such differences into account. Thus, regardless of whether our results mainly reflect a systematic early bias, or a more balanced mix of low-level and high-level mechanisms, they may be highly informative and suggest new possibilities for the science of consciousness.

Specifically, general, ubiquitous and unique individual variability in NVPS cannot be accounted for by existing frameworks for thinking about prioritization for awareness. Previous literature identified many factors influencing prioritization of specific stimuli in specific paradigms (e.g., Abir et al., 2018; Balcetis et al., 2012; Sklar et al., 2012; Stein et al., 2012; Zeelenberg et al., 2006). However, no existing view can explain findings across factors and tasks. The current findings help in highlighting the need for such a theoretical expansion and provide important input.

3.3. Neural correlates of consciousness

Finally, robust individual variance, as we found here, offers a new and powerful tool for examining the neural correlates of consciousness (NCC). The robustness of NVPS could be utilized in future research to link individual variability in NVPS with individual variability on the neural level (e.g., variability in the strength or speed of neural ignition response to stimuli or variability in connectivity between occipito-temporal cortex and association cortices; Dehaene et al., 2006; Moutard, Dehaene, & Malach, 2015) or informational level (e.g., variability in the speed of change in integrated information measures; Tononi, 2008). Such findings would offer a new independent source of evidence for the ongoing effort to tie conscious experiences to neural processing. Indeed, a similar approach was instrumental to identifying the neural underpinning of a related phenomenon - multistable perception (Kleinschmidt et al., 2012).

This new approach is particularly important for the search for NCC as it avoids a major hurdle in the current literature – differentiating the processes that generate conscious experience from those that result from it (Block, 2019; Dehaene et al., 2014). As we measured it here, individual variance in the process(es) generating conscious experiences (and therefore its potential neural correlates) is unique, and does not correlate with some of the usual suspects of post-awareness processing (e.g., conscious response speed, attentional capacity). The approach proposed here may therefore offer an important tool to the NCC literature (Dehaene et al., 2014), generating new results to arbitrate theoretical disagreements.

3.4. General behavior

To close a circle to the first paragraph of this paper – NVPS may affect many other processes and behaviors. Indeed, to the extent that it is not limited to the masking paradigms used here – people with short NVPS are likely notice more of their surroundings, with positive (e.g., less accidents, better knowledge of one's surrounding) and negative (e.g., less time for thinking, shallower processing) consequences. These fascinating possibilities are left for future empirical examination.

4. Expended methods

4.1. Participants

In all experiments, participants were Hebrew university students, 20, 28, 30, 53,[5] 36,[6] 42, 63, 65, 27 and 92 in Experiments 1 through 8 respectively,[7] of these 15, 14, 18, 38, 26, 38, 47, 13 and 54 were female in Experiments 1 through 8 respectively. Participants' Mean age was 23.3, 24.4, 25.6, 23.2 and 23.3 in Experiments 1 through 4 respectively, 23.0 in Experiment 6, 24.4 in Experiment 7 and 24.03 in Experiment 8. Due to errors no age data was collected in Experiments 3b 5. All participants had normal vision and participated in the experiments in exchange for course credit or 10 NIS in Experiment 1, 15 NIS in Experiments 2 through 5, 30 NIS in Experiments 6 and 8 and 35 NIS in Experiment 7 (1 NIS = approximately $0.25). In Experiment 8, participants were compensated by being included in a lottery with a single 200 NIS (approximately $50). All participants provided informed consent prior to participating.

4.2. Apparatus

In Experiments 1–2b and 4–8 stimuli were presented on a 15-in. CRT monitor (800 pixel by 600 pixel resolution in Experiment 1, 1024 pixel by 768 pixel resolution in Experiments 4 through 8). In Experiments 1–2b and 4–8 participants viewed the screen through a Screenscope mirror stereoscope placed approximately 30 cm from the screen. In Experiments 3a and 3b, stimuli were presented on a Samsung SyncMaster SA950 3D monitor. Participants viewed the screen through matching Samsung 3D glasses, using a chin rest positioned approximately 60 cm from the screen. Stimulus presentation was controlled by DirectRT Version 2012 in Experiment 1 and the psychophysics toolbox extension for MATLAB (Brainard, 1997) in Experiments 2a through 8.

4.3. Stimuli

In Experiment 1 target stimuli were grayscale images of faces, cropped into 80 × 80 pixels squares, displaying either a sad, a happy or a neutral facial expression. Images were taken from the standard Ekman set of facial expressions (Ekman, Friesen, & Press, 1975). Four identities (two male) were used, each was presented displaying all three emotional expressions. In Experiments 2a and 2b target stimuli were 46 two-words expressions in Hebrew. Expressions varied on their affective valence as rated by a separate group of participants. All expressions were composed of affectively neutral words (see Experiments 4a & 4b in Sklar et al., 2012). In experiment 3 and 6 target stimuli were a random subset of 30 faces drawn from the 300 randomly generated faces stimulus set (Oosterhof & Todorov, 2008). All face stimuli were 145 × 235 pixels in size. In Experiment 6, 25 additional faces were randomly generated for the memory task. For additional information regarding the stimuli used in Experiment 6 see Experiments 1 and 2 (Abir et al., 2018). In Experiment 3b, target stimuli were 24 face images drawn from NimStim (Tottenham et al., 2009) and the Chicago Face Database (Ma, Correll, & Wittenbrink, 2015), cropped into ovals containing only the face and presented in grayscale, 175 × 140 pixels in size. In Experiment 4 target stimuli were 20 images of faces and 20 images of houses cropped into squares of 100 × 100 pixels. In each task, 10 face images and 10 house images were used so that images were not repeated between the two tasks. In Experiment 5 target stimuli were 52 three number subtraction arithmetic statements (e.g. 6–1-2 = 3), displayed in 16 pt. Ariel font. In Experiment 6 target stimuli for the CFS task were 300 faces generated randomly on FaceGen 3.1 (Oosterhof & Todorov, 2008). In Experiment 7, target stimuli were 16 grayscale images of faces, cropped into 100 pixels × 100 pixels squares.

Mask stimuli were Mondrian patterns (grayscale in Experiment 1 and colored in Experiments 2a through 8, see Fig. 1) changing at 10 hz. (i.e., each frame of the mask was presented for 100 milliseconds). Mask stimuli size was 170 × 170 pixels in Experiment 1, 250 × 250 pixels in Experiments 2a, 2b, 4, 5 and 7, and 600 × 250 pixels in Experiments 3, 6 and 8.

4.4. Experiment 1 procedure

Participants completed 8 training trials, with faces displaying neutral expressions of identities not included in the experimental trials, followed by 192 experimental trials (16 repetitions of each expression by identity combination) presented in random order. In each trial, the target stimulus appeared randomly in one of the four corners of the display area, fading in linearly up to 100% contrast over the first second of presentation. The mask stimulus was presented at full contrast during the first second of presentation and then linearly faded out over five seconds, or until a response was registered at which point the trial ended. Target stimuli and mask stimuli were each presented monocularly to different eyes in order to induce interocular suppression. Eye of presentation was varied randomly between trials so that each eye was presented with the target stimuli on 50% of trials. Participants were asked to respond by pressing one of four keys to indicate the corner of the display area at which the target stimulus appeared. Participants were instructed to respond as soon as they noticed any part of the target face. Upon response, the trial terminated and a blank screen was presented for 400 milliseconds followed by the next trial.

4.5. Experiments 2a and 2b procedure

During each trial, a fixation cross was presented binocularly at the center of each eye's visual field. The expressions were presented monocularly in 15-pt Ariel font and gradually ramped up in contrast (from 0% to 50%) during the first 900 milliseconds of presentation. Target stimuli appeared either below or above fixation (probability = 0.5). Participants' task was to indicate whether the sentences (or any part of them—a word, letter, or feature) appeared above or below fixation by pressing the appropriate key. They were instructed to respond as quickly as they could, trials ended after 10 s if no response was given. Upon response, the trial terminated and a blank screen was presented for 800 milliseconds followed by the next trial. The mask was randomly presented to one eye, and the expression was presented to the other eye (probability = 0.5).

4.6. Experiment 3a procedure

Participants completed two experimental blocks: One with a bCFS task, and one with a bRMS task. Order of tasks was counterbalanced across participants. During trials in both tasks, a fixation cross was presented binocularly at the center of each eye's visual field, and a double line framed the area in the visual field in which Mondrians would be presented. In the bCFS task, face images were presented monocularly, gradually ramping up in contrast (from 0% to one of six levels of maximal contrast, logarithmically spaced between 30% and 90%) during the first second of presentation. On each trial the mask was randomly

[5] An additional 12 participants in Experiment 3 reported during debriefing they had closed one of their eyes during the CFS presentation and are therefore excluded entirely from the sample.

[6] An additional 14 participants in Experiment 3b either reported during debriefing they had closed one of their eyes during the CFS presentation or experienced equipment failure leading to monocular instead of binocular presentation and are therefore excluded entirely from the sample.

[7] To detect a correlation of $r = 0.6$ with reasonable (80%) power, the required sample size is 18 (Hautus, 1995), we therefore set 20 as a conservative minimal sample size required for all further experiments based on the results of Experiments 1-2b. When it was possible given participant pool constraints, larger samples were obtained. See Experiment 8 procedure for a thorough description of the sampling for Experiment 8.

presented to one eye, and the face stimulus to the other (probability = 0.5). In the bRMS task, both faces and Mondrians were presented binocularly. Faces and Mondrians were presented in alternation, each face presentation lasting 33 ms and each Mondrian presentation lasting 67 ms. Each trial began with a Mondrian presentation. Faces were presented at one of six contrast levels, logarithmically spaced between 30% and 90% contrast. In both tasks, face stimuli appeared either to the left or the right of fixation (probability = 0.5). Participant's task was to indicate whether the faces appeared to the left or right of fixation by pressing an appropriate key. They were instructed to respond as quickly as they could. For both tasks, trials ended after 10 s if no response was given. Upon response, the trial terminated and a blank screen was presented for one second followed by the next trial. For both tasks face stimuli appeared either in their cardinal orientation or flipped by 180° (probability = 0.5). Overall, participants completed 360 trials for each of the tasks. Each task was preceded by a training block, 25 trials long.

4.7. Experiment 3b procedure

Participants completed 144 trials of the bCFS task, 72 trials with each masking type (Mondrian or grayscale numbers masks). During each trial, the target face stimulus linearly increased in contrast over the first second of presentation up to the maximal contrast (50% for Mondrian mask trials, 70% for the grayscale numbers mask). Mask stimuli covered a display area 400 × 300 pixels in size, with target stimuli appearing in either the left edge, centre or right edge of the display area, with each stimulus appearing in each position on one third of the trials. Mondrian masks were identical to those used in Experiments 2 and 3. Grayscale number masks were composed or four overlapping layers of numbers with each layer including numbers at a different shade of grey and in different size (see Fig. 1). Face stimuli appeared upright on half the trials and inverted on half the trials. Participants were asked to report the position of the target stimulus by pressing one of three keys as quickly as possible. Upon response, there was a one second intertrial interval. If no response was given, trials terminated after 10 s.

4.8. Experiment 4 procedure

Participants completed two tasks. First, participants completed 100 trials of the face/house identification task. Next, participants completed 150 trials of the CFS task. Each task started with an additional 8 training trials with stimuli and display parameters that were the same as those used in the rest of the task. For each participant, one stimulus category was designated as frequent and the other was designated as infrequent. Participants saw 8 repetitions of each of the 10 frequent category stimuli and 2 repetitions of each of the 10 infrequent category stimuli in the identification task (100 trials in total). Participants saw 12 repetitions of each of the 10 frequent category stimuli and 3 repetitions of each of the 10 infrequent category stimuli in the CFS task (150 trials in total).

In the identification task, on each trial an image (either a house or a face) appeared in one quadrant of the display area and participants were asked to identify the image as either a house or a face by pressing a corresponding key.

In the CFS task, on each trial an image, either a house or a face, linearly faded in over the first second of presentation up to 20% contrast. The mask stimulus was presented at full contrast during the first seven seconds of presentation and then linearly faded out over three seconds. Target stimuli and mask stimuli were each presented monocularly to different eyes in order to induce interocular suppression. Eye of presentation was varied randomly between trials so that there was a 50% likelihood each eye was presented with the target stimulus on any given trial. Trials terminated as soon as a response was registered, or after a total of 10 s has elapsed. Participants were asked to respond by pressing one of four keys to indicate the corner of the display area at which the target image appeared. Participants were instructed to respond as soon as they noticed any part of the target image. A blank screen was presented for 800 milliseconds after a trial terminated.

4.9. Experiment 5 procedure

Participants completed two tasks. First, participants completed 104 trials (two presentations of each statement) of the CFS task. Next, participants completed 104 trials (two presentations of each statement) of the control task. Before the CFS task, participants completed 8 training trials identical to trials used in the actual task. Due to the high similarity between the CFS and control tasks, no training preceded the control task, which immediately followed the CFS task with no additional instructions.

In the CFS task, on each trial a statement linearly faded in over the first second of presentation up to 20% contrast. The mask stimulus was presented at full contrast during the first seven seconds of presentation and then linearly faded out over three seconds. Target stimuli and mask stimuli were each presented monocularly to different eyes in order to induce interocular suppression. Eye of presentation was varied randomly between trials so that there was a 50% likelihood each eye was presented with the target stimulus on any given trial. Trials terminated as soon as a response was registered, or after a total of 10 s has elapsed. Participants were asked to respond by pressing one of two keys to indicate whether the statement was presented in the upper or lower half of the display area. Participants were instructed to respond as soon as they noticed any part of the statement.

In the control task, presentation was changed so that both the masks and target statements were presented to both eyes simultaneously on each trial, with the target statement superimposed over the mask. In order to induce reaction times that were similar to those of the CFS task, target statements faded in linearly over three seconds. All other display parameters were identical between the two tasks and participants were acting under the same instructions as in the CFS task. A blank screen was presented for one second after a trial terminated.

4.10. Experiment 6 procedure

Participants completed two tasks. First, participants completed 34 trials of the memory task. Then participants completed two blocks, 300 trials each, of the CFS task. The memory task was preceded by 4 practice trials; the CFS task was preceded by 25 practice trials.

In the memory task, 25 faces were presented binocularly for 4 s, with an inter-trail interval of 1 s. Face stimuli faded in linearly up to 35% contrast over the first second of presentation. Nine randomly selected faces appeared twice consecutively. Participants had to indicate by pressing one of two keys whether the face presented is different or identical to the previous one. The color of the frame around the stimulus was changed after key press to provide feedback (green for correct, red for incorrect).

In the CFS task, on each trial a face stimulus faded in linearly over the first second of presentation up to 35% contrast. The mask stimulus was presented at full contrast during the first seven seconds of presentation and then linearly faded out over three seconds. Target stimuli and mask stimuli were each presented monocularly to different eyes in order to induce interocular suppression. Eye of presentation was varied randomly between trials so that there was a 50% likelihood each eye was presented with the target stimulus on any given trial. Trials terminated as soon as a response was registered, or after a total of 10 s has elapsed. Participants were asked to respond by pressing one of two keys to indicate whether the face was presented in the upper or lower half of the display area. Participants were instructed to respond as soon as they noticed any part of the face. A blank screen was presented for one second after a trial terminated.

4.11. Experiment 7 procedure

Participants completed three tasks, the CFS task, the ANT and a perceptual acuity measure which was the Landolt C procedure from the adaptive Freiburg Vision Test (Bach, 1996). Participants first completed 96 trials (proceeded by 9 training trials, identical to the critical trials) of the CFS task. Next, participants completed the 288 trials of the ANT task (preceded by 24 training trials in which feedback was given), which lasted for approximately 20 min. Participants than completed another 96 trials of the CFS task (again preceded by 9 training trials). Finally, participants completed 24 trials of the Landolt C procedure with each eye (while manually covering the other eye).

In the CFS task, on each trial a face image linearly faded in over the first second of presentation up to 20% contrast. The mask stimulus was presented at full contrast during the first seven seconds of presentation and then linearly faded out over three seconds. Target stimuli and mask stimuli were each presented monocularly to different eyes in order to induce interocular suppression. Eye of presentation was varied randomly between trials so that each eye was presented with the target stimulus on 50% of trial. Trials terminated as soon as a response was registered, or after a total of 10 s has elapsed. Participants were asked to respond by pressing one of four keys to indicate the corner of the display area at which the target stimulus appeared. Participants were instructed to respond as soon as they noticed any part of the target face. A blank screen was presented for 800 milliseconds after a trial terminated. Each face image was presented six times on each of the CFS task blocks, twice in an upright orientation, twice in an inverted orientation (turned 180°) and twice in sideways orientation (turned 90° either clockwise or counterclockwise).

In the ANT, each trial consisted of a flanker task with various pre-cues. In the flanker task, participants were asked to report the orientation (right or left pointing) of a central arrow, ignoring flanker which could be congruent (arrows in the same orientation), incongruent (arrows in the opposite orientation) or neutral (non-arrow line). This flanker display appeared either above or below a central fixation and was preceded by one of four possible cue displays occurring 500 milliseconds before the flanker display and presented for 100 milliseconds. In the no cue condition, no cue was displayed. In the center cue condition, a cue was presented in the center of the display. In the double cue condition, cues above and below the display area's center were presented. In the spatial cue condition, a single cue was presented either above or below the display area's center (Fan et al., 2002).

In the Landolt c task, participants were asked to report the orientation of a C like stimulus (a circle with a gap) out of four possible orientations. An adaptive algorithm varied the size of the stimulus based on the participant's ability to correctly identify orientation on each previous trial (Bach, 1996).

4.12. Experiment 8 procedure

The procedure of the bCFS tasks was identical to Experiment 6 except that for some participants face stimuli were inverted or diffeomorphicly scrambled. See Abir et al. (2018) for additional details regarding procedure and stimuli of the bCFS tasks. We attempted to telephonically contact all participants who completed a CFS task using similar stimuli (faces or scrambled face images) during the 18 months previous to data collection. These participants had been part of one of experiments 3, 4 or 6 from Abir et al. (2018) or a follow up experiment using the same face stimuli (Abir & Hassin, n.d.).

Participants were contacted telephonically and asked the six questions comprising the short version of the Highly Sensitive Person scale (Aron et al., 2012). For use in other projects in the lab, participants were additionally asked to report whether they had a driver's license, four additional question regarding involvement in car accidents and driving, ten additional questions regarding curiosity and three questions about attention to details.

4.13. Data preparation

Participants who responded correctly on less than 90% of the trials (6, 1, 2, 2, 12, 10, 3, 4, 6 and 8 participants in Experiment 1 through 8 respectively) as well as participants who's mean reaction time in the CFS task was more that 3 standard deviations from the group mean (1 participant in Experiment 3, 1 participant in Experiment 5 and 1 participant in Experiment 6) were excluded from analysis. Trials at which participants did not respond correctly on the bCFS task (5.02%, 1.7%, 2.1%, 5.88%, 3.5% 2.5%, 2.5%, 2.3% and 3.7% of trials in Experiment 1 through 7 respectively) or bRMS task (8.5% of trials in Experiment 3), as well as trials with reaction times more than 3 standard deviations from the participants mean in the bCFS task (1.6%, 3.3%, 3.9%, 1.93%, 1.6%, 1.7%, 1.8%, 1.7% and 2.1% of trials in Experiments 1 through 7 respectively) or bRMS task (1.81% of trials in Experiment 3) were excluded from analysis.

In Experiment 4 trials in the identification task at which participants did not respond correctly (2.5% of trials), as well as trials with reaction times more than 3 standard deviations from the participants mean (1.8% of trials) were excluded from analysis.

In Experiment 5 trials in the control task at which participants did not respond correctly (1.8% of trials), as well as trials with reaction times more than 3 standard deviations from the participants mean (1.1% of trials) were excluded from analysis.

Declaration of Competing Interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cognition.2021.104638.

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