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The affective prediction hypothesis assumes that visual expectation allows fast and accurate processing of emotional stimuli. The prediction corresponds to what an object is likely to be. It therefore facilitates its identification by setting aside what the object is unlikely to be. It has then been suggested that prediction might be inevitably associated with the inhibition of irrelevant possibilities concerning the object to identify. Several studies highlighted that the facilitation of emotional perception depends on low spatial frequency (LSF) extraction. However, most of them used paradigms in which only the object to identify was present in the scene. As a consequence, there have yet been no studies investigating the efficiency of prediction in the visual perception of stimuli among irrelevant information. In this study, we designed a novel priming emotional Stroop task in which participants had to identify emotional facial expressions (EFEs) presented along with a congruent or incongruent word. To further investigate the role of early extraction of LSF information in top-down prediction during emotion recognition, the target EFE was primed with the same EFE filtered in LSF or high spatial frequency (HSF). Results reveal a reduction of the Stroop interference in the LSF compared to the HSF priming condition, which supports that visual expectation, depending on early LSF information extraction, facilitates the inhibition of irrelevant information during emotion recognition.

Citation: Beffara, B., Wicker, B., Vermeulen, N., Ouellet, M., Bret, A., Funes Molina, M. J., & Mermillod, M. (2015). Reduction of interference effect by low spatial frequency information priming in an emotional Stroop task. *Journal of Vision*, *15*(6):16, 1–9, http://www.journalofvision.org/content/15/6/16, doi:10.1167/15.6.16.

doi: 10.1167/15.6.16 Received April 9, 2014; published May 20, 2015 ISSN 1534-7362 © 2015 ARVO

Introduction

Cognitive systems are efficient by using previous knowledge from past experiences in order to anticipate and adapt to future events (Clark, 2013; Pezzulo, 2012; Pezzulo, Hoffmann, & Falcone, 2007). The production of simulations about future events allows for predictions about the possible consequences of a present event. The predictions are created on the basis of both real and previously imagined experiences (Pezzulo, 2008). Anticipatory representations are stored in memory and available during precocious active perception. The perception of the environment therefore relies on the knowledge of past events as much as incoming sensory information.

Several works in visual neuroscience have brought experimental evidence favoring this view (Bar, 2003; Bullier, 2001). Bar (2003) proposed a model in which object perception and recognition benefit from top-down predictions generated in the orbito-frontal cortex (OFC). According to this model, a preselection of guesses (potential objects similar to the perceived one) in the OFC happens before actual object recognition in the infero-temporal (IT) cortex, facilitating its perception on the basis of anterior knowledge. Interestingly, the model proposes that predictions are generated via early extraction of low spatial frequency (LSF) information transmitted via magnocellular pathways after the retinal coding. This conduction of LSF information is faster than high spatial frequency (HSF) information, which is fine information transmitted via the parvocellular pathways. This fast processing allows the OFC to use the coarse information (from the occipital cortex through the dorsal stream) before the IT cortex can use the fine information (from the occipital cortex through the ventral stream). Thus, the IT cortex may use the information from the OFC as a global shape of the object to prepare and facilitate its identification. As a result, the IT cortex benefits from two types of information: a framework rapidly established by the OFC that allows an orientation of visual information processing and a slow but fine and detailed version of the object that validates and refines this framework.

Several results from studies using magneto-encephalography (MEG) and computational modeling support this hypothesis (Bar et al., 2006; Kveraga, Ghuman, & Bar, 2007). Results from a MEG study using an object recognition task revealed that the OFC was activated 50 ms earlier than the temporal areas involved in full recognition (Bar et al., 2006). Because this early activity was associated with correct recognition at a behavioral level, the authors suggested that it reflected a top-down facilitation effect occurring during visual perception.

More recently, this model of object recognition was extended to objects with affective value (Barrett & Bar, 2009). What is more, perception and decisions made on the basis of affective valence not only concern highly emotional stimuli, but also microvalenced objects (i.e., objects near to the neutral point of the valence scale), meaning that emotional content associated with objects is almost always involved in behavioral responses to external stimulations (Lebrecht, Bar, Barrett, & Tarr, 2012). Interestingly, Shenhav, Barrett, and Bar (2013) showed that affective prediction during object recognition shared a common cortical substrate (medial OFC) with associative processing. This experimental result is totally in line with Barrett and Bar's (2009) model and supports the fact that a top-down prediction made on the basis of stored representations is strongly dependent on the affective valence associated with these representations.

The predictions generated by the brain concern both highly probable (leading to expectations) and unlikely future events. In this way, the generation of expectations is likely to entail the inhibition of irrelevant alternatives (Bar, 2009; Pezzulo, Candidi, Dindo, & Barca, 2013; Yardley, Perklovsky, & Bar, 2012). Many studies described here highlighted that the facilitation of emotional perception depends on LSF extraction. However, the paradigms used so far only used stimuli in which only the object to identify was present in the scene. As a consequence, there have yet been no studies investigating the efficiency of prediction in the visual perception of stimuli among irrelevant information.

A classical task allowing the presentation of a target along with irrelevant information is the Stroop task (Stroop, 1935). The Stroop task consists of identifying the color of a word representing a color itself. Participants generally tend to read the word (irrelevant information) instead of naming the color of the letters (relevant information). The word produces interference with the color of the letters, impairing the task performance. Participants have to inhibit (internal intention) the irrepressible tendency to read the word in order to focus their attention on the color of the letters. A recent study replicated this Stroop effect with emotional faces (Ovaysikia, Tahir, Chan, & DeSouza, 2011). The authors showed that the concurrent presentation of an incongruent emotional word interfered with the perception of a face when participants had to identify the emotion of the face. They found a larger number of errors and an increase in reaction times (RTs) for incongruent compared to congruent trials, meaning that the incongruent words had to be inhibited in order to recognize the emotional facial expression (EFE).

This study directly aims to test if visual expectation facilitates the identification of an EFE in the presence of contradictory information more than confirmatory

Figure 1. Examples of targets (congruent target on the left, incongruent target on the right; joie = happiness; colère = anger).

information. This should be the case if the role of expectations is to overcome the ambiguities present in the complex environment (Bar, 2009; Yardley et al., 2012). In order to test this hypothesis, we used a repetition priming prior to an experimental procedure similar to Ovaysikia et al. (2011). Each EFE prime was low-pass filtered (LSF), high-pass filtered (HSF), or unfiltered (UF). The same but UF EFE was presented in the Stroop-like task with a word printed on it. If, as predicted by Bar's model (Bar, 2003), top-down prediction is made on the basis of LSF, then we expect a reduction of the emotional Stroop effect after an LSF priming but not after an HSF priming. Indeed, we expect that LSF extraction will lead to a rapid triggering of attentional focus on the relevant stimulus, diminishing the distraction induced by the incongruent word. Therefore, we hypothesize that the difference in RTs between the incongruent and congruent conditions of the Stroop task will be lower after LSF priming than after HSF priming. We also expect that the difference in accuracy between incongruent and congruent trials will be reduced by LSF priming.

Materials and methods

Participants

Sample size was determined on the basis of a previous experiment on perception of spatial frequency information (Mermillod, Droit-Volet, Devaux, Schaefer, & Vermeulen, 2010). Thirty-four volunteers participated in the study. One was excluded because he didn't fully understand the task (he was not a native French speaker) and three because they were left-handed. As a result, 29 participants (20 females, nine males, mean age = 20.41, $SD = 1.52$) were included in the data analysis. All participants included in the

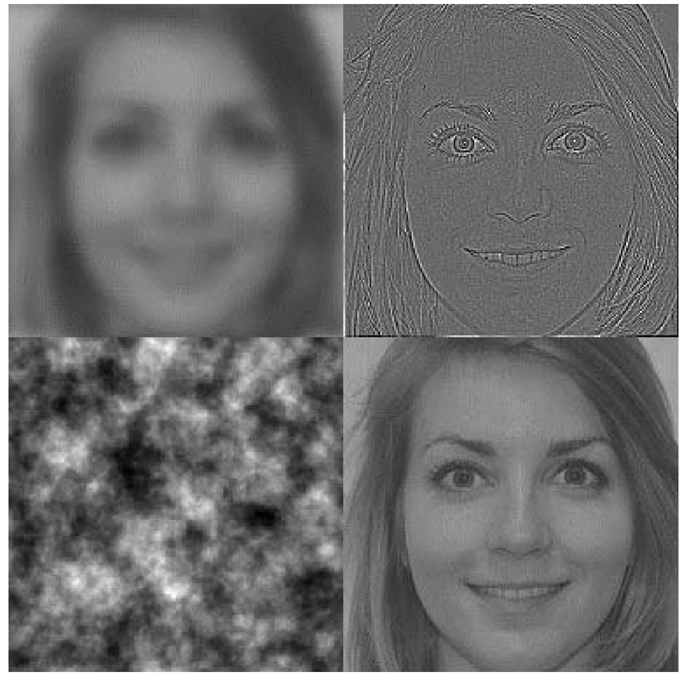

Figure 2. Examples of primes (top left: LSF face; top right: HSF; bottom left: white noise; bottom right: UF face).

statistical analysis were right-handed and had normal or corrected-to-normal vision. The study was carried out in accordance with the Declaration of Helsinki.

Stimuli and procedure

Participants were seated in a dark and quiet room in front of a computer screen (Dell UltraScan P991, aspect ratio 4:3, 19 in. (17.952-in. viewable image size) CRT Trinitron monitor, refresh rate = 60 Hz) at a distance of 110 cm. The resolution was set at 640×480 pixels. Target stimuli were 30 unfiltered pictures of faces (15 males, 15 females) expressing happiness and anger from the Karolinska Directed Emotional Faces database (Calvo & Lundqvist, 2008), displayed using E-prime software (E-prime Psychology Software Tools Inc., Pittsburgh, PA; 256 per 256 pixels, $\sim 7.60°$ per $7.60°$ of visual angle). The word "joie" ("joy" in French) or "colère" ("anger" in French) was displayed in yellow on the forehead of the face (see Figure 1). There were 30 faces $\times$ 2 emotions $\times$ 2 labels = 120 different targets.

Prime stimuli were either faces or control pictures. Faces were the same faces as those presented as targets, but they were unlabeled, and their spatial frequency content was either manipulated (LSF or HSF) or not (UF). Control pictures were made of spatial white noise respecting the $1/f$ decreasing of the energy spectra of natural scenes (Mermillod, Droit-Volet, et al., 2010).

Figure 3. Example of trial (here with an LSF prime, LSF mask, and a congruent word; the face expresses "happiness," so the good answer is "right").

Therefore, we had a total of 30 faces × 3 spatial frequencies × 2 emotions + 11 pictures of spatial white noise = 191 different primes (see Figure 2). LSF and HSF stimuli were filtered (from the UF images) in two bands: less than 8 cpi (cycles per image) for LSF and more than 64 cpi for HSF, using the MATLAB software (MathWorks, Natick, MA). For emotions of anger and happiness expressed by the faces contained in this database, these two cutoffs allow maximizing the differences of intrinsic information contained by LSF and HSF (Mermillod, Bonin, Mondillon, Alleysson, & Vermeulen, 2010). We therefore chose these cutoffs in order to maximize the gap between the two types of information and then created two distinct conditions of our variable, avoiding spatial frequency overlap (Awasthi, Friedman, & Williams, 2011; Liu, Collin, Rainville, & Chaudhuri, 2000). This range of filters is used to select either the magnocellular or the parvocellular channel brought into play during the visual task (Cheung & Bar, 2013; Harel & Bentin, 2013; Vuilleumier, Armony, Driver, & Dolan, 2003). All stimuli were normalized in contrast and luminance.

Each participant completed 320 trials. The 320 trials were randomly displayed, corresponding to a total of 20 faces displayed per category (20 faces × 2 emotions × 2 labels × 4 primes). Before the experimental block, a training block was presented to the participant in presence of the experimenter (10 trials with different stimuli from the experimental block). Each trial started (see Figure 3) with a fixation cross displayed for 1500 ms. A prime stimulus was then presented for 51 ms. After the prime, a mask appeared for 33 ms in order to prevent retinal persistence (LSF mask for LSF prime, HSF mask for HSF prime, UF mask for UF prime or noise prime).

Then, the target was shown until the participant responded for a maximum of 2000 ms. The participant's task was to look at the stimuli (prime and target) and judge whether the EFE target expressed happiness or anger. Visual feedback was presented after the participant's response: "juste" ("true" in French) displayed in blue if the participant gave a correct answer, "faux" ("false" in French) displayed in red if the participant gave a wrong answer, and "pas de réponse" ("no answer" in French) displayed in black if she/he did not respond before 2000 ms. Auditory feedback was also presented to the participant in case of a wrong response and another acoustic feedback in case of no response. Responses were given by pressing a joystick button with the thumb, one in each hand. Participants had to press the button of the right-hand joystick to answer "happiness" and that of the left-hand joystick for "anger." We chose not to counterbalance the side of the response because numerous works showed, especially through the body-specific hypothesis (Casasanto, 2009), that there is a mental link between the rightward space and positive concepts (e.g., "happiness") and between the leftward space and negative concepts (e.g., "anger") for right-handed persons. This choice was made in order to make the responses intuitive, avoiding eventual interference between response side and emotion (De la Vega, Dudschig, De Filippis, Lachmair, & Kaup, 2013). Finally, the experimenter clearly specified and insisted on the fact that the participant had to be as accurate and as fast as possible.

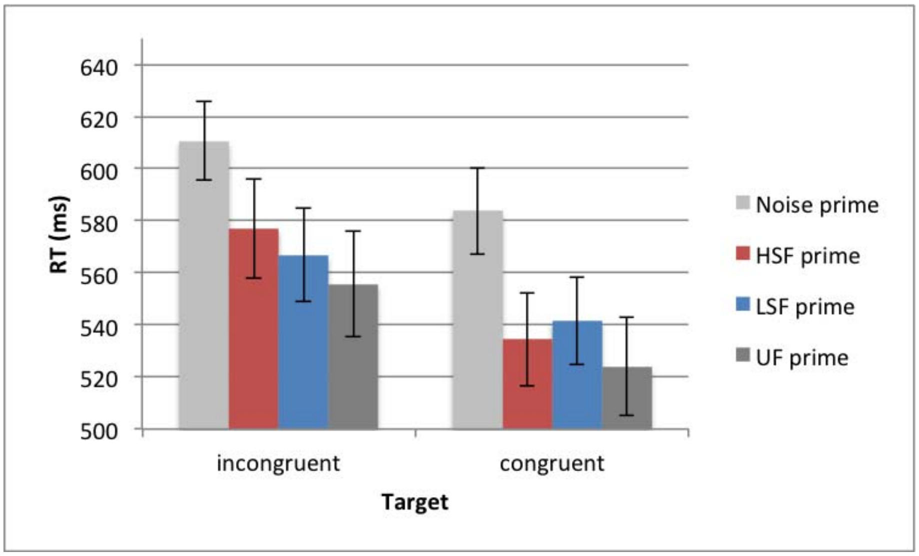

Figure 4. Mean reaction time as a function of target congruency and prime type (error bars indicate standard errors of the means).

Data analysis

We performed ANOVAs in order to test the efficiency of the classical Stroop effect and the efficiency of the priming effect on the basis of our specific material. For each analysis, we dismissed RTs under 150 ms for correct answers (only one on the totality). We used specific a priori orthogonal (Helmert) contrast analysis in order to test our main hypothesis. Indeed, as we aimed to show that LSF priming reduces the Stroop effect (interference), the dependent variable corresponding to the Stroop effect is the difference of performance between incongruent and congruent trials. Then, the contrast of interest on the Stroop effect is the difference (in RT, proportion of correct responses, or inverse efficiency score) between HSF and LSF priming. The aim of this contrast is to test our main hypothesis by comparing the effect of the prime (HSF vs. LSF) on the Stroop effect. Two other orthogonal contrasts (UF vs. HSF and LSF and noise vs. UF and HSF and LSF) were specified in order to test the significance of residual variance. We can conclude that our model is parsimonious only if the contrast of interest is significant and if the two orthogonal contrasts are not (Brauer & McClelland, 2005).

Results

RTs

An ANOVA was conducted on RTs in a 2 congruency (congruent or incongruent) × 4 primes (LSF, HSF, UF, or control) conditions in a within-subject design. The analysis was done on successful trials only (see Figure 4). As expected, a significant effect was found for congruency, $F(1, 28) = 41.57$, $MSE = 1398.99$, $p < 0.001$, $n^2_p = 0.60$. Congruent targets ($M = 545.93$ ms, $SE = 17.11$) were identified faster than incongruent ones ($M = 577.60$ ms, $SE = 17.48$). A significant effect was also observed for the type of prime, $F(3, 84) = 38.93$, $MSE = 907.18$, $p < 0.001$, $n^2_p = 0.58$. No significant effect appeared for the general interaction between congruency and type of prime, $F(3, 84) = 1.210$, $MSE = 724.24$, $p = 0.31$.The contrast of interest (HSF vs. LSF) calculated on the Stroop effect was marginally significant, $F(1, 28) = 3.48$, $MSE = 1230.63$, $p = 0.073$, $n^2_p = 0.11$. The two orthogonal contrasts were not significant, $F(1, 28) < 1$, $MSE = 1446.62$ and $F(1, 28) < 1$, $MSE = 1668.00$.

Accuracy (proportion of correct responses)

We also computed an ANOVA on the proportion of correct responses (PC). Following the same design as before (see Figure 5), a significant effect was again observed for congruency, $F(1, 28) = 19.27$, $MSE = 0.00$, $p < 0.001$, $n^2_p = 0.41$. Congruent targets ($M = 0.99$, $SE = 0.00$) were better assessed than incongruent ones ($M = 0.96$, $SE = 0.01$). The type of prime effect was also significant, $F(3, 84) = 4.21$, $MSE = 0.00$, $p = 0.01$, $n^2_p = 0.13$. General interaction between congruency and prime was not significant, $F(3, 84) < 1$, $MSE = 0.00$. The contrast of interest was not significant, $F(1, 28) < 1$, $MSE = 0.00$. The second contrast was not significant, $F(1, 28) < 1$, $MSE = 0.00$, and the third contrast (noise vs. UF, HSF, LSF) was marginally significant, $F(1, 28) = 3.16$, $MSE = 0.00$, $p = 0.086$, $n^2_p = 0.10$.

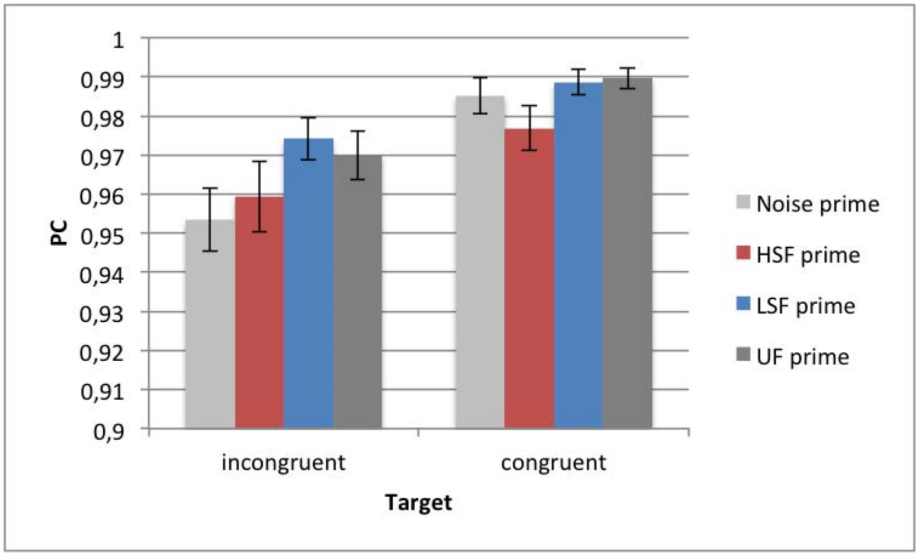

Figure 5. Mean proportion of correct responses (PC) as a function of target congruency and prime type (error bars indicate standard errors of the means).

Inverse efficiency score

Overall, LSF priming did not reduce RTs but enhanced accuracy compared to HSF priming. To better clarify this result, we computed an ANOVA on the inverse efficiency score (IES; Townsend & Ashby, 1978): IES = RT/PC where RT is the mean reaction times and PC the proportion of correct answers in a given condition. Indeed, both variables are indicators of the whole performance. Because the mean RTs are divided by a measure without unit, we will present the results in terms of rapidity pondered by accuracy in ms (see Figure 6). According to Bruyer and Brysbaert (2011), IES is relevant if the accuracy is not too low (i.e., if the proportion of correct answers is >0.90). In our study, average PC was equal to 0.97 ($SD = 0.03$), and the lower value was 0.82 and thus compatible with IES analysis. As noticed by Ramon and Rossion (2012), IES constitutes a useful tool as it can increase the sensitivity of data without necessarily increasing dispersion.

A significant effect of congruency was observed, $F(1, 28) = 55.58$, $MSE = 2227.61$, $p < 0.001$, $n^2_p = 0.67$, showing that responses given to congruent ($M = 554.38$ ms, $SE = 17.21$) compared to incongruent ($M = 600.58$ ms, $SE = 18.84$) targets were faster. A significant effect of the type of prime was also observed, $F(3, 84) = 38.45$,

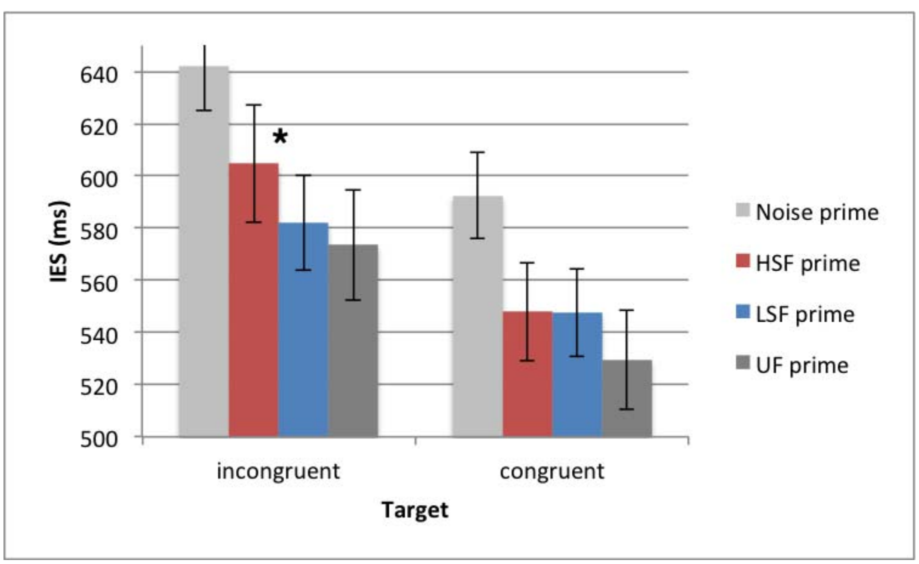

Figure 6. Overall performance (IES = RT/PC) as a function of target congruency and prime type (error bars indicate standard errors of the means).

$MSE = 1214.51$, $p < 0.001$, $\eta^2_p = 0.58$. Again, no significant effect was observed for the interaction between congruency and prime, $F(3, 84) = 1.33$, $MSE = 958.43$, $p = 0.27$.

The most interesting result appeared for our contrast of interest (LSF vs. HSF priming on the Stroop effect), which was significant, $F(1, 28) = 4.62$, $MSE = 1544.98$, $p = 0.04$, $\eta^2_p = 0.14$. The two other orthogonal contrasts were not significant, $F(1, 28) < 1$, $MSE = 1800.04$ and $F(1, 28) < 1$, $MSE = 2405.36$, meaning that the contrast of interest was a parsimonious model to explain the data. In order to examine the contrast of interest more precisely, we computed pairwise comparisons between HSF and LSF for the congruent and incongruent trials. As predicted, LSF priming ($M = 582.03$ ms, $SE = 18.20$) led to faster IES responses than HSF ($M = 604.75$ ms, $SE = 22.47$) for the incongruent targets, $t(28) = 2.42$, $p = 0.02$. Interestingly, for the congruent targets, no differences were observed, $t(28) = 0.64$, $p = 0.96$, between LSF priming ($M = 547.50$ ms, $SE = 16.72$) and HSF ($M = 548.04$ ms, $SE = 18.83$).

Discussion

The present study aimed to test whether LSF visual information is used preferentially to trigger top-down inhibitory processes during recognition of EFEs. We used an emotional Stroop-like task and measured the influence of LSF versus HSF primes when a top-down control was required to perform the task. As suggested by a recent neurocognitive model of visual object perception and recognition (Bar, 2003), the LSF information would be the unique visual information that is treated fast enough to reach the OFC and enable top-down control on the IT cortex. Our results show that LSF stimuli have primed on the relevant stimulus (i.e., the face), decreasing the effect of the distractor (i.e., the word). By contrast, when no top-down inhibitory control was required (congruent condition), there was no difference between LSF and HSF priming. This confirms that LSF information was predominantly efficient to recognize an EFE only if its identification required top-down inhibitory processing in a task requiring both functional inhibition and affective decision making. The effect of LSF priming is clearly a reduction of the Stroop effect, compared to HSF priming. Therefore, we suggest here that this early supply of LSF information by the primary visual system may have enhanced the well-known inhibitory function of the OFC (Krueger et al., 2011; Miller & Cohen, 2001; Schoenbaum, Roesch, Stalnaker, & Takahashi, 2009). This involvement of the OFC during this inhibitory process has to be confirmed by further neuroimaging studies. The behavioral results obtained in this study totally support the hypothesis formulated by Bar (2009) toward the cognitive function of prediction. The reduction of Stroop interference by LSF versus HSF priming suggests that prediction is closely associated with inhibition. The availability of LSF information facilitated the identification of the EFE in the presence of the irrelevant information, highlighting that prediction was useful when the complexity of the stimulus to process increased. This experiment brings evidence toward a functional role of prediction in complex environments and toward a relationship between expectation and inhibition.

Aside from the executive process used in our behavioral paradigm, further studies have to investigate the importance of LSF information for predictive coding related to emotional processes. Future studies will also have to replicate the effect obtained here and to transfer the paradigm to nonemotional stimuli. We have focused our attention on emotional stimuli because (a) affective valence plays an important role in prediction (Barrett & Bar, 2009; Lebrecht et al., 2012), and (b) the OFC is highly related to emotional processing and functional inhibition (Krueger et al., 2011; Rolls, 2000; Schoenbaum et al., 2009). However, a similar process might be involved more generally for any kind of visual stimuli. This kind of study could allow determining whether there is a preferential effect of LSF priming for emotional stimuli versus nonemotional stimuli. Again, this kind of experiment should be run while recording brain signals with high temporal resolution neuroimaging. In our opinion, it is of importance to find the neural correlates of executive functioning while processing different spatial frequencies. It remains to find the causal and dynamic relationships between executive functions and spatial frequency processing.

Conclusions

Within the theoretical framework of Bar's (2003) and Barrett and Bar's (2009) models, we proposed an experimental design allowing the study of the functional role of early LSF information extraction in emotional prediction and inhibition. The experiment reported in this paper brings out a new point of view about the role of LSF information in visual perception of emotions. Our data show that the early extraction of LSF information allows focusing on a relevant target when a distractor is present in the environment. To our knowledge, this is the first study showing the efficiency of LSF extraction in a task involving the inhibition of irrelevant information. As this inhibition process was facilitated by LSF priming, we can conclude that very

early extraction of visual features is crucial for nonautomatic behaviors.

Keywords: top-down prediction, visual perception, emotional facial expressions, spatial frequencies, emotional Stroop

Acknowledgments

This work was supported by the French CNRS (UMR 5105) and a grant from the Institut Universitaire de France to MM. We thank Eric Guinet and the Caltech group for technical support. We thank the English native speaker for scientific language editing of the manuscript.

Commercial relationships: none.
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