Mindfulness

Mindfulness and de-automatization: Effect of mindfulness-based interventions on emotional facial expressions processing

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We are very grateful for the opportunity to publish this article in *Mindfulness*. We have edited the paper according to all you recommendations, and all the authors have approved this final version. Bellow you will find the details about the corrections.
Best regards,

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Mindfulness and de-automatization: Effect of mindfulness-based interventions on emotional facial expressions processing

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Abstract

Objectives. Past research has suggested that mindfulness training reduces automaticity while processing socio-emotional stimuli. This study aimed to analyze how mindfulness practice may reduce the use of prior knowledge during the recognition of emotional facial expressions. Based on a predictive brain model, we hypothesized that mindfulness practice would reduce the top-down processing of Low Spatial Frequency information. **Methods.** This experiment compared the performance of a mindfulness group (n=32) and a waitlist control group (n=30) in an emotional Stroop task before and after an 8-week training course. The emotional Stroop task comprised two emotional facial expressions (joy or anger) topped with a congruent or incongruent word, and was primed by facial expressions filtered in two spatial frequency bands: High Spatial Frequency (HSF) or Low Spatial Frequency (LSF). **Results.** Having measured the reaction time, the results showed a significant interaction between group (mindfulness vs. control) and session (before vs. after training; $p = 0.04$; $R^2 = 0.001$), irrespective of spatial frequency channels. Breaking down the interaction showed that mindfulness-trained participants responded significantly faster than the controls to any type of information. The interaction Group by Session by Priming was not significant. **Conclusion.** These results are in line with research underlining the effects of mindfulness-based interventions on global attentional control. More precisely, the global reduced reaction time did not support lower top-down predictive coding abilities specifically driven by low spatial frequency channels, but indicated a better general sensitivity to the perceptual environment.

It is of primary importance for cognitive systems to be able to predict and anticipate events in order to efficiently process information from the complex environment (Pezzulo, 2008; Pezzulo et al., 2013). However, a growing body of research suggests that given the complexity and the instability of the environment, it can also become risky and maladaptive for individuals to rely solely on prior knowledge to perceive and act efficiently (Amodio et al., 2007). This may particularly be the case when preconceptions lead to discrimination (Pearson et al., 2009). It is necessary to constantly revise estimations about environmental objects or events, and to update prior knowledge, as predictions and expectations only represent the likelihoods of a changing environment (Payzan-LeNestour et al., 2013; Schoenbaum et al., 2009). Hence, although past research has shown that most automatic human processes are a useful means of adapting to situations, more recent studies have shown that this is not always the case, and that greater cognitive flexibility can help reduce the interference from past experience on present moment attention. Indeed, several studies have underlined that too strong a reliance on previous categories, expectancies, and schemata can be associated with diminished flexibility and difficulties in updating knowledge (Amodio et al., 2007; Hinze et al., 1997; Hirsh et al., 2012; Horstmann, 2015; Schützwohl, 1998).

In social contexts, the complexity and unpredictability of interactions may lead to inappropriate automatic responses because of existing schemata. For instance, unexpected events within an interaction can be perceived as threats (Bartholow et al., 2001; Mendes et al., 2007). It would therefore be useful to be able to reduce the tendency to rely mainly on predictions, i.e., top-down processes, and to be able to rely more on upcoming information from the senses, i.e., bottom-up processes in certain circumstances, as this would lead to greater flexibility and more adjusted responses to complex situations. It has been shown that previous knowledge (such as concepts) can enhance emotion processing (Nook et al., 2015).

However, there could be a need to reduce this default tendency of automatic prediction, given the number of biases which emerge from automaticity in perception, along with automaticity in socio-emotional functioning such as dogmatism, for instance (Greenberg et al., 2010; Kang et al., 2013; Lueke & Gibson, 2014; Macrae & Bodenhausen, 2000; Olson & Fazio, 2006; Whitmarsh et al., 2013). Emotional stimuli are often used in such studies because the default tendency and skill for prediction, anticipation, and expectation has been found to be strongly associated with emotional processing in the human brain (Barrett & Bar, 2009; Lebrecht et al., 2012; Shenhav et al., 2013).

In order to help individuals to better cope with changes, uncertainty, and the new actions required by the environment, cognitive flexibility is particularly useful. Cognitive flexibility is partly linked to attentional processes, and can be trained. As mindfulness-based practices have been shown to increase attentional skills, they are considered as a form of cognitive training which helps an individual in monitoring and regulating attention (Lutz et al., 2008). Mindfulness, is defined as the awareness that emerges through purposively and non-judgmentally paying attention in the present moment to the unfolding experience, on a moment by moment basis (Kabat-Zinn, 2003). It is considered as a means of reducing inappropriate automatic cognitive and behavioral responses to external and internal cues (Segal et al., 2002). Mindfulness-based practices are derived from Buddhist mental training techniques in which individuals focus their attention on present events in a non-evaluative and non-reactive way. Evidence has accumulated regarding the effects of mindfulness practices on improving cognitive (Heeren et al., 2009), and executive flexibility (Hodgins & Adair, 2010), and are associated with neurophysiological changes indicative of greater cognitive and physiological flexibility (Deepeshwar et al., 2015; Krygier et al., 2013; Malinowski, 2013). Research has been carried out on the effects of mindfulness on automatic processes such as interference in the Stroop task (Moore & Malinowski, 2009), or cognitive rigidity in the

Einstellung water jar task (Greenberg et al., 2010). Prior studies have shown that mindfulness-based training improved performance in Stroop tasks (e.g., Wang et al., 2012), and that mindfulness is related to higher cognitive and physiological flexibility (Burg & Wolf, 2012; Garland, 2011; Krygier et al., 2013). Several studies have also attested that this type of cognitive training produces greater flexibility in visual processing by reducing the automatic and habitual use of categories based on new information (Hodgins & Adair, 2010; Moore et al., 2012; Moore & Malinowski, 2009; Wenk-Sormaz, 2005).

When considering signal processing, predictive coding is an economic way to perceive the environment since the expected information is already encoded and reused, while only unexpected variations of the stimulus need processing (Clark, 2013). In the visual domain, predictions are generated on the basis of anterior knowledge triggered by an early version of the visual input which can be associated with this anterior knowledge (Bar, 2003; Bar et al., 2006; Chaumon et al., 2013; Kveraga et al., 2007). This early version of the stimulus contains the coarse features of the object, and can activate the associated representations encoded in memory in order to guide and facilitate their visual perception (Bar, 2009). Visual prediction can be triggered by, and based on, coarse visual features, which can be artificially selected in images by separating the low (coarse information) and the high spatial frequencies (fine information; e.g., Mermillod et al., 2010a, 2010b). Bar's model (2003) suggests that low spatial frequencies (i.e., the coarse features of visual stimuli) are rapidly conveyed from the retina to the primary visual cortex and, more importantly, to the orbitofrontal cortex for predictive coding of the visual scene, which is later recognized at the level of the temporal cortex (Bar et al., 2006; Figure 1). In other words, the role of the orbitofrontal cortex is to generate predictions (i.e., guesses) about the object to be identified, on the basis of previous knowledge. This model has been further tested in magnetoencephalography studies for object recognition (Bar et al., 2006), and fMRI studies for scene categorization (Kauffmann et al., 2014, 2015), which have confirmed that the left orbitofrontal cortex was activated before the recognition-related areas in the temporal cortex. This early activation was modulated by the low spatial frequency of the stimuli, supporting the hypothesis that there is top-down facilitation in stimulus recognition. Thus, predictive coding was shown to influence perceptual processes in general, but recent studies also suggested a strong involvement in affective processes and emotion perception (Barrett & Bar, 2009; Lebrecht et al., 2012; Shenhav et al., 2013).

Facial expressions are considered to be important signals in providing information both about people's internal states and environmental events (Waller & Micheletta, 2013). The success of the communication engaged through facial expressions is dependent on the signaling and the decoding of the facial expression (Jack, 2013; Jack & Schyns, 2015). Regarding emotional facial expressions processing, the recognition of someone's emotion is dependent on the top-down influence linked to previous knowledge (Beffara et al., 2012; Brown & Brüne, 2012; Hamilton, 2013; Likowski et al., 2008; Wang & Hamilton, 2012). In line with Bar's (2003) model (see Figure 1), past studies have found that Low Spatial Frequency (LSF) content (coarse information) played a major role in the recognition of emotional facial expressions (e.g., Beffara et al., 2015; Mermillod et al., 2010a; Vlamings et al., 2009).

[Please insert Figure 1. Illustration of the predictive brain model]

The current study aimed at testing whether mindfulness-based practices could reduce automatic processes (i.e., reading the word) in an emotional Stroop task using low and high spatial frequency primes. Filtering and selecting the spatial frequencies of the stimuli was used to determine if mindfulness-based training could improve cognitive flexibility and further reduce automatic associative biases associated with top-down processing. Since the predictive system tends to rely more on low spatial frequency (LSF) information when processing unexpected information, the hypothesis was that mindfulness-based training would diminish the advantage of LSF primes observed in the emotional Stroop task (Beffara et al., 2015). In other words, we assumed that the reaction time for emotional facial expression identification during a Stroop task with LSF (vs. HSF) primes would increase after a mindfulness-based training compared to a control group, because of reduced automatic top-down predictions. An integrated mindfulness-based training was selected for this study as it proposes a training that is mainly based on everyday brief and informal practices through information perceived by the senses and body movements. These practices aim to reduce top-down driving information (assumed to be provided by LSF information) and to enhance the participants' ability to be open to new information coming through their senses.

Methods

Participants

Based on a prior study on the modified Stroop task with High and Low Spatial Frequencies priming (Beffara et al., 2015), at least 30 participants in each condition (experimental and wait-list control) had to be recruited. The participants were recruited via flyers and the FOVEA website. General population adults were recruited and randomly assigned to the FOVEA group (i.e., the mindfulness experimental group), or placed on a waiting-list (i.e., the control group) by the research assistant from the Vittoz institute (more specifically, the first ten participants who contacted the institute were placed in the experimental group, the next ten were placed in the waiting-list control group, the following ten in the experimental group, etc.). In the sample recruited for the overall FOVEA study (Shankland et al., 2020), a subsample of 70 participants were contacted to perform the emotional Stroop task. Before the beginning of the program, 32 FOVEA participants (mean age = 51.13; 80% women) and 30 controls (mean age 46.04; 93.75% women) consented to complete the emotional Stroop task at T1 (i.e., at baseline), out of which 25 FOVEA participants and 26 controls completed the task at T2 (i.e., after the end of the training period of the experimental group).

Procedure

This study was carried out on a subsample of participants from a larger study on the effects of an integrated mindfulness practices program called FOVEA which focused on stress reduction and increased well-being. FOVEA stands for Flexibility and Openness, based on the Vittoz method, to enhance Experiential Awareness. Vittoz was a Swiss physician who developed a method mainly based on informal (integrated to everyday life) mindfulness practices such as mindful eating, mindful walking, or mindful listening. The program format was similar to that of classical validated mindfulness-based group interventions such as MBSR (Mindfulness Based Stress Reduction; Kabat-Zinn, 1990) and MBCT (Mindfulness Based Cognitive Therapy; Segal et al., 2002), with a two-hour session every week for eight weeks. In the FOVEA program, each week the practices focused on one of the five senses in order to train the participants to remain aware of stimuli and to develop an open, non-judgmental and non-reactive stance, in order to help reduce top-down interference.

For this program (see Table 1 for a description of each session and between-session practices), FOVEA instructors were recruited among the national Vittoz association, which trains Vittoz instructors (four years of training, 24 days per year, individual therapy 1h per week in year 1 and 2, individual training 1h per week year 3 and 4, and supervision once qualified to be a Vittoz instructor). A group of ten practitioners with between 2 and 15 years of experience (m = 9.2 years of practice) received a further two days of training in the FOVEA protocol in order to use the FOVEA manual in the framework of a larger study on integrated mindfulness practices (see Shankland et al., 2020). Among those instructors, five were asked to inform their participants that they could take part in the present study, which consisted of performing an emotional Stroop Task before and after the FOVEA program (experimental group) or while waiting for the beginning of the program (waiting-list, control group).

During the research, the instructors filled a follow-up workbook at the end of each session indicating the practices performed during the session, as well as any comments that could be useful for the research protocol. This procedure enabled the researchers to assess the extent to which the instructors had followed the manual. The instructors had a supervision and could ask the research investigators any question at any time during the study regarding the FOVEA manual in order to be as close as possible to the research investigators' aims during each session.

[Please insert Table 1]

The study was approved by the ethical committee of the local university (CERNI n° 2013-11-06-27). All the participants included in the study signed an informed consent form, and received 15 euros each time they completed the emotional Stroop task: once before the program (T1), and again at the end of the program (T2). The control group completed the same task at the same interval of time without receiving the training. Before performing the emotional Stroop task, the participants began with a 5-minute resting time in order to be in a comparable state.

Adherence was measured through a daily practice journal that the participant self-completed (daily practice time and frequency of practice), and reported at the end of the program via an anonymous online questionnaire. On average, 95% of the participants performed daily integrated practices between the sessions (see Shankland et al., 2020).

Measures

The modified emotional Stroop task was performed individually by each participant at two time-points, separated by about 10 weeks (before the beginning of the experimental group's program and after the end of it). The participants were seated in a quiet room in front of a computer screen (DELL Inspiron, aspect ratio 4:3, 15.6 inches, refresh rate = 60 Hz) at a distance of 70 cm. The resolution was set at 640x480 pixels. The target stimuli were 30 unfiltered pictures of faces (15 males, 15 females) expressing happiness and anger, taken from the Karolinska Directed Emotional Faces database (Calvo & Lundqvist, 2008), and displayed using E-prime software (E-prime Psychology Software Tools Inc., Pittsburgh, USA, 256 per 256 pixels, ~7.60º per 7.60ºof visual angle). The word "joie" ("joy" in French) or "colère" ("anger" in French) was displayed in yellow on the forehead of the face (Figure 2). There were 30 faces * 2 emotions * 2 labels = 120 different targets.

[Please insert Figure 2. Examples of targets]

The prime stimuli were the same faces as those presented as targets, but they were unlabeled and their spatial frequency content was manipulated (LSF or HSF; (see Figure 3). The LSF and HSF stimuli were filtered (from the original unfiltered images) in two frequency bands: less than 8 cycles per image (cpi) for LSF, and more than 64 cpi for HSF, using MATLAB software (MathWorks, Natick, MA). For the chosen stimuli in the database (i.e., 30 faces * 2 emotions), these two cutoffs allowed us to maximize the difference in the intrinsic information contained by LSF and HSF (Mermillod et al., 2010a). In other words, it allows to maximize the gap between the two types of information, avoiding spatial frequency overlap (Awasthi et al., 2011; Liu et al., 2000).

[Please insert Figure 3. Examples of primes]

Each participant completed 240 trials presented in one block (duration 15 minutes). These 240 trials were randomly displayed, and corresponded to a total of 30 faces displayed per category (30 faces * 2 emotions * 2 labels * 2 primes). Before the experimental block, a practice block was presented to the participant in the presence of the experimenter (eight trials with different stimuli from the experimental block). Each trial started 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, and HSF mask for HSF prime). The mask stimuli were generated on the basis of spatial white noise, respecting the 1/f decreasing of the energy spectra of natural scenes (Beffara et al., 2015; Mermillod et al., 2010b) (Figure 4) .

After the mask, 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 to judge whether the target expressed joy or anger. Visual feedback was presented after the participant's response: "juste" (meaning "correct") was displayed in blue if the participant gave the correct answer, while "faux" (meaning "incorrect") was displayed in red if the participant gave the wrong answer, and "pas de réponse" ("no answer" in French) was displayed in black if she/he did not respond before 2000 ms. Responses were given by pressing the left or right arrow keys on the keyboard with the index finger (left index finger on the left arrow and right index finger on the right arrow). The participants had to press the right arrow to answer "joy", and the left arrow for "anger". We chose not to counterbalance the side of the response since numerous studies have shown, particularly in terms of the body-specific hypothesis (Casasanto, 2009), that for right-handed individuals there is a mental link between the rightward space and positive concepts (e.g., "joy"), and between the leftward space and negative concepts (e.g., "anger"). This choice was made in order to try to ensure that the responses would be intuitive, avoiding eventual interference between the response side and emotion (De la Vega et al., 2013). Finally, the experimenter clearly specified that the participant should seek to be as accurate and as fast as possible, and that there will be no break until the end of the task.

[Please insert Figure 4. Example of trial]

Data Analyses

Given the sample size recruited (df = 45), a power = 0.8 and a significance level $p<0.05$, we should be able to observe an effect size of (at least) $R^2 = 0.17$. This analysis was performed with 'pwr' package under R (https://github.com/heliosdrm/pwr). This computation was performed based on the general linear model because such estimations are hard to perform for linear mixed models (LMM).

Reaction time (RT) was the key measure in all the analyses. We did not analyze accuracy (ACC), because the mean ACC across all conditions was >98%; nonetheless, only correct trials were included in the RT analyses. Data were analyzed using R software (R Core Team, 2015) and lme4 package (Bates et al., 2015). Two separate LMMs were tested. First, data at baseline (i.e., T1) were entered into an LMM including fixed effects for Congruency (congruent vs. incongruent stimuli), Priming (LSF vs. HSF primes), and Emotion (positive vs. negative valence), and random intercepts for participants, so:

LMM1: *log(RT) ~ Congruency*Priming*Emotion + (1|Participant)*.

Second, data from both time points were entered into a second LMM including fixed effects for Congruency, Priming, and Emotion (similarly to LMM1), along with additional fixed effects for Group (mindfulness vs. controls) and Time point (Before vs. After), random intercepts for Participant, and random slopes for Time point, so:

LMM2: *log(RT) ~ Time point*Group*Congruency*Priming*Emotion + (1+Timepoint|Participant)*.

Results

As stated above, the mean ACC per group and time point was above 98% for all conditions, so only the RT was considered in the analyses (see Table 2 for descriptive statistics of the RT and ACC according to each conditions).

[Please insert Table 2]

Baseline Performances

The LMM1 revealed a significant effect of Congruency [$F(1, 14600) = 162.88$, $p < 0.001$], Priming [$F(1, 14600) = 5.30$, $p = 0.02$], and Emotion [$F(1, 14600) = 86.62$, $p < 0.001$]. As expected, the RT was lower for congruent stimuli in comparison to incongruent stimuli. However, HSF primes produced faster RT compared to those with LSF primes. Stimuli with happy expressions also produced faster RT than angry expressions. There was also a significant double interaction between these three variables [$F(1, 14600) = 4.09$, $p = 0.04$]. Planned comparisons revealed significant faster RT for congruent stimuli expressing anger with HSF priming vs. congruent stimuli expressing anger with LSF priming [$b = 0.02$; $z = 2.58$; $p = 0.01$] as well as a trend for faster RT for incongruent stimuli expressing joy with HSF priming vs. incongruent stimuli expressing joy with LSF priming [$b = 0.01$; $z = 1.75$; $p = .08$] (Figure 5).

[Please insert Figure 5]

In order to simplify and understand this two-ways interaction, a reduced model was built with the difference in RT between incongruent and congruent stimuli (namely, the Stroop effect) as the dependent variable. This analysis showed no significant main effect of Priming [$F(1, 185.21) = 0.85$, $p = 0.34$] and Emotion [$F(1, 185.21) = 0.35$, $p = 0.55$] but a significant interaction between Priming and Emotion [$F(1, 185.21) = 3.76$, $p = 0.05$]. The Stroop effect was smaller in the LSF priming condition in comparison to the HSF priming condition, but only for the angry emotion [$b = 17.63$; $z = 2.01$; $p = 0.04$], and marginally smaller for Joy vs. Anger in the LSF priming condition [$b = -15.60$; $z = -1.78$; $p = 0.08$] (Figure 6).

[Please insert Figure 6]

Effects After a Mindfulness Training

Similarly to the results at baseline, the analysis performed with both time-points showed a significant main effect of Congruency [$F(1, 26614.1) = 344.18$, $p < 0.001$], Priming [$F(1, 26614.1) = 4.37$, $p = 0.02$], and Emotion [$F(1, 26614.1) = 105.23$, $p < 0.001$]. The RTs for the congruent stimuli were faster than those for the incongruent stimuli, faster for HSF vs. LSF priming, and faster for Joy vs. Anger. Importantly, we observed a significant interaction between Time-point and Group [$F(1, 52.3) = 4.37$, $p = 0.04$]. Post-hoc comparisons (Tukey's test) revealed that the participants were faster after the mindfulness-based training [$b = 0.05$, $z = 10.99$, $p < 0.001$], and slower after re-test for the wait-list control group [$b = 0.01$, $z = 3.92$, $p < 0.001$], while there was no significant difference between groups at T1 [$b = 0.01$, $z = 0.29$, $p > 0.1$] (Table 3, Figure 7).

[Please insert Figure 7]

It is worth noting, however, that the Spatial Frequency of the Prime did not modulate this interaction, neither on the overall level [Group-by- Time-point-by-Priming: $F(1, 26614.1) = 1.87$, $p = 0.17$], nor for specific congruency and emotion conditions [Group-by-Time-point-by-Congruency-by-Priming: $F(1, 26614.1) = 0.26$, $p = 0.61$; Group-by-Time-point-by-Priming-by-Emotion: $F(1, 26614.1) = 1.29$, $p = 0.26$; Group-by-Time-point-by-Congruency-Priming-Emotion: $F(1, 26614.1) = 0.53$, $p = 0.47$]. In other words, the reaction time was faster after mindfulness training independently of the experimental condition. Detailed results of each effect tested are shown in Table 3 and Figure 8.

[Please insert Table 3]

[Please insert Figure 8]

In order to simplify the model, we also tested a model with the Stroop effect [RT(congruent) – RT (incongruent)] as a dependent variable, and Group, Time-point, Priming and Emotion as independent variables. However, no significant effect was observed with this model (Table 4 and Figure 9). In other words, the Priming-by-Emotion interaction on the Stroop effect observed at baseline was not modulated by the training effect [Group-by-Time-point: $F(1, 55.35) = 1.92$, $p = 0.17$; Group-by-Time-point-by-Priming: $F(1, 335.46) = 0.29$, $p = 0.59$; Group-by-Time-point-by-Priming-by-Emotion: $F(1, 335.46) = 2.73$, $p = 0.10$] (see detailed statistics in Table 4).

[Please insert Table 4]

[Please insert Figure 9]

Discussion

The aim of this study was to determine the extent to which the practice of mindfulness could reduce the use of prior knowledge, at a purely perceptual level, during the recognition of emotional facial expressions, when compared to a wait-list control group. More precisely, the experiment tested the effect of an integrated mindfulness-based training on low-level visual processing during an emotional Stroop task. The hypotheses were based on previous research which suggested that mindfulness-based training could lead to a de-automatization of perception. The prediction was that the default use of coarse features in order to cope with uncertainty (Stroop interference) would be reduced after the mindfulness-based training, but not after repeating the task without intervention. At baseline, a lower Stroop interference was observed after Low Spatial Frequency priming, but in the Anger condition only. However, contrary to Beffara et al. (2015), reaction time at T1 was not lower for LSF compared to HSF for incongruent trials. After mindfulness-based training, there was a significant global reaction time decrease in the experimental group, while it did not decrease in the control group, but faster reaction time was not modulated by spatial frequency.

As this study was carried out among a subsample of a larger study focusing on self-reported questionnaires, we did not use the participants' questionnaires scores in the present study. However, it is useful to report that participants included in the FOVEA program significantly increased their mindfulness skills as measured by the Five Facets Mindfulness Questionnaire (Baer et al., 2009; French validation Heeren et al., 2011) compared to the wait-list group (for more information, see Shankland et al., 2020). This previous result ensured that the FOVEA program acted upon the targeted mindfulness abilities.

In the present study, we used an emotional Stroop task with a priming by emotional facial expressions filtered in high or low spatial frequency to measure top-down predictive coding. This task was built in line with Bar's model (2003), which suggests that low spatial frequencies (coarse features of visual stimuli) are conveyed rapidly from the retina to the primary visual cortex and, more importantly, to the orbitofrontal cortex for predictive coding of the visual scene. This information is later recognized and categorized by neural processes at the level of the temporal cortex. According to this model, the orbitofrontal cortex generates predictions about the object being identified on the basis of the individual's previous knowledge triggered by information generated from low spatial frequencies. As was argued above, making predictions and expectations about the environment can be useful in seeking to optimize behavioral responses on the basis of previous experiences. From this perspective, prediction will be particularly useful when the environment is complex and generates uncertainty. In order to induce complexity, uncertainty, and above all, the necessity to inhibit cognitive and emotional responses in the task being performed, the presentation of the stimulus was designed in the form of a modified emotional Stroop task, i.e., with incongruent information with a probability of 0.5 (Beffara et al., 2015).

The training used in the present study (FOVEA) was designed to increase flexibility through an integrated mindfulness-based training program. Because it aims to increase attention to, and awareness of, the information coming from the five senses, and to develop an open, non-judgmental and non-reactive stance toward stimuli, this kind of training was presumed to reduce the automaticity of the top-down influence in emotion perception (as assessed in the current study by the modified emotional Stroop task).

With respect to the aim of the study, we observed that participants were faster after the mindfulness-based training than before the training, and in comparison to the control group. However, contrary to the initial hypothesis, this global effect was not modulated by the spatial frequency content of the stimuli. It appears that the faster responses of the participants after the training, in both congruent and incongruent situations, was not specific to LSF (which is supposed to be implicit and automatic) or HSF (which is supposed to be explicit and conscious) stimuli processing. This result appears to be in line with past research showing that mindfulness increases attentional control, and thus reduces reaction time in such tasks (for a review, see Chiesa et al., 2011). This suggests that the modulation of this visual processing might not be possible on a specific spatial frequency alone, but rather, induce a general improvement in emotional facial expressions recognition.

These findings are consistent with recent models of conscious recognition which have presented a convergence of results suggesting that conscious perceptions of exogenous stimuli may be achieved within the cortical temporal pathway (processing High Spatial Frequency information). For instance, Navajas et al. (2014) and Quian Quiroga et al. (2008) each provided iEEG data pointing to the importance of temporal lobes (e.g., hippocampus, entorhinal cortex) in the conscious recognition of visual stimuli. Further neuroimaging studies (i.e., fMRI studies or iEEG or MEG studies for a high temporal resolution) are necessary to test the neural pathways assumed to be involved in the experiment carried out.

Suggested Mechanisms

Which mechanisms involved in mindfulness-based training are likely to influence this low-level visual processing of emotional stimuli? Recent work exploring how mindfulness can reduce the use of implicit knowledge in cognitive processing of stimuli also showed reduced automatic responding (Whitmarsh et al., 2013). The preference and use of implicit knowledge was assessed by these researchers after artificial grammar learning, who showed that mindfulness (as a trait) was negatively associated with sensitivity to the grammar. This suggests that the individual's reliance on implicit leaning was reduced with greater mindfulness. Interestingly, reducing the weight of past experience and automatic, habitual responding can be adaptive and efficient in problem solving (Greenberg et al., 2010). The way in which mental training has an impact upon the reliance on previous knowledge is probably a question of attention and resource allocation. Indeed, Slagter et al. (2007) showed that mental training reduced attentional blink: they found that mental training diminished reliance on a first relevant target, allowing for the processing of a second relevant target - not by a reduction of resource depletion, but rather by a reduction of attentional reactivity. This finding was important, as it suggested that mental training may limit the effect of a salient stimulus in order to process other relevant forthcoming stimuli.

The results of our study, taken together with those of the studies listed above, supported the idea that mindfulness-based training increases flexibility and attentional efficiency when processing stimuli from the environment (Hodgins & Adair, 2010; Holzel et al., 2011; Lutz et al., 2008; Moore & Malinowski, 2009). There is growing evidence that mindfulness-based training increases cognitive, physiological (Burg & Wolf, 2012; Garland, 2011; Krygier et al., 2013), and psychological flexibility, defined by Kashdan & Rottenberg (2010) as the ability to persist with, or change behaviors, when doing so, helps to serve valued ends rather than performing automatic behaviors.

An important benefit of mindfulness is the de-automatization of maladaptive behaviors and increase in adaptive behaviors (Greenberg et al., 2010; Kang et al., 2013; Wenk-Sormaz, 2005; Whitmarsh et al., 2013). For example, de-automatization and flexibility have been shown to result in pro-sociality and reduced discrimination (Flook et al., 2015; Kang et al., 2014; Lueke & Gibson, 2014). Further studies are needed to support the link between mindfulness, automaticity, visual processes, and threat perception, but recent research seems to consistently support this hypothesis (Brown et al., 2012; Heppner et al., 2008; Kashdan et al., 2011; Niemiec et al., 2010).

Limitations and Future Research

The main limitation is that this study did not test whether the changes observed were maintained over time. A follow-up study is therefore needed in order to analyze the sustainable effects of this program. Second, FOVEA is a new manualized integrated mindfulness-based practices program which has not been extensively used yet. Further studies should test the same hypotheses using classical mindfulness-based programs such as the MBSR, or compare the two programs to a control condition, in order to study the specificity of informal daily practices compared with more formal meditation practices. Hence, future studies should seek to replicate these findings in order to confirm the efficacy of informal mindfulness practices on visual information processing. In addition, it would be useful to compare to an active control condition rather than a wait-list control condition.

Furthermore, it would also be useful to analyze the effect of gender and the instructor effect in order to establish if these variables need to be controlled for when performing statistical analyses. As the sample of this study was quite small, with only between 4 to 8 participants per instructor who took part in this experiment, it did not allow for these specific analyses. Future studies on larger samples may study specific moderators such as age or depression levels on such modified emotional Stroop tasks, as these variables have been shown to moderate the benefits of mindfulness-based programs (e.g., Gallegos et al., 2013).

In sum, although the results of this study suggested that the default low-level visual processing proposed by Bar (2003) is not modulated by a mindfulness-based training, further research is still needed to analyze this effect in more detail, for example with experimental tasks using geometric-optical illusions which are based on top-down cognitive predictions (e.g., Kloosterman et al., 2015; Meng & Tong, 2004). Furthermore, as the prior research on reduced attentional biases through mindfulness practices has suggested that this effect may be due to reduced social stress (e.g., Lueke & Gibson, 2014), future studies using this research design should measure stress levels both before and after intervention. A further line of research could also explore the effects of mindfulness-based interventions on a related field of research which studies a different type of bottom-up information processing: embodiment research (e.g., Niedenthal, 2007). As has been suggested by Michalak et al. (2012), mindfulness practices may lead to modified postures which in turn affect thoughts, which may be one of the mechanisms of change in mindfulness programs based on bottom-up information processing.

Compliance with ethical standards

Conflict of interest: none.

Research involving human participants: The study was approved by the ethics committee of University Grenoble Alpes, France, and has been performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki.

Informed consent: Informed consent was obtained from all individual participants included in the study.

Author Contributions

RS: designed and carried out the study, wrote the introduction, methods and discussion of the article. PF: performed the statistical analyses and wrote the results and part of the methods and the discussion section. IK: contributed to the design of the study and the writing of the article. MM: designed the study, contributed to the data analyses and the writing of the article. All authors approved the final version of the manuscript for submission.

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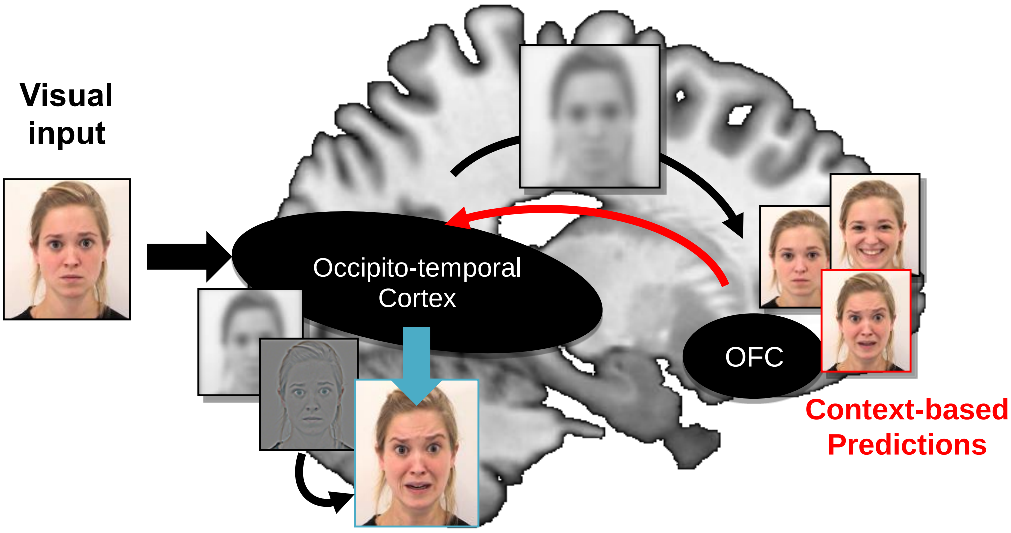

Figure 1. Illustration of the predictive brain model. LSF expectations are rapidly sent to the orbitofrontal cortex and fed back to the occipito-temporal cortex to enhance categorization based on full spectrum images

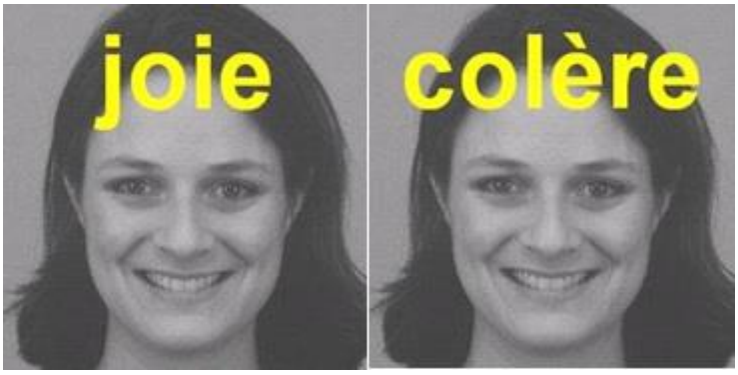

Figure 2. Examples of targets (Congruent Target on the Left, Incongruent Target on the Right. Joie = joy; colère = anger)

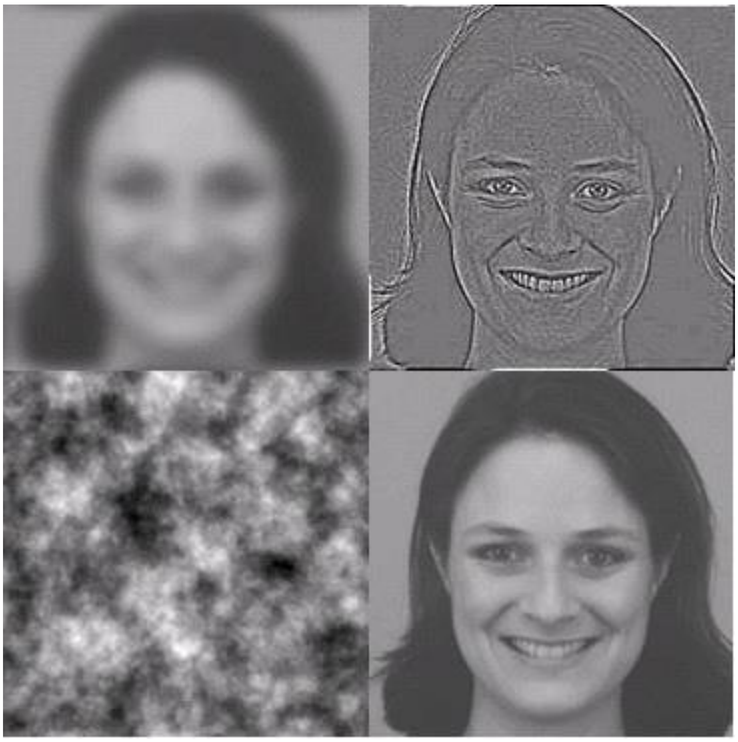

Figure 3. Examples of primes (top left: LSF face, top right: HSF), white noise mask (bottom left) and original broad frequency (unfiltered) image (bottom right).

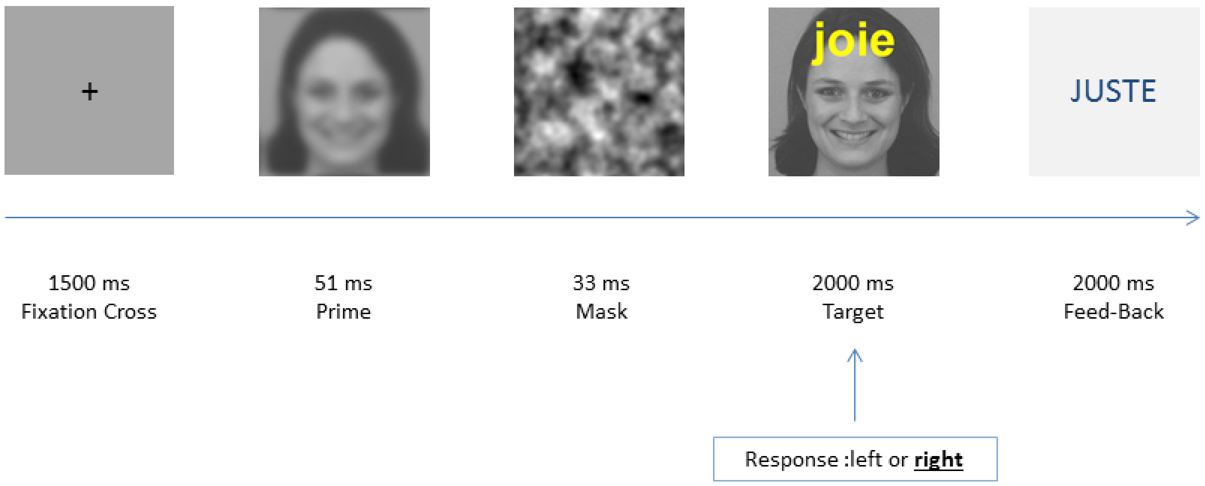

Figure 4. Example of trial (here with an LSF prime, LSF mask, and a congruent word. The face expresses "joy" so the good answer is "right")

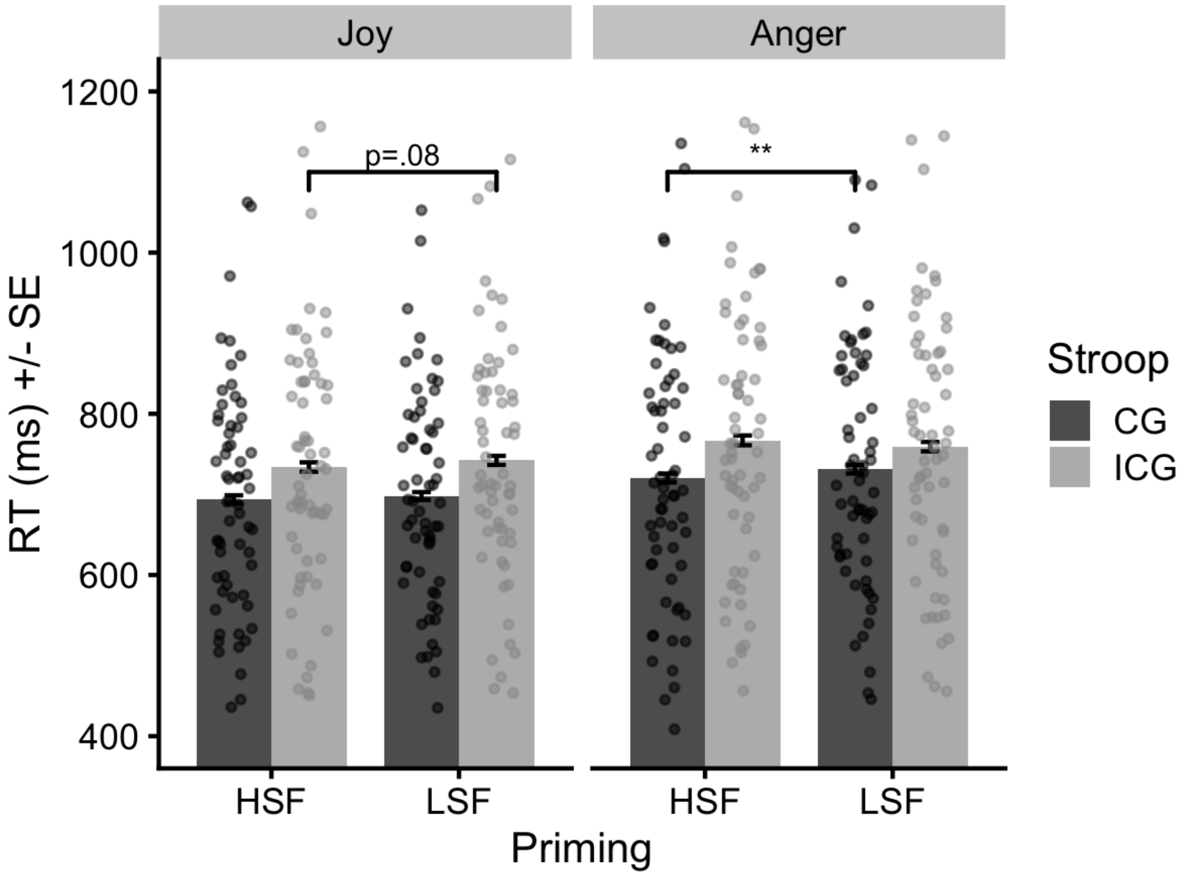

Figure 5. Factorial plots (2X2X2) of the task for the means of Reaction Times (RTs), for each condition defined by congruency, spatial frequency of the prime and emotion. Error bars reflect the standard error for the means. Dots represent average individual data. CG = Congruent, ICG = Incongruent, HSF = High Spatial Frequency, LSF = Low Spatial Frequency.

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$

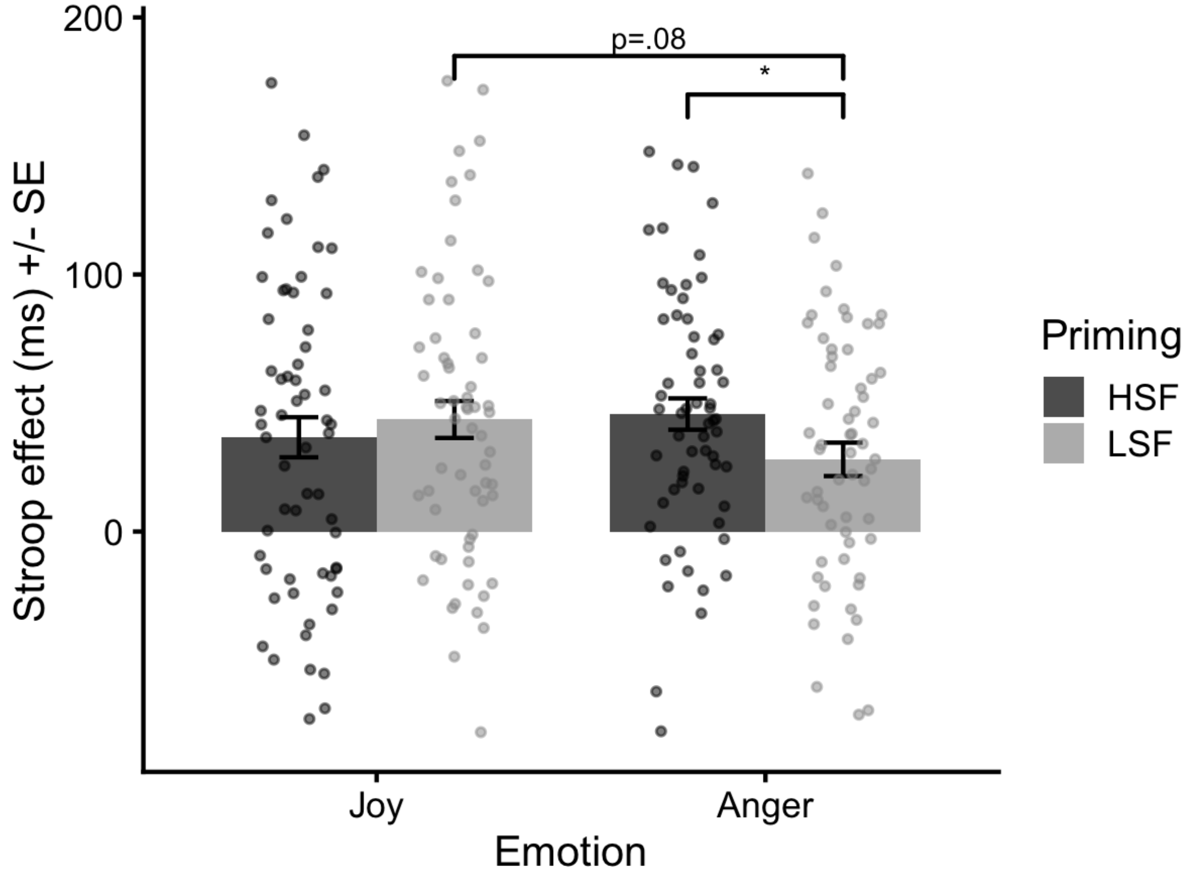

Figure 6. Factorial plots (2X2) of the task for the mean Stroop effect (RT difference between incongruent and congruent stimuli) for each condition defined by the spatial frequency of the prime and the emotion. Error bars reflect the standard error for the means. Dots represent average individual data. HSF = High Spatial Frequency, LSF = Low Spatial Frequency.

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$

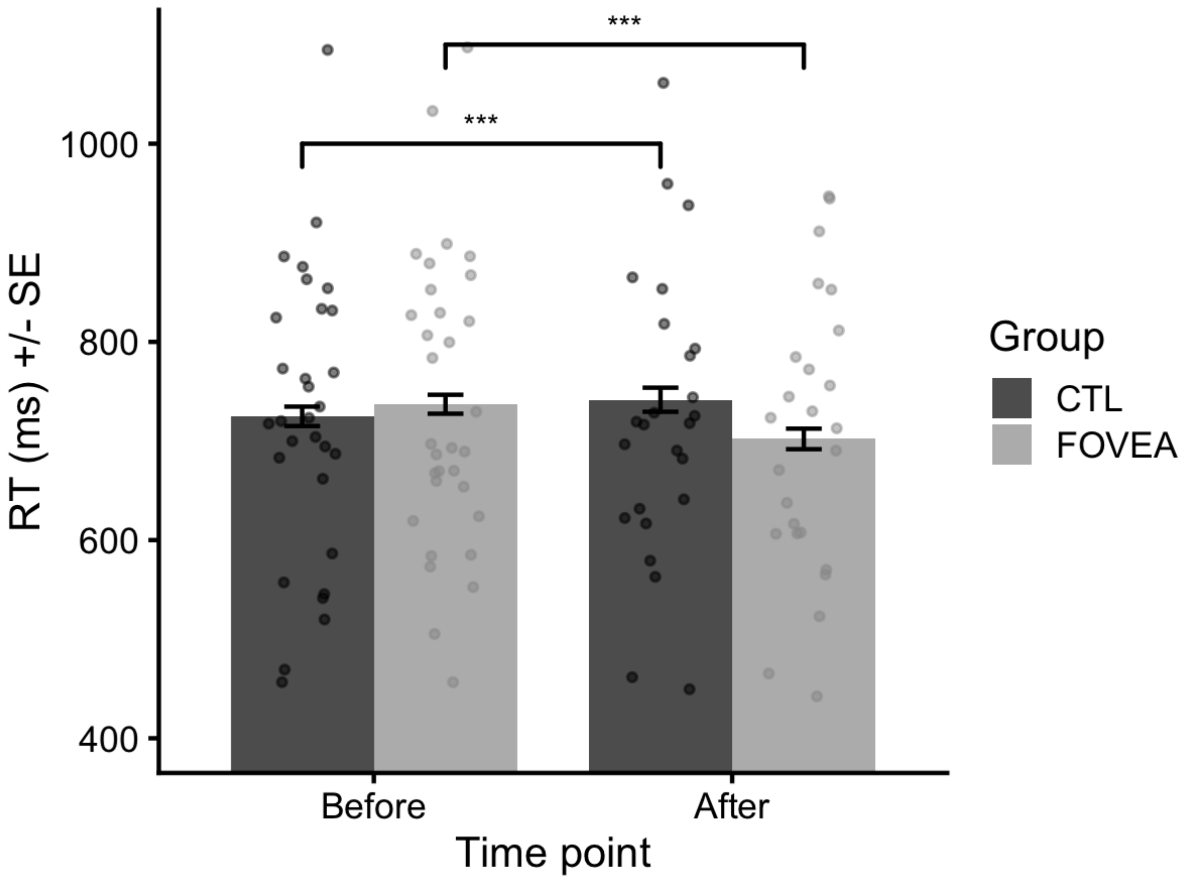

Figure 7. Factorial plots (2X2) of the task for the mean RTs for the group and the time point. Error bars reflect the standard error for the means. Dots represent average individual data.

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$

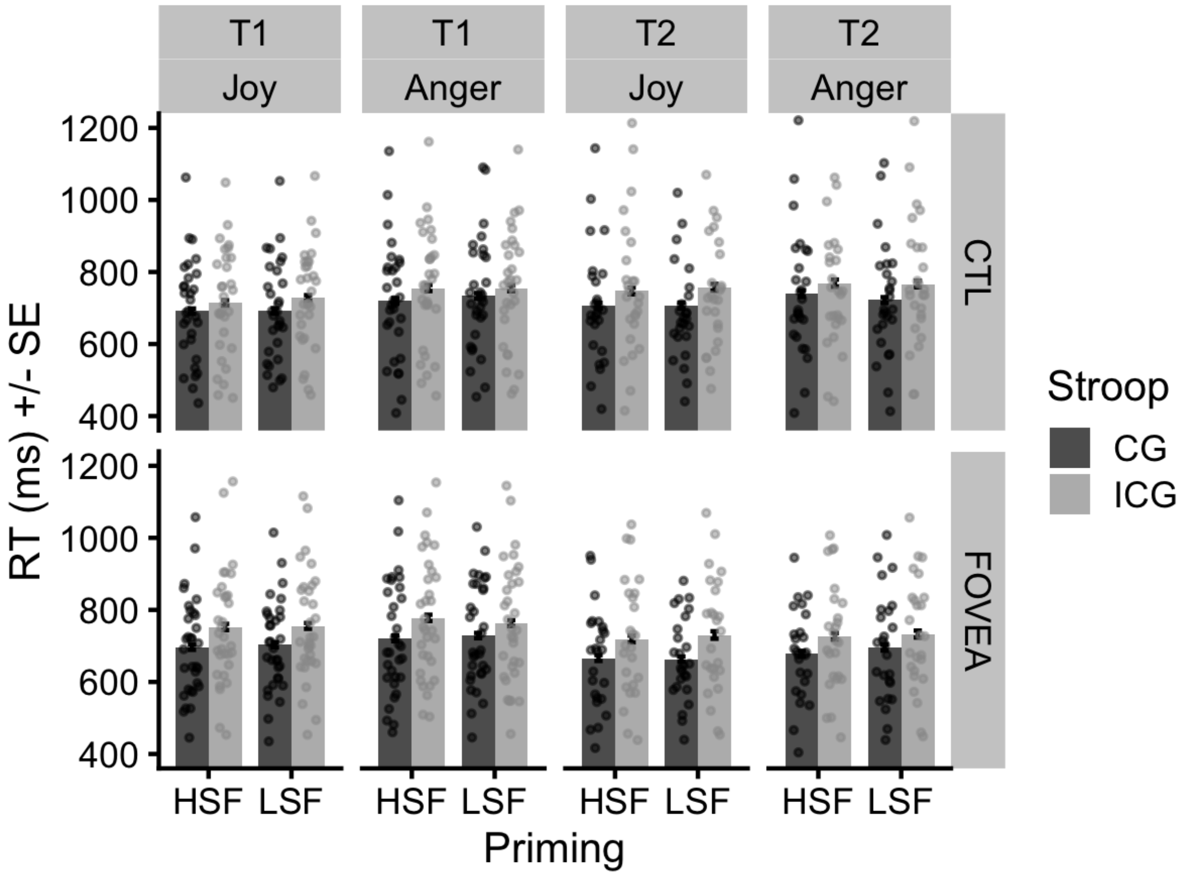

Figure 8. Factorial plots (2X2X2X2) of the task for the mean RTs for the Group, the time-point, the priming, the congruency and the emotion. Error bars reflect the standard error for the means. Dots represent average individual data. CG = Congruent, ICG = Incongruent, HSF = High Spatial Frequency, LSF = Low Spatial Frequency.

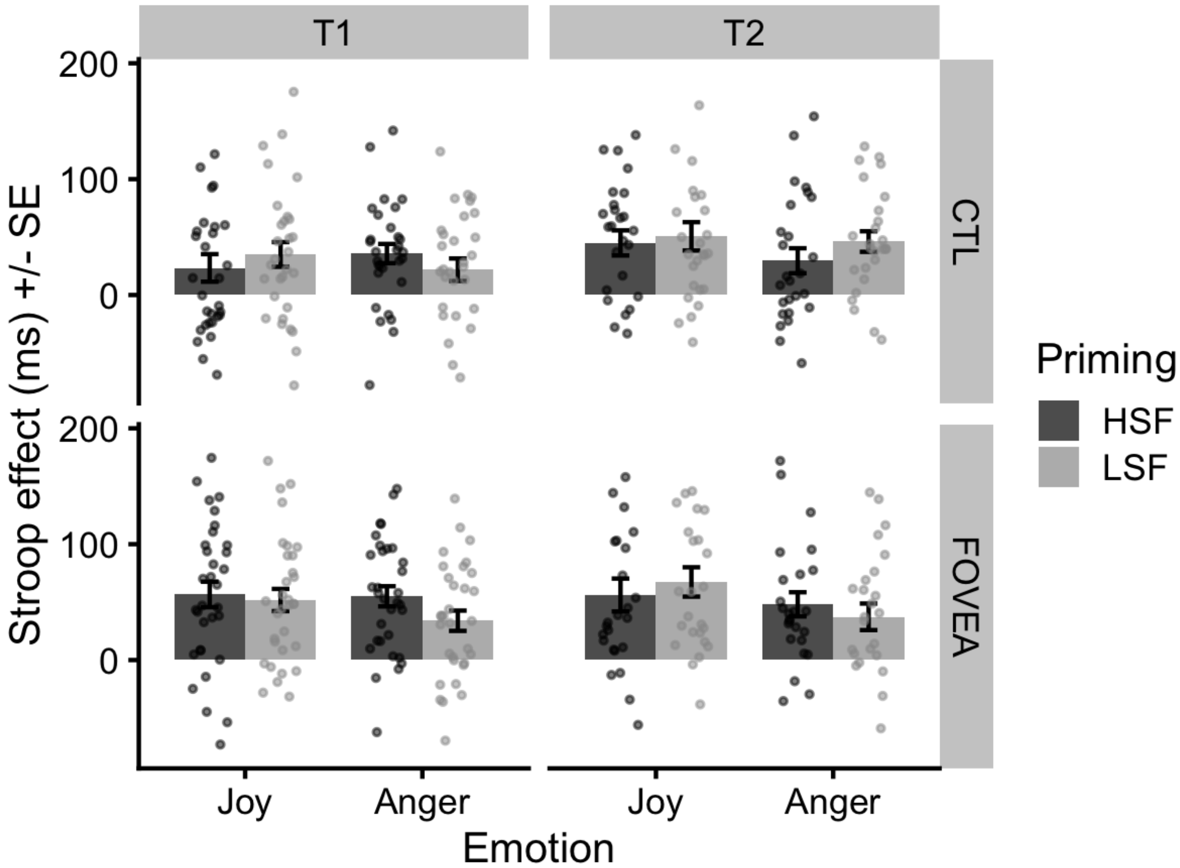

Figure 9. Factorial plots (2X2X2X2) of the task for the mean Stroop effect (RT difference between incongruent and congruent stimuli) for each condition defined by the Group, the time-point, the spatial frequency of the priming and the emotion. Error bars reflect the standard error for the means. Dots represent average individual data. HSF = High Spatial Frequency, LSF = Low Spatial Frequency.

Table 1.
Description of the FOVEA program

Session number	Main theme and in-session practices	Between-session practices
1	Introduction; Brief body-scan; Mindful listening; Mindful Sitting	Mindful listening and Brief body-scan
2	Mindful Sitting; Mindful touching; Mindful talking and listening; Mindful breathing	Mindful touching and Mindful sitting
3	Mindful Sitting; Mindful breathing; Mindful olfaction; Mindful standing; Mindful writing	Mindful olfaction and Mindful standing
4	Mindful Sitting; Brief body-scan; Mindful tasting; Mindful walking; acting with awareness; Mindful breathing	Mindful tasting and Mindful walking
5	Mindful Sitting; Mindful watching; Mindful contact with emotions; Mindful decision making; Mindful breathing	Mindful watching and Mindful breathing
6	Mindful Sitting; Mindful movements; Mindful reading + reading aloud; Mindful breathing	Acting with awareness (movements) and Mindful talking
7	Mindful Sitting; acting with awareness; global present moment awareness; Mindful breathing	Acting with awareness and global present moment awareness
8	Body-scan; next steps; Mindful breathing	Each participant chooses the practices that are most useful to continue to integrate in their everyday life

Table 2.
Descriptive statistics of the reaction time (ms) and the accuracy (%) during the modified emotional Stroop task according to the Group, Time-point, Congruency, Priming and Emotion

	Congruent								Incongruent							
	Anger				Joy				Anger				Joy			
	HSF		LSF		HSF		LSF		HSF		LSF		HSF		LSF	
Reaction Time																
	Mean	*Sd*	*Mean*	*Sd*	*Mean*	*Sd*	*Mean*	*Sd*	*Mean*	*Sd*	*Mean*	*Sd*	*Mean*	*Sd*	*Mean*	*Sd*
T1-Control	720	228	734	227	691	221	692	204	755	250	755	249	714	223	728	227
T1-FOVEA	721	240	729	227	696	217	703	212	778	265	763	253	753	268	756	250
T2-Control	740	247	722	225	707	218	707	230	769	276	767	251	747	256	757	261
T2-FOVEA	678	211	696	231	666	221	663	193	727	247	733	263	719	257	730	284
Accuracy																
	Mean	*Sd*	*Mean*	*Sd*	*Mean*	*Sd*	*Mean*	*Sd*	*Mean*	*Sd*	*Mean*	*Sd*	*Mean*	*Sd*	*Mean*	*Sd*
T1-Control	98%	14%	99%	9%	99%	11%	99%	8%	98%	16%	98%	13%	98%	14%	99%	12%
T1-FOVEA	99%	10%	100%	6%	99%	9%	99%	9%	97%	16%	99%	11%	98%	14%	98%	14%
T2-Control	99%	7%	99%	9%	99%	11%	99%	11%	98%	14%	97%	16%	98%	15%	98%	15%
T2-FOVEA	99%	10%	99%	9%	100%	6%	99%	10%	98%	14%	99%	10%	98%	14%	99%	12%

Table 3.

Linear Mixed Model results for the fixed effects (Group, Session, Priming, Congruence and Emotion) on the log(RT).

Effect	**Mean Sq**	**NumDF**	**DenDF**	***F*-value**	**Rsq**	***P*(>*F*)**	**sign**
Session	0.05	1	52.25	0.96	0.0001	0.33	NS
Group	0.01	1	62.82	0.14	<0.0001	0.71	NS
Congruency	**17.52**	**1**	**26614.09**	**344.18**	**0.0003**	**0**	*****
Priming	**0.29**	**1**	**26614.03**	**5.63**	**<0.0001**	**0.02**	***
Emotion	**5.36**	**1**	**26614.05**	**105.23**	**<0.0004**	**0**	*****
Session:Group	**0.22**	**1**	**52.25**	**4.37**	**<0.0006**	**0.04**	***
Session:Congruency	0.12	1	26614.14	2.45	0.0001	0.12	NS
Group:Congruency	**0.52**	**1**	**26614.09**	**10.22**	**<0.0002**	**0**	****
Session:Priming	0.03	1	26614.06	0.56	<0.0001	0.45	NS
Group:Priming	0.01	1	26614.03	0.10	<0.0001	0.75	NS
Congruency:Priming	0.01	1	26614.05	0.25	<0.0001	0.62	NS
Session:Emotion	**0.28**	**1**	**26614.12**	**5.44**	<0.0001	**0.02**	***
Group:Emotion	0.17	1	26614.05	3.41	<0.0001	0.06	NS
Congruency:Emotion	**0.21**	**1**	**26614.02**	**4.17**	<0.0001	**0.04**	***
Priming:Emotion	0.02	1	26614.04	0.36	<0.0001	0.55	NS
Session:Group:Congruency	0.07	1	26614.14	1.31	<0.0001	0.25	NS
Session:Group:Priming	0.09	1	26614.06	1.87	<0.0001	0.17	NS
Session:Congruency:Priming	0.12	1	26614.05	2.26	<0.0001	0.13	NS
Group:Congruency:Priming	0.14	1	26614.05	2.82	<0.0001	0.09	NS
Session:Group:Emotion	0.07	1	26614.12	1.37	<0.0001	0.24	NS
Session:Congruency:Emotion	0.03	1	26614.05	0.66	0.0001	0.41	NS
Group:Congruency:Emotion	0.02	1	26614.02	0.33	<0.0001	0.56	NS
Session:Priming:Emotion	0.00	1	26614.06	0.10	0.0001	0.76	NS
Group:Priming:Emotion	0.00	1	26614.04	0.04	<0.0001	0.84	NS
Congruency:Priming:Emotion	0.11	1	26614.02	2.19	0.0001	0.14	NS
Session:Group:Congruency:Priming	0.01	1	26614.05	0.26	<0.0001	0.61	NS
Session:Group:Congruency:Emotion	0.00	1	26614.05	0.01	<0.0001	0.92	NS
Session:Group:Priming:Emotion	0.07	1	26614.06	1.29	0.0001	0.26	NS
Session:Congruency:Priming:Emotion	0.08	1	26614.02	1.54	0.0001	0.21	NS
Group:Congruency:Priming:Emotion	0.02	1	26614.02	0.41	<0.0001	0.52	NS
Session:Group:Congruency:Priming:Emotion	0.03	1	26614.02	0.53	<0.0001	0.47	NS

Table 4.

Linear Mixed Model results for the fixed effects (Group, Session, Priming and Emotion) on the Stroop effect.

Effect	**Mean Sq**	**NumDF**	**DenDF**	***F*-value**	**Rsq**	***P*(>*F*)**	**sign**
Session	3502.9	1	55.35	1.55	0.0005	0.22	NS
Group	**10227.94**	**1**	**58.07**	**4.53**	**0.0051**	**0.04**	*****
Priming	10.07	1	335.45	0.00	0.0026	0.95	NS
Emotion	4600.63	1	335.39	2.04	0.0048	0.15	NS
Session:Group	4337.78	1	55.35	1.92	0,0000	0.17	NS
Session:Priming	2833.64	1	335.46	1.26	0.0057	0.26	NS
Group:Priming	2954.63	1	335.45	1.31	0.0004	0.25	NS
Session:Emotion	1042.07	1	335.38	0.46	0.0072	0.50	NS
Group:Emotion	2536.25	1	335.39	1.12	0.0029	0.29	NS
Priming:Emotion	5433.54	1	335.45	2.41	0.0068	0.12	NS
Session:Group:Priming	648.99	1	335.46	0.29	0.0013	0.59	NS
Session:Group:Emotion	274.74	1	335.38	0.12	0.004	0.73	NS
Session:Priming:Emotion	2918.00	1	335.46	1.29	0.0077	0.26	NS
Group:Priming:Emotion	1321.66	1	335.45	0.59	0.0009	0.44	NS
Session:Group:Priming:Emotion	6168.87	1	335.46	2.73	0.0054	0.10	NS