Subliminal emotional faces do not capture attention under high attentional load in a randomized trial presentation

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ABSTRACT

In spatial cueing paradigms, emotional stimuli generally orient attention more efficiently, leading to modulations of behavioural and neuronal responses according to stimulus valence. In a previous study, we showed that when emotional stimuli are not consciously perceived, they cannot orient attention and that emotion is not processed when attentional load is high. In the present studies, we were able to confirm these behavioural findings, even when stimulus duration is randomized, which was not the case in the original study. These results confirm the original findings and show that even in a randomized sequence, irrelevant emotional expressions displayed under the threshold of awareness do not capture attention when the task involves high attentional load.

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In a spatial cueing task, when attention is directed to a location in space, people are faster and responses more accurate when responding to targets appearing in the directed field while reaction times (RTs) and errors increase if a target pops up at an uncued site (Chica et al., 2013; Posner, 1980). This effect of facilitation by spatial attention has been highlighted with exogenous as well as endogenous cues. Typically, endogenous attention is tested with a central cue (for example an arrow) indicating where the target is more likely to appear (e.g., left or right visual field). The participant must direct their attention on the side of the screen indicated by the arrow. A target then appears on the side where attention is allocated (valid trials) or on the opposite side (invalid trials), giving rise to faster RTs for valid than invalid trials. In the case of exogenous attention, a peripheral cue shifts attention but is not predictive of stimulus location (Posner, 1980). This shifting is involuntary and, unlike endogenous attention, a short SOA leads to faster RTs if the target appears at the location of the preceding cue, compared to the opposite location, which is reversed with a longer SOA.

In the field of attention research, one of the elements that has provided conflicting results is how irrelevant stimuli capture attention. In goal-directed behaviours, attention needs to be engaged towards goal-relevant stimuli, while distractors irrelevant to the ongoing task need to be ignored. According to the load theory of attention, distractors are processed differently based on the amount of perceptual and working memory load engaged in an attention orientation task (Lavie et al., 2004) such that increasing perceptual load decreases distractor interference while increasing working memory load increases distractor interference. Perceptual load refers to “the amount of information involved in the perceptual processing of the task stimuli” (Macdonald & Lavie, 2011, p. 1780). While some researchers have confirmed that distractors seem to capture attention more efficiently when perceptual load is low (Lavie, 1995; Lavie et al., 2004), other studies showed that distraction by abrupt irrelevant stimuli is diminished in low perceptual load conditions (Cosman & Vecera, 2009, 2010). On the other hand, inconsistent findings have also been reported regarding the...
interaction between working memory load and distractor processing. In line with the load theory of attention, high working memory load leads to greater capture by irrelevant stimuli in some studies (de Fockert et al., 2001; Lavie et al., 2004; Simon et al., 2016). However, in other studies increasing working-memory load led to decreased capture by irrelevant distractors, as indexed by event-related potentials (Berti & Schroger, 2003; Rose et al., 2005).

In sum, while perceptual and working-memory loads seem to impact selective attention, the direction of these relationships is not yet clearly understood and attentional processes might depend on other aspects such as stimulus valence.

Indeed, the effect of facilitation in spatial cueing tasks has been used to investigate how emotion interacts with these attentional processes. For example, emotional stimuli orient attention more efficiently (Compton, 2003; Öhman et al., 2001; Vuilleumier, 2005) and detecting an emotional stimulus is faster in visual search tasks (Eastwood et al., 2001; Fox, 2002). This type of capture appears to be exogenous but can be modulated by certain types of personality traits, like anxiety (Bishop et al., 2004; Fox et al., 2007).

In the case of selective attention, modified versions of the Stroop task have been used to study attentional biases toward emotional stimuli (Richards & Blanchette, 2004; Williams et al., 1996). In these studies, participants were slower at naming the colour of emotional words. Moreover, selective attention modulated by fearful faces has been explored in a study (Mathews et al., 2003) where a face (neutral versus fearful) was presented at the centre of the screen, with its gaze directed ahead, to the right or to the left. Immediately afterwards, target letters were presented to the right or to the left side of the screen and anxious participants were faster at responding to targets appearing at the location indicated by the fearful (versus neutral) gaze.

Another question is whether these emotional stimuli affect attention even when they do not reach consciousness. Attentional capture using pairs of subliminal faces showed that detecting a target following an angry face was faster, with a more pronounced effect when the target appeared in the left visual field, suggesting a greater implication of the right hemisphere (Mogg & Bradley, 1999). Other studies showed that perceptual awareness is not necessary for cue-induced attentional capture (Ansorge et al., 2009). For example, masked colour singleton cues (Ansorge et al., 2010) or binocularly suppressed colour singletons (Lamy et al., 2015) captured attention only if they were task relevant in spatial cueing paradigms, as reflected by cue validity effects. By contrast, in a recent study, emotional faces were found to produce an attentional shift only after awareness was reached (Qiu et al., in press). In addition, gaze-cueing effects have been investigated at the subliminal level, where only dynamic gaze (versus static gaze pointing to a direction) led to a cueing effect (Chen et al., 2014). Taken together, these findings show that subliminal stimuli might affect attention, but only in specific experimental settings that take into account stimulus valence or stimulus relevance for the ongoing task.

When investigating the effects of task relevance, another study showed that emotional expression cannot be processed when faces are attended but the emotion is irrelevant to the task (Tipura et al., 2019). Moreover, this study showed that selective attention is not impacted when cues are not consciously perceived: in a gender categorization task, targets appearing at validly cued locations produced quicker responses than targets at invalidly cued locations in the supraliminal condition only. These results were confirmed at the electrophysiological level. However, subliminal and supraliminal trials were displayed in blocs in this study, always starting with the supraliminal condition. This sequence allowed participants to consciously learn the rule of the experiment in the first half of the study. Researchers studying face perception at different levels of awareness often opt for a randomization of trial presentation across all the conditions, to avoid biasing the outcome that is measured (e.g., Balconi & Lucchiari, 2007; Ihrke & Behrendt, 2011; Liddell et al., 2004; Pegna et al., 2011). Ensuring that the effects are not due to the block structure of the experiment therefore seems necessary.

Moreover, some studies have shown that reaction times differ in initial (versus subsequent) blocs, revealing that effects of trial order may be confounded with experimental conditions (Lock & Berger, 1993). One might therefore ask if conclusions would differ if subliminal and supraliminal trials were randomized, which would reflect a bias due to the blocked trial presentation. There is also evidence that consciousness is necessary for some aspects of integration,
i.e., the process of combining different aspects of an object in a an integrated concept (Mudrik et al., 2014). Before being able to integrate face gender and associate it to the attention orientation task, it would therefore be necessary to first make this association at the conscious level. A study showed that subliminal priming of complex chess configurations was present only in expert chess players, suggesting that previous exposure is required to integrate visual information at an unconscious level (Kiesel et al., 2009). In another study investigating whether unconscious noncontiguous events can be integrated in long-term memory, unconscious integration between pair words sharing elements (e.g., “winter red” and “red compute”) was observed, showing that consciousness is not necessary in this case (Reber & Henke, 2012). In line with this effect, unconscious integration was found in tasks where unconscious trials were followed or surrounded by conscious trials. For example, Armstrong and Dienes (2013) highlighted subliminal processing of negation in a study where a subliminal instruction was presented to pick or not pick a noun in each trial, followed by a forced-choice task between two nouns. Lin and Murray (2014) showed unconscious integration of an abstract concept in a go no-go task.

The aim of the present paper is therefore to address the question of whether trial randomization may influence reaction times in a spatial cueing task and if a pre-existing conditioning is necessary for the integration of face gender and attention orientation. Moreover, our paradigm will allow us to test whether high attentional load, defined as “the perceptual load of target processing” (Lin & Yeh, 2014, p. 197) prevents the processing of emotion when face gender is task relevant. Pessoa et al. (2002) showed that brain regions responding to faces’ emotions were less activated when attentional load was high, suggesting that attentional resources are necessary to allow emotion processing. We conducted two studies. The first is identical to the original study (Tipura et al., 2019) while the second is a modified version of the original study where all the trials were randomly assigned in the sequence. The same analyses were conducted in the two studies, allowing us to test if trial randomization leads to the same overall conclusions. Moreover, a Bayes factor was calculated to test the likelihood of the data under the null (H0) and the alternative (H1) hypotheses associated with each effect. Moreover, in a randomized trial presentation, one might question whether intertrial priming may influence responses in a spatial cueing task. In other words, are the responses in subliminally cued trials affected by the preceding trial where the cue was consciously perceived? In line with this question, Ansorge et al. (2009; 2010) did not find any intertrial priming effect using masked colour singletons in a spatial cueing task. If the preceding supraliminal trial affects the following subliminal trial, reaction times should differ between blocked and randomized trial presentation.

Materials and methods

Participants

Two studies were conducted. In the first study, stimulus duration was not randomized (Tipura et al., 2019). In the second study, supraliminal and subliminal trials were randomized. Forty-six students at the University of Geneva were randomly assigned to one of the two experiments. Four participants were excluded from the analysis due to a lack of focus during the task leading to a lot of errors (>70%). The final sample of the first study consisted of 14 females and 5 males (mean age = 19.42; SD = 1.01). The final sample of the second study consisted of 16 females and 7 males (mean age = 19.56; SD = 1.4).

Stimuli and experimental procedure

In this attentional cueing task, 10 (5 males, 5 females) greyscale photographs expressing angry (50%), happy (25%) and neutral (25%) emotions were the cue stimuli (Ekman & Friesen, 1975). Happy and neutral expressions were merged in the analysis and represented the neutral condition. This procedure was used in the original study to control for low level features of emotional expression and avoid biasing the EEG data due to perceptual differences between angry and neutral emotions. The cue stimuli were oval-shaped faces that measured 9.5 cm horizontally (visual angle: 5.4°) and 14 cm vertically (visual angle: 8°). For the backward masking procedure, a mask was created by morphing one neutral female face and one neutral male face (not present in the target stimuli) and dividing it into 28 squares that were
then randomly placed in the oval. Stimuli were displayed on a black background. All the stimuli were created using Adobe Photoshop V6 which allowed us to control for isoluminance across all categories.

Each trial started with a fixation cross (300–600 ms). A face was then presented either subliminally (16 ms) or supraliminally (166 ms) and was immediately followed by the mask. The total duration of the face-mask pair was 300 ms. The participants were instructed to orient their attention to a left or right location on the screen depending on face gender. For half of the participants, the rule was to orient their attention on the right side of the screen if a male was displayed and on the left side if it was a woman. For the other half of participants, the rule was reversed. A random SOA (250–350 ms) separated the cue from the target. The target was a bar situated either on the right or on the left side of the screen. The side on which the bar appeared was cue-valid in 80% of the trials and invalid in 20% of the trials. The task was to determine the orientation (vertical or horizontal) of the bar as quickly as possible (see Figure 1). The response options were indicated by two stickers placed on two letters on the keyboard, representing a horizontal and a vertical bar. Response fingers were counterbalanced across subjects.

The experiment was divided into ten blocks of 48 trials. In the first study, the five first blocks were the supraliminal (166 ms) and the five last blocks were subliminal (16 ms). In the second study, stimulus duration was randomized across trials and blocks.

The study was accepted by the local ethics committee (University of Geneva) and all participants signed an informed consent form before participating. The study was performed in agreement with the Declaration of Helsinki.

**Analyses**

For both studies, a 2 (emotion: angry/neutral) × 2 (duration: subliminal/supraliminal) × 2 (validity: valid/invalid) frequentist repeated measures ANOVA was performed on the median RTs. To test the evidence of each effect and compare the two studies, a Bayesian mixed ANOVA was performed with factors 2 (emotion: angry/neutral) × 2 (duration: subliminal/supraliminal) × 2 (validity: valid/invalid) × 2 (category: stimulus duration randomized/stimulus duration not randomized). Analyses were performed in JASP (2020). For the Bayesian ANOVA, the default settings implemented in JASP were used and models were compared to the null model. We interpreted the Bayes factors of each effect based on Schönbrodt and Wagenmakers (2018; Table 1). Unlike the null hypothesis significance testing approach (Pernet, 2015), the Bayes factor allows the quantification of the strength of evidence for both H1 and H0, by comparing the probability of data under each model and determining which of

![Figure 1. Experimental procedure.](image-url)
the two models (both can be wrong) is more likely given the data. In this case, the Bayes factor for all the effects testing the comparison between the two studies (factor “Category”) is of interest.

RTs shorter than 200 ms and longer than 2000 ms were removed. Trials leading to incorrect responses were also removed from the analysis. 6.24% of the trials were removed.

**Results**

**First study – stimulus duration not randomized**

RTs were shorter for valid than invalid trials ($F(1, 18) = 28.19$, $p = .00004$, $\eta^2_p = .61$; see Table 1). The effect of duration was also significant ($F(1, 18) = 11.14$, $p = .003$, $\eta^2_p = .38$; see Table 1), with subliminal presentations leading to shorter RT’s than supraliminal presentations. The interaction duration × validity was significant ($F(1, 18) = 17.86$, $p = .0005$, $\eta^2_p = .49$). Post-hoc Tukey HSD test showed that in the supraliminal condition valid trials led to shorter RTs than invalid trials ($p = .0001$), which was not the case in the subliminal condition ($p = .51$) (see Table 2 and Figure 2 left).

**Second study – stimulus duration randomized**

RTs were shorter for valid than invalid trials ($F(1, 22) = 25.04$, $p = .00005$, $\eta^2_p = .53$; see Table 1). The effect of duration was not significant ($F(1, 22) = 1.63$, $p = .21$, $\eta^2_p = .07$). The interaction duration × validity was significant ($F(1, 22) = 34.66$, $p = .000006$, $\eta^2_p = .61$). Post-hoc Tukey HSD test showed that in the supraliminal condition valid trials led to shorter RTs than invalid trials ($p = .0001$), which was not the case in the subliminal condition ($p = .98$) (see Table 2 and Figure 2 right).

**Bayesian results**

There was anecdotal evidence for H0 for the Duration × validity × category interaction ($BF_{incl} = .436$), strong evidence for H0 for the main effect of Emotion ($BF_{incl} = .031$) and for the interaction Validity × category ($BF_{incl} = .203$), very strong evidence for H0 for the Emotion × duration ($BF_{incl} = .021$), Emotion × validity ($BF_{incl} = .024$) and Emotion × category ($BF_{incl} = .021$) interactions, and decisive evidence for H0 for the Emotion × duration × validity ($BF_{incl} = .007$), Emotion × duration × category ($BF_{incl} = .006$), Emotion × validity × category ($BF_{incl} = .003$) and Emotion × duration × validity × category ($BF_{incl} = 1.108e-4$).

There was substantial evidence for H1 for the main effect of Category ($BF_{incl} = 4.666$), strong evidence for the interaction Duration × category ($BF_{incl} = 19.452$), and decisive evidence for H1 for the main effects of Duration ($BF_{incl} = \infty$) and Validity ($BF_{incl} = \infty$) and for the interaction Duration × validity ($BF_{incl} = 1.777e+11$).

**Discussion**

In this paper, we tested if stimulus block presentation has an influence on reaction times, as compared to a randomized trial sequence, in a spatial cueing task. In a previous report (Tipura et al., 2019), a central

Table 1. Median reaction times (in ms) and standard deviations for subliminal, supraliminal, valid and invalid trials, averaged across the levels of the other factors for the blocked design study (B: stimulus duration not randomized) and the randomized study (R: stimulus duration randomized).

|          | Median | Std. Deviation |
|----------|--------|----------------|
| Subliminal B | 510.63 | 60.15          |
| Supraliminal B | 548.69 | 77.79          |
| Valid B | 509.88 | 55.46          |
| Invalid B | 514.06 | 66.62          |

Table 2. Median reaction times (in ms) and standard deviations for valid subliminal, valid supraliminal, invalid subliminal and invalid supraliminal trials for the blocked design study (B: stimulus duration not randomized) and the randomized study (R: stimulus duration randomized).

|          | Median | Std. Deviation |
|----------|--------|----------------|
| Valid Subliminal B | 512.5  | 60.45          |
| Valid Supraliminal B | 504.38 | 76.91          |
| Invalid Subliminal B | 460.0  | 55.81          |
| Invalid Supraliminal B | 508.75 | 64.77          |
stimulus (cue) was presented, whose role was to orient attention to a specific location in space. Awareness of the cue was manipulated by varying its duration of presentation. At the behavioural level, this study showed that selective attention and awareness act at distinct levels and are dissociated, and that cues can be processed only when faces are consciously perceived. Indeed, a significant effect of validity was observed in supraliminal but not in subliminal conditions, with valid trials leading to shorter RTs than invalid trials. This result is consistent with the effect found in many studies on selective attention (Brosch et al., 2011; Chica et al., 2013; Posner, 1980) and corroborates previous papers reporting similar findings. The absence of a validity effect in the subliminal conditions supports the idea that facial characteristics must be processed to an explicit level of awareness if the features are to be used to orient attention. The new findings reported in this paper are consistent with this interpretation, since both studies showed a significant interaction between duration and validity. These results were confirmed by the Bayesian interaction which showed decisive evidence for the alternative hypothesis and thus for the model with the interaction.

It has been shown that capture by visible (supraliminal) cues varies on a trial-by-trial basis, as reflected by introspective awareness of performance differences (Adams & Gaspelin, 2020) and oculomotor capture by salient stimuli (Adams & Gaspelin, 2021). Awareness of attentional capture (i.e., informing participants when their attention is captured at the trial level) leads to less capture (Anderson & Mrkonja, 2021), raising the question of how awareness of attentional capture might influence reaction times when cues are task-relevant. To better understand the relationships between subliminal capture, emotion perception and attention, investigating effects of awareness of capture might therefore be an interesting avenue for future research. In our paradigm, faces were used as cues in an endogenous manner, as opposed to exogenous attention where faces capture attention in a stimulus-driven way (Chica et al, 2013). This allowed us to test if perception of emotional cues can be processed at an unconscious level and impact selective attention. We show that focusing attention on face gender prevents emotion processing in a spatial cueing task and that unconscious stimuli do not impact selective attention.

The effect of duration was significant in the blocked presentation study but not in the randomized study. This result was confirmed with the Bayes factor for the interaction between duration and study, showing strong evidence for the alternative hypothesis. When responding to targets following subliminal (versus supraliminal) trials, responses were faster. This effect can be interpreted as a stronger engagement of attentional processes when cues are consciously perceived, but only when stimulus duration is presented in blocks. It has been shown that interindividual differences (such as sex) and within-session experience (such as presentation order) have an influence on reaction times (Lock & Berger, 1993). In blocked trial presentations, participants were slower in the first blocks in a simple reaction times task but quicker in the first block in a discrimination task. The latter would reflect participants’ use of strategies to increase accuracy across trial blocks. On the other hand, a decrease in reaction times over time may reflect habituation rather than a
decrease in computation necessary to perform the task or engage attentional processes to prepare specific actions (Wong et al., 2017). In our case, the decrease in reaction times over time in the blocked presentation can either reflect a habituation effect or a lesser computation time since the features necessary for attention orientation cannot be processed at the subliminal level. Conversely, there was no evidence for this effect of duration in the randomized study, where RTs were overall quicker than in the blocked presentation study. This may indicate less processing time when duration is randomized.

While it is generally assumed that randomizing trials in an experimental paradigm is necessary, some research questions might want to explore processes that involve the use of a blocked trial presentation. In this study, the use of blocks of supraliminal and subliminal trials allows us to ensure that participants are able to learn the rule of the experiment and use face features to orient their attention. At the duration level, the first part of the experiment acts as a learning phase while the second half is an implementation of the rule transposed at an unconscious level. In this respect, it is important to test whether a study where duration is randomized would lead to the same conclusions. In this report, we show that randomizing the factor duration influences the effect of duration but has no influence on the other effects. Importantly, the interaction between duration and validity has proven convincing in the original study (Tipura et al., 2019), as well as in two new studies, again showing that face features need to be consciously perceived to orient attention in a spatial cueing task. However, the transposition of the rule as integrated at the conscious level does not seem to be a pre-requisite for unconscious processing in this task.

Importantly, other manipulations of emotional valence can be assessed for their effects on spatial cueing. To further investigate how subliminal emotional stimuli might affect spatial cueing, other types of stimuli that are more similar to targets could be used. As such, target-like bars containing emotionally valenced words (instead of faces) could be used to assess how task relevance impacts the cueing effect using emotional stimuli. A study has used subliminal and supraliminal words (“right” and “left”) as cues for a visual colour search display task and showed no effect of spatial cueing in the subliminal condition (Baier & Ansorge, 2020). However, subliminal words were processed in a subsequent target discrimination task. Subliminal words therefore seem to be processed at the unconscious level but are unable to orient attention in this case. These effects could be investigated using emotional words as cues, which would allow an assessment of the relationship between time of presentation (subliminal vs. supraliminal), capture, and task relevance.

**Conclusion**

In this study, we were able to confirm previous behavioural findings showing that when attentional load is high, unconscious irrelevant emotional expressions do not capture attention. This was the case even when stimulus duration was randomized. These results indicate that pre-exposure to face stimuli at a conscious level is not required to transpose the rule at an unconscious level. Instead, face features need to be processed at an explicit level of awareness to be able to orient attention.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

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