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Explicit and implicit emotional processing in peripheral vision: A saccadic choice paradigm

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ABSTRACT

We investigated explicit and implicit emotional processing in peripheral vision using saccadic choice tasks. Emotional-neutral pairs of scenes were presented peripherally either at 10, 30 or 60° away from fixation. The participants had to make a saccadic eye movement to the target scene: emotional vs neutral in the explicit task, and oval vs rectangular in the implicit task. In the explicit task, pleasant scenes were reliably categorized as emotional up to 60° while performance for unpleasant scenes decreased between 10° and 30° and did not differ from chance at 60°. Categorization of neutral scenes did not differ from chance. Performance in the implicit task was significantly better for emotional targets than for neutral targets at 10° and this beneficial effect of emotion persisted only for pleasant scenes at 30°. Thus, these findings show that explicit and implicit emotional processing in peripheral vision depends on eccentricity and valence of stimuli.

1. Introduction

Sensory systems are constrained by their limited capacity of processing while they have to deal with an enormous flow of stimuli. Among the different brain mechanisms allowing to cope with these limitations, emotional processes are critical, by enabling prioritization of affective stimuli over neutral cues in order to react adaptively to potentially advantageous or harmful stimuli. Indeed, converging evidence suggests that emotional information captures attentional resources and disrupts ongoing goal-oriented processing (e.g., see Bradley, Keil, & Lang, 2012; Ohman & Mineka, 2001; Pourtois, Schettino, & Vuilleumier, 2013; Vuilleumier & Huang, 2009; Vuilleumier, 2005, 2015). In fact, numerous studies have shown that the emotional content of visual stimuli can have an influence at the behavioral and neural levels when the attention is focused on a non-emotional aspect of these stimuli (i.e. in implicit conditions) as often in daily life (e.g., Cohen, Moyal, Lichtenstein-Vidne, & Henik, 2016; Critchley et al., 2000; Hariri, Bookheimer, & Mazziotta, 2000). However, although affective cues probably arise mainly in the periphery of the visual field in everyday life, only a few studies have investigated the ability of human observers to process emotional stimuli either explicitly or implicitly when they are not the target of the gaze. Yet, the properties of the retina constrain visual perception in such a way that visual acuity is not uniform across the visual field (see Livingstone & Hubel, 1987 Livingstone & Hubel, 1988; Nassi & Callaway, 2009; Wandell, 1995). Consequently, peripheral vision is far less capable of fine discrimination than central vision (Boucart, Moroni, Thibaut, Szaffarczyk, & Greene, 2013). This loss of spatial resolution in the periphery has several physiological reasons: (1) the considerable drop of the density of cone photoreceptors as eccentricity increases from the fovea (Curcio et al., 1991); (2) the reduced receptor density in peripheral retina (Chui, Song, & Burns, 2008); and (3) the larger receptive fields in periphery. Moreover, since retinotopic projection to cortex prioritizes foveal inputs, there is a disproportionately large representation of central retinal locations in the visual cortex (e.g., Horton & Hoyt, 1991) whereas the cortical representation of peripheral parts of the retina decreases as eccentricity increases (Azzopardi & Cowey, 1993; Duncan & Boynton, 2003; Popovic & Sjostrand, 2001). Despite these physiological limitations, peripheral vision allows coarse discriminations such as object and scene categorization, even at very large eccentricities (up to 70°; Boucart et al., 2013; Thorpe, Gegenfurtner, Fabre-Thorpe, & Bulthoff, 2001).

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Regarding emotion, there is no consensus on the basis of the available data concerning the processing of emotional scenes (see Bayle, Schoendorff, Henaff, & Krolak-Salmon, 2011; Calvo, Fernandez-Martin, & Nummenmaa, 2014; Rigoulot et al., 2011; Rigoulot, D'Hondt, Honore, & Sequeira, 2012 for studies on emotional facial expressions processing). On the one hand, several data suggest that emotional scenes are explicitly processed in near peripheral vision. For instance, eye-tracking studies have shown that emotional scenes presented concurrently with neutral scenes in the visual periphery (the centre of the pictures was located approximately between 8° and 12° away from initial fixation) are more likely to attract the first fixation. This emotional effect is observed during tasks requiring to determine whether the scenes are either similar or different in valence (Calvo & Lang, 2004; Nummenmaa, Hyona, & Calvo, 2006). Nummenmaa et al. (2006) also observed that emotional stimuli were more likely to be fixated first than neutral pictures, simultaneously presented, when participants were told to attend to the neutral picture first, which suggests that emotional content captures visual attention exogenously. However, this result was nuanced by the fact that the probability of a first eye fixation on an emotional picture in this condition remained lower than when they had to attend to the emotional picture first. Thus, as concluded by the authors, participants were to some extent able to inhibit their first eye fixation on an emotional picture in this latter condition. Moreover, Calvo, Rodriguez-Chinea, & Fernandez-Martin, 2015 have recently found that emotional scenes were reliably discriminated from simultaneously presented neutral scenes in near peripheral vision (at 12.75° eccentricity) in a task where participants had to judge on wich side the emotional picture was located. In the same study, participants were also more accurate and faster when the emotional scenes appeared in the left than in the right visual field, in line with the "right hemisphere hypothesis" postulating a dominance of this hemisphere in emotional processing (e.g., Demaree, Everhart, Youngstrom, & Harrison, 2005; Gainotti, 2012; Heller, Nitschke, & Miller, 1998). On the other hand, few studies investigated implicit emotional processing (i.e. when the attention is not focused on the emotional content of the visual stimuli) in near peripheral vision. Eye-tracking studies have found that, in these conditions too, the emotional scenes are more likely to attract the first fixation than the simultaneously presented neutral scenes (during recognition tasks using these scenes as primes; (Calvo & Lang, 2005); Calvo, Nummenmaa, & Hyona, 2007,Calvo, Nummenmaa, & Hyona, 2008). In agreement with this privileged status of emotional pictorial stimuli, we recently provided behavioral and magnetoencephalographic evidence that non-predictive emotional information in peripheral vision at 12° eccentricity interferes with subsequent responses to foveally presented targets (D'Hondt et al., 2013). Moreover, Keil, Moratti, Sabatinelli, Bradley, and Lang (2005) also observed a right hemisphere dominance for implicit emotional processing at 3.9° eccentricity. In their study, participants had to count silently occasional random-dot patterns embedded in a 10 Hz flicker of colored pictures presented to both hemifields. They found that unpleasant scenes, as compared to neutral scenes, increased steady-state visual evoked potentials (ssVEPs) amplitude in the occipito-temporal and parietal cortex and that this effect was most pronounced at right temporal electrodes when these pictures were presented to the left visual field. Taken as a whole, these results suggest that the processing of emotional scenes could be effective in peripheral vision both in explicit and implicit conditions. However, these results were obtained for relatively low eccentricities.

To the best of our knowledge, only two event-related potentials (ERP) studies have investigated the processing of emotional scenes at larger eccentricities. Rigoulot et al. (2008) explored the affective (unpleasant vs neutral) categorization of natural scenes in central vision (0°) and at 30° eccentricity. The authors found that response latency was delayed for unpleasant pictures compared to neutral pictures and affective modulation of early ERP components existed whatever the eccentricity. While these results suggest that emotional pictures were discriminated from neutral pictures, the behavioral performance in terms of accuracy did not differ from the chance level for unpleasant pictures in peripheral vision. De Cesarei, Codispoti, and Schupp (2009) also performed a study comparing emotional processing between central (0°) and peripheral vision but at smaller eccentricities (8.2° and 16.4° eccentricity) and in passive viewing conditions as well as during a non-emotional active task (aiming at indicating whether a box presented in central vision contained a gap or not). When pictures were presented in central vision, they found, both during passive viewing and active task conditions, similar effects than previous studies using explicit emotional categorization tasks (e.g., Codispoti, Ferrari, De Cesarei, & Cardinale, 2006; Schupp, Junghofer, Weike, & Hamm, 2003, Schupp, Junghofer, Weike, & Hamm, 2004; Schupp, Flaisch, Stockburger, & Junghofer, 2006): emotional scenes, as compared to neutral scenes, induced larger early ERP components recorded at occipito-temporal sites, which may reflect perceptual encoding, and a larger late positive potential (LPP), indexing stimulus representation in working memory. At 8.2° eccentricity, similar results were found for the LPP in the passive viewing condition but the emotional effect on the early ERP components was observed only in the left visual field. No emotional modulations of early and late ERP components were observed in the active task. At 16.4° eccentricity, there were no emotional modulations in both conditions. Thus, the ability to process emotional stimuli might decline with increasing eccentricity and even though this has not been tested yet, we can suppose that effect of eccentricity could differ between explicit and implicit conditions.

Several data show that emotional stimuli differ in the way they influence task performance and associated brain activity as a function of whether their emotional content is explicitly or implicitly processed (e.g., Cohen et al., 2016; Critchley et al., 2000; Habel et al., 2007; Hariri et al., 2000; Scheuerecker et al., 2007; see also Codispoti et al., 2006; Schupp et al., 2006). Interestingly, in a recent study by Schupp, Schmälzle, & Flaisch, 2014, participants were presented with central target pictures (animal images or images depicting non-animal content) that were overlaid upon emotional or neutral background pictures. Emotional modulations of early and late ERP components, similar to those classically observed during the explicit emotional processing of natural scenes in central vision, were found in the passive viewing condition but not when participants were engaged in the animal-/non-animal-categorization task. Furthermore, the valence of the background pictures did not modulate the performance (both for speed and accuracy) in the task. In line with the results found by De Cesarei et al. (2009) in peripheral vision, this study reinforces the idea that implicit emotional processing in the peripheral visual field might be not possible if no sufficient resources are available. Another relevant line of evidence comes from the study by De Cesarei and Codispoti (2006) in which the authors investigated emotional modulations induced by pictures presented in different sizes during an animal/person categorization task. Indeed, given that size reduction also reduces discriminability because of the loss of fine details in the scene (e.g., Loftus & Harley, 2005), one can assume that modulation of picture size can give some insights about how the processing of emotional scenes is performed in conditions of low spatial resolution. De Cesarei and Codispoti (2006) observed that LPP amplitude was larger for both unpleasant and pleasant stimuli compared to neutral stimuli and these emotional effects were stable across all sizes. Pleasant pictures also elicited higher LPP amplitude than unpleasant pictures. However, emotional effect on the early ERP component was found only for pleasant pictures and was both reduced in amplitude and delayed with decreasing picture size.

At the behavioral level, responses were, compared to neutral pictures: (1) faster for pleasant pictures and slower for unpleasant pictures, and size reduction induced a more pronounced slowing for unpleasant pictures than for other valences; (2) more accurate for pleasant pictures and less accurate for unpleasant pictures, and size reduction induced a more pronounced decrease of accuracy for unpleasant pictures than for other valences.

Considering these results and that visual discriminations are likely to become more and more resource-consuming with increasing eccentricities, one could assume that implicit emotional processing could be even more altered than explicit emotional processing. In other words, implicit emotional processing could be no longer possible at a nearer eccentricity compared to explicit emotional processing. Moreover, results from the study by De Cesarei and Codispoti (2006) also suggest that differences in the processing of unpleasant and pleasant stimuli are likely to emerge, at least in implicit conditions. If previous studies on explicit and implicit emotional processing in peripheral vision suggest that both unpleasant and pleasant scenes capture attention in near peripheral vision, it remains unknown whether the valence of stimuli has an influence in the processing of emotional scenes according to visual eccentricity. Actually, some authors argue that negative stimuli have a privileged status and even suggest the existence of a "negativity bias": owing to their high adaptive value, negative stimuli would more readily capture attention than neutral and positive stimuli (e.g., Carretié, Mercado, Tapia, & Hinojosa, 2001; Carretié et al., 2013; Hansen & Hansen, 1988; Ohman, Flykt, & Esteves, 2001; Pratto & John, 1991; Smith, Cacioppo, Larsen, & Chartrand, 2003). Other authors argue that allocation of spatial attention depends on arousal rather than valence (Vogt, De Houwer, Koster, Van Damme, & Crombez, 2008), which suggests that both pleasant and unpleasant stimuli could equally facilitate orienting and capture eye movements (e.g., Vuilleumier, 2015), providing that they have similar levels of arousal.

Accordingly, the aim of the current study was two-fold as we wanted to assess the ability of healthy adults to categorize affective stimuli from near to far peripheral vision either when the emotional content (whether pleasant or unpleasant) of visual scenes is the focus of attention or not. More precisely, we compared performance in two conditions: (1) explicit emotional processing in which participants had to select the target on the basis of its emotional content and (2) implicit emotional processing in which participants had to select a target on the basis of its shape regardless of its emotional content. We used a saccadic choice paradigm in which participants were presented with two lateralized (to the left and right of a central fixation point) pictures of natural scenes and had to make a saccadic eye movement toward one of the two scenes according to the instruction given by the experimenter (Boucart, Calais, Lenoble, Moroni, & Pasquier, 2014; Kirchner & Thorpe, 2006). Pairs of pictures were composed of one neutral scene and one emotional scene. Emotional scenes were either unpleasant or pleasant but were equally arousing so that we were able to test for potential effects of valence. Moreover, the fact that one given image within a pair could be presented either in the left or in the right visual field allowed the investigation of the potential hemispheric differences in emotional processing. In the explicit task, one group of participants had to detect emotional scenes and the other group had to detect neutral scenes. We hypothesized that if emotional categorization is effective in peripheral vision, then performance should be better for the "emotional" group than for the "neutral" one and it should be significantly greater than the chance level across the visual field at least in the emotional group. In fact, emotional scenes may attract attention, leading to a saccadic capture and potentially more errors when participants have to categorize neutral stimuli, as observed in the study by Nummenmaa et al. (2006). In the implicit task, unpleasant, neutral and pleasant scenes were used and were modified to create two versions of each: one with an oval shape and the other with a rectangular shape. One group of participants had to detect oval scenes and the other group had to detect rectangular scenes. The aim of this task was to compare the performance of participants between emotional and neutral targets. We hypothesized that if emotional information is processed independently of the ongoing task in peripheral vision, then performance in the implicit task should differ between neutral and emotional scenes.

2. Materials and methods

2.1. Participants

Nineteen healthy students were recruited for the present study, all of whom were right-handed (Hécaen, 1984), had normal or corrected-to-normal vision and lacked any history of neurological or psychiatric disorders, or drug consumption. The experimental procedures were approved by the local ethics committee. In accordance with the tenets of the Declaration of Helsinski, all participants provided their informed consent before participating in the experiment.

2.2. Stimuli

Given the documented differences between men and women in the processing of emotional stimuli (e.g., Bradley, Codispoti, Sabatinelli, & Lang, 2001; Collignon et al., 2010), emotional and neutral pictures from the international affective picture system (IAPS; Lang, Bradley, & Cuthbert, 2008) were selected according to gender.[1] More precisely, for each task, we selected two sets of 96 pictures by considering the normative valence and arousal ratings provided for men and women. As a result, 57 pictures and 59 pictures were included both for men and women in the explicit and implicit tasks respectively, while the others pictures were specific to men or women. Each of the 4 gender-based sets comprised 2 subsets of emotional stimuli, 24 unpleasant (U) and 24 pleasant (P), as well as 2 subsets of 24 neutral stimuli (N1, N2).

For each of these 4 gender-based sets, controls were performed on emotional parameters and physical low-level image properties. First, one-way (4: U, N1, N2, P) ANOVAs were conducted both for valence ratings (on a scale of 1–9 in which 1 indicated a very unpleasant picture and 9 indicated a very pleasant picture) and arousal ratings (on a scale of 1–9 in which 1 indicated a very calm picture and 9 indicated a very arousing picture; see Table 1) and revealed significant differences between subsets (all $ps < 0.05$). Bonferroni post hoc comparisons were run both for valence and arousal and the following statistical differences were observed (all $ps < 0.05$): the mean valence value of U was significantly inferior to that of N1, N2 and P, the mean valence values of N1 and N2 were significantly inferior to that of P, and the mean valence values of N1 and N2 were not significantly different; the mean arousal values of U and P were not significantly different, but they were both significantly different from that of N1 and N2, and the mean arousal values of N1 and N2 were not significantly different.

Then, for each picture, we assessed the jpeg file size as an index of perceptual complexity (Calvo et al., 2015; Peyk, Schupp, Keil, Elbert, & Junghofer, 2009) as well as the following physical properties: the mean luminance value, standard deviation (SD) of the luminance (i.e., contrast index), skewness, kurtosis, and color saturation levels (red, green, blue). These measures were analyzed in one-way (4: U, N1, N2, P) ANOVAs and no significant differences were observed (all $ps > 0.05$).

[1] The picture numbers can be given upon request.

Table 1
Mean valence [M (SD)] and arousal [M (SD)] values for the different subsets (U, N1, N2, P) used in the explicit and in the implicit tasks for women and men.

			U	N1	N2	P	One-way ANOVA
Valence	Explicit Task	Women	2.30 (0.59)	5.11 (0.62)	5.25 (0.73)	7.34 (0.80)	$F(3,92) = 216.841$ $p < 0.001$
		Men	2.88 (0.61)	5.00 (0.30)	5.01 (0.42)	7.28 (0.51)	$F(3,92) = 342.402$ $p < 0.001$
	Implicit Task	Women	2.44 (0.71)	5.18 (0.58)	5.36 (0.78)	7.22 (0.81)	$F(3,92) = 176.109$ $p < 0.001$
		Men	2.79 (0.73)	4.94 (0.25)	5.09 (0.41)	7.16 (0.53)	$F(3,92) = 295.394$ $p < 0.001$
Arousal	Explicit Task	Women	6.19 (0.57)	3.41 (0.62)	3.05 (0.60)	5.73 (0.66)	$F(3,92) = 161.622$ $p <0.001$
		Men	5.85 (0.80)	3.04 (0.48)	2.83 (0.50)	5.88 (0.93)	$F(3,92) = 138.508$ $p < 0.001$
	Implicit Task	Women	6.10 (1.02)	3.09 (0.67)	3.22 (0.75)	5.82 (0.49)	$F(3,92) = 111.083$ $p <0.001$
		Men	5.91 (0.85)	2.80 (0.50)	2.93 (0.47)	5.78 (1.25)	$F(3,92) = 102.022$ $p < 0.001$

U: Unpleasant scenes; N1: Neutral scenes paired with unpleasant scenes; N2: Neutral scenes paired with pleasant scenes; P: Pleasant scenes.

Finally, we built two kinds of emotional-neutral pairs by associating the U and N1 sets as well as the P and N2 sets. Since one given image within a pair could be presented either in the left or in the right visual field, each picture that appeared on one side of the screen in a given trial was the mirror picture of the same picture that was first presented on the opposite side of the screen (IrfanView Software). Thus, the various elements of any given picture were equidistant from the fixation point when it was projected in either the left or the right visual hemifield (see Bryson, McLaren, Wadden, & MacLean, 1991). We computed differences between the emotional and neutral pictures of pairs for each emotional value and physical parameter that have been mentioned above. No significant difference was observed between the "U + N", "N + U", "P + N", and "N + P" conditions ($ps > 0.05$). The angular size of the photographs was 18° (horizontal) × 13.5° (vertical) at a fixed viewing distance of 2.04 m. The pictures were displayed on a grey background.

2.3. Apparatus

The stimuli were displayed by means of three projectors (SONY CS5) fixed on the ceiling, and connected to a PC computer (Windows 7 professional 32-bit SP1 operating system) with an Intel Core i7–3540 M (3.00 GHz) processor and 4 GB RAM, as well as an NVIDIA NVS5200 M graphic (1024 MB GDDR5) card (field rate of 60 Hz). Participants were seated 2.04 m from a hemispheric rigid light grey (68 cd/m2) screen covering 90° eccentricity on each side of the central fixation (0°). The presentation software was written by the laboratory engineer in Matlab. Eye movements were recorded by means of the iViewXTM HED eye tracker from SensoMotoric Instruments (Teltow, Germany) with a scene camera. The video based eye tracker is head-mounted, using infrared reflection to provide an eye-in-head signal at a sampling rate of 50 Hz and accuracy about 1°. The scene camera mounted on the head was positioned so that its field of view was coincident with the observer's line of sight. Calibration was performed using a five-point grid. Following calibration, the eye tracker creates a cursor, indicating eye-in-head position that is merged with the video from the scene camera. As the scene camera covers 40° and the hemispheric screen covers 180° we could only record the direction of the saccade (left/right). Before the experiment, participants were presented with a central white square (40° × 40°) containing five calibration points. The participant was asked to fixate the black dots (centre, top right, top left, bottom right, bottom left) while his/her eye positions were recorded by the system. Once the calibration was completed, this was removed, and the participant started the saccadic-choice task. As the head-mounted eye tracker records eye movements on one eye, half of the participants in each group were recorded on the left eye and the other half on the right eye.

2.4. Procedure

The participants were advised to ask for breaks during the experiment whenever necessary. Each trial started with a central white fixation cross displayed for 500 ms on a grey background. This was followed, after a gap of 200 ms, by a pair of photographs of scenes displayed for 1 s. The centre of each lateral picture was located either 10°, 30° or 60° from fixation. In the explicit task, a group of nine participants [5 females; mean age (SD): 22 (2) years] were asked to make a saccadic eye movement to the picture containing an emotional scene, either pleasant or unpleasant, and the other group of ten participants [5 females; mean age (SD): 24 (4) years] were asked to make a saccadic eye movement to the picture containing a neutral scene. There were 24 trials per condition for a total of 288 trials (24 trials × 3 eccentricities × 2 lateralities × 2 valences). In the implicit task, the same group of nine participants had to make a saccadic eye movement to the oval picture and the other group of ten participants had to make a saccadic eye movement toward the rectangular picture, regardless of the emotional content of the scenes. A trial was triggered when fixation had been stable for 500 ms and a saccade was detected by the camera if the eye moved by 3° from fixation. There were 12 trials per condition for a total of 288 trials (12 trials × 3 eccentricities × 2 lateralities × 2 valences × 2 targets). In both experiments, the left/right location of the target occurred randomly and equally. The trial order was selected randomly. The task order was fixed. The experiment began with the implicit task. Before starting the explicit task, examples of unpleasant, neutral and pleasant scenes were presented. The session lasted approximately 15 min.

2.5. Data analysis

The video records were analyzed using the software BeGaze from SensoMotoric Instruments (Teltow, Germany). The detection parameters for a saccade in BeGaze are set to a fixation duration shorter than 80 ms and a movement longer than 100 pixels. We recorded the latency of the first saccade (from the onset of the photographs). For each participant, saccadic latencies above the lower quartile minus 1.5 interquartile range and beyond the upper quartile plus 1.5 interquartile range were considered as fast and slow outliers respectively, and were removed from the analysis.

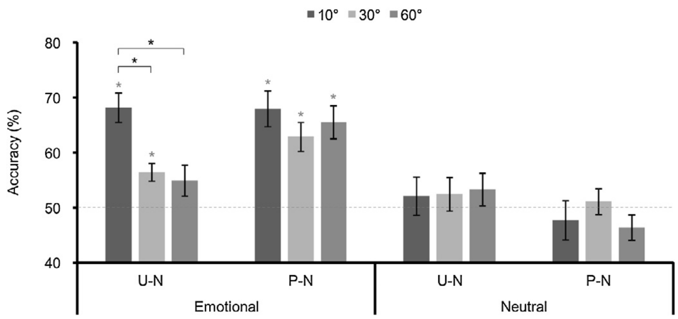

Fig. 1. Accuracy in the explicit task. Percentage of correct responses for the group that performed the emotional categorization and the group that performed the neutral categorization of unpleasant-neutral (U-N) pairs and pleasant-neutral (P-N) pairs as a function of eccentricity (10°, 30°, 60°). The black star (*) indicates p < 0.05 (after Bonferroni correction). The light grey star (*) indicates p < 0.05 (one sample *t*-test). Error bars denote standard errors of the mean. The light grey dashed line indicates the chance level.

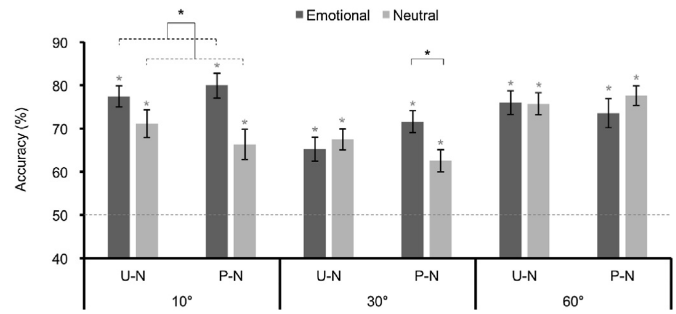

Fig. 2. Accuracy in the implicit task. Percentage of correct responses at 10°, 30°, and 60° of eccentricity for the unpleasant-neutral (U-N) pairs and the pleasant-neutral (P-N) pairs as a function of target (emotional or neutral). The black star (*) indicates p < 0.05 (after Bonferroni correction). The light grey star (*) indicates p < 0.05 following (one sample *t*-test). Error bars denote standard errors of the mean. The light grey dashed bar indicates the chance level.

Response accuracy (i.e. the percentage of correct responses) and saccade latencies for correct responses were examined using IBM SPSS Statistics for Windows (Version 22.0. Armonk, NY: IBM Corp.). For the explicit task, both measures were submitted to repeated measures analyses of variance (ANOVA; a Greenhouse-Geisser correction was applied when appropriate) with the eccentricity (10°, 30°, 60°), laterality of emotional scene (left visual field, right visual field) and valence (unpleasant-neutral, pleasant-neutral) as within-subjects factors and the group (emotional, neutral) as between-subjects factor. Regarding the implicit task, both measures were submitted to preliminary repeated measures analyses of variance (ANOVA; a Greenhouse-Geisser correction was applied when appropriate) with the eccentricity (10°, 30°, 60°), laterality of the emotional scene (left visual field, right visual field), valence (pleasant, unpleasant) and target (emotional, neutral) as within-subjects factors and group (emotional, neutral) as between-subjects factor. No main effect of group or interaction involving the factor group were found and results are reported collapsed across this factor.

Higher order interactions implying the group in the explicit task and the eccentricity or the target in the implicit task were followed-up with lower order interactions and main effects as appropriate. Main effects of eccentricity were followed-up with *t*-tests. Bonferroni correction was applied for multiple comparisons [adjusted *p*-values (p_c) are reported]. Finally, one sample *t*-tests were also run to determine whether performance in terms of accuracy was different from chance level, as defined as a performance of 50%.

3. Results

3.1. Explicit task

Results in terms of accuracy and saccade latency for correct responses are presented in Table 2.

3.1.1. Accuracy

The main effect of group [$F(1,17) = 25.302$, $p < 0.001$, $\eta^2_p = 0.598$] was qualified by valence by group [$F(1,17) = 8.588$, $p = 0.009$, $\eta^2_p = 0.336$] and eccentricity by valence by group interactions [$F(2,34) = 4.064$, $p = 0.026$, $\eta^2_p = 0.193$; Fig. 1]. The simple two-way interaction between eccentricity and valence was not significant in the neutral group [$F(2,18) = 1.338$, $p_c = 0.574$], but evident in the emotional group [$F(2,16) = 5.145$, $p_c = 0.038$]. Further analysis in the emotional group revealed that accuracy differed as a function of eccentricity for unpleasant-neutral pairs [$F(2,16) = 8.675$, $p_c = 0.006$], but not for pleasant-neutral pairs [$F(2,16) = 1.061$, $p_c = 0.738$]: accuracy for unpleasant-neutral pairs was significantly higher at 10° [68.14 (8.14) %] than at 30° [56.38 (4.77) %; $t(8) = 4.802$, $p_c = 0.004$], at 10° than at 60° [54.88 (8.47) %; $t(8) = 3.202$, $p_c = 0.038$], but did not differ between 30° and 60° [$t(8) = 0.412$, $p_c = 1.000$]. Moreover, performance in the emotional group was significantly higher than chance for each valence at each eccentricity [Fig 1; $ts(8) > 4.020$, $ps < 0.004$] except for unpleasant-neutral pairs at 60° [$t(8) = 1.729$, $p = 0.122$]. Performance in the neutral group did not differ from chance either pair or eccentricity [all $t(9) < 1.58$, $p > 0.140$].

3.1.2. Saccade latency

There was only a main effect of eccentricity [$F(2,34) = 57.852$, $p < 0.001$; $\eta^2_p = 0.773$]: mean saccade latencies were significantly shorter at 10° [mean (SD): 281 (44) ms] than at 60° [350 (61) ms; $t(18) = -7.877$, $p_c < 0.001$], and at 30° [285 (50) ms] than at 60° [$t(18) = -9.917$, $p_c < 0.001$], but there was no significant difference between 10° and 30° [$t(18) = -0.777$, $p_c = 1.000$].

3.2. Implicit task

Results in terms of accuracy and saccade latency for correct responses are presented in Table 3.

3.2.1. Accuracy

Accuracy was higher when emotional scenes appeared in the left visual field [mean (SD): 75.79 (8.92) %] than in the right visual field [68.34 (12.10) %; $F(1,18) = 4.626$, $p = 0.045$, $\eta^2_p = 0.204$]. Main effects of eccentricity [$F(2,36) = 8.850$, $p = 0.001$, $\eta^2_p = 0.330$] and of target [$F(1,18) = 7.885$, $p = 0.012$, $\eta^2_p = 0.305$] were qualified by eccentricity by target [$F(2,36) = 7.558$, $p = 0.002$, $\eta^2_p = 0.296$], valence by target [$F(1,18) = 8.531$, $p = 0.009$, $\eta^2_p = 0.322$], and valence by eccentricity by target interactions [$F(2,36) = 3.616$, $p = 0.037$, $\eta^2_p = 0.167$; Fig. 2]. On the one hand, separate analyses were conducted for each eccentricity. At 10° eccentricity, the simple valence by target interaction was not significant [$F(1,18) = 4.987$, $p_c = 0.114$] but accuracy was higher for emotional targets [78.71 (10.00) %] than neutral targets [68.73 (14.13) %; $F(1,18) = 13.510$, $p_c = 0.006$]. At 30°, there was a significant simple interaction between valence and target [$F(1,18) = 9.521$, $p_c = 0.018$] reflecting that accuracy was higher for emotional targets [71.59 (11.25) %] than neutral targets [62.58 (11.21) %] in the pleasant-neutral pair condition [$F(1,18) = 12.741$, $p_c = 0.004$] but not in the unpleasant-neutral pair condition [65.22 (12.06) % and 67.52 (10.56) %, respectively; $F(1,18) = 0.722$, $p_c = 0.814$]. At 60°, no significant results emerged [$F(1,18) < 1.0$]. On the other hand, separate analyses were conducted for each type of valence. For unpleasant-neutral pairs, accuracy was higher at 10° [74.30 (10.77) %] than at 30° [66.37 (9.67) %; $t(18) = 2.909$, $p_c = 0.028$],

Table 2
Mean accuracy [M (SD)] and saccade latencies for the correct responses [M (SD)] in the explicit emotional task.

			Emotional			Neutral		
			10°	30°	60°	10°	30°	60°
Accuracy in%	U-N	LVF	74.92 (13.45)	64.15 (17.70)	57.11 (18.13)	56.90 (21.69)	57.07 (17.49)	56.22 (27.07)
		RVF	61.36 (18.22)	48.62 (17.96)	52.66 (13.96)	47.26 (22.17)	47.77 (22.66)	50.33 (25.75)
	P-N	LVF	77.19 (16.09)	74.61 (11.03)	67.01 (14.98)	51.83 (22.51)	57.15 (19.89)	58.02 (29.48)
		RVF	58.70 (19.11)	51.14 (23.84)	63.9 (16.66)	43.55 (18.44)	45.00 (26.37)	34.65 (20.20)
Saccade latency in ms	U-N	LVF	260 (33)	254 (33)	309 (35)	295 (50)	283 (60)	357 (65)
		RVF	278 (34)	293 (31)	342 (42)	314 (58)	305 (64)	377 (97)
	P-N	LVF	255 (33)	252 (40)	325 (43)	292 (59)	297 (83)	358 (109)
		RVF	264 (30)	274 (30)	352 (56)	287 (66)	319 (87)	377 (113)

U-N: Unpleasant-neutral pairs; P-N: Pleasant-neutral pairs; LVF: emotional scene in the left visual field; RVF: emotional scene in the right visual field.

Table 3
Mean accuracy [M (SD)] and saccade latencies for the correct responses [M (SD)] in the implicit emotional task.

			10°		30°		60°	
			Emotional	Neutral	Emotional	Neutral	Emotional	Neutral
Accuracy in%	U-N	LVF	79.88 (16.52)	72.71 (19.49)	72.70 (12.67)	76.03 (16.01)	78.17 (15.71)	75.76 (19.05)
		RVF	75.02 (14.29)	69.57 (18.48)	57.73 (19.94)	59.02 (21.91)	73.87 (21.79)	75.76 (16.61)
	P-N	LVF	80.35 (15.79)	66.44 (19.20)	80.47 (14.80)	69.66 (13.60)	76.68 (22.14)	80.59 (15.71)
		RVF	79.58 (17.33)	66.17 (18.36)	62.72 (21.08)	55.50 (18.29)	70.5 (20.97)	74.70 (22.33)
Saccade latency in ms	U-N	LVF	282 (28)	295 (41)	272 (43)	266 (40)	350 (45)	343 (52)
		RVF	287 (37)	286 (42)	283 (44)	278 (64)	368 (50)	361 (55)
	P-N	LVF	275 (40)	275 (33)	260 (41)	279 (46)	345 (61)	346 (49)
		RVF	279 (32)	289 (42)	294 (49)	279 (56)	356 (52)	360 (39)

U-N: Unpleasant-neutral pairs; P-N: Pleasant-neutral pairs; LVF: emotional scene in the left visual field; RVF: emotional scene in the right visual field.

at 60° [75.89 (9.53) %] than at 30° [$t(18) = 3.508$, $p_c = 0.008$], but did not differ between 10° and 60° [$t(18) = -0.710$, $p_c = 1.000$; main effect of eccentricity, $F(2,36) = 7.870$, $p_c = 0.002$]. The eccentricity by target interaction was not significant [$F(2,36) = 2.075$, $p_c = 0.280$]. For pleasant-neutral pairs, the eccentricity by target interaction was significant [$F(2,36) = 9.274$, $p_c = 0.002$] and further analysis revealed that accuracy differed as a function of eccentricity for neutral targets [$F(2,36) = 13.427$, $p_c < 0.001$] but not for emotional targets [$F(2,36) = 2.421$, $p_c = 0.244$]: accuracy for neutral targets was higher at 60° [77.65 (9.80) %] than at 10° [66.31 (15.39) %; $t(18) = 3.261$, $p_c = 0.013$], at 60° than at 30° [62.58 (11.21) %; $t(18) = 6.312$, $p_c < 0.001$], but did not differ between 10° and 30° [$t(18) = 1.216$, $p_c = 0.719$]. Moreover, performance was significantly higher than chance for each valence and each target at each eccentricity [Fig. 2; $ts(19) > 4.619$, $ps < 0.001$].

3.2.2. Saccade latency

Main effects of laterality [$F(1,18) = 7.946$, $p = 0.011$, $\eta^2_p = 0.306$] and eccentricity [$F(2,36) = 73.074$, $p < 0.001$, $\eta^2_p = 0.802$] were qualified by an eccentricity by laterality by valence by target interaction [$F(2,36) = 3.854$, $p = 0.030$, $\eta^2_p = 0.176$]. Separate analyses at each level of eccentricity revealed neither a significant simple three-way interaction between laterality, valence and target [all $F(1,18) < 4.300$, $p_c > 0.150$] or a main effect of target [all $F(1,18) < 4.310$, $p_c > 0.150$].

4. Discussion

The aim of this study was to investigate, by using a saccadic choice task, the explicit and implicit processing of emotional information as a function of eccentricity in peripheral vision. The main results can be summarized as follows. First, in the explicit task, pleasant scenes were reliably categorized as emotional up to 60° while the performance for unpleasant scenes decreased between 10° and 30° and became non-significantly different from the chance level at 60°. Conversely, the categorization of neutral scenes was never significantly different from the chance level. Second, the emotional content of the scenes influenced the performance in the implicit task, which was significantly better for emotional targets than for neutral targets at 10° of eccentricity. This beneficial effect of emotion persisted only for pleasant scenes at 30°.

4.1. Explicit emotional processing in peripheral vision

While previous studies have found evidence for explicit emotional processing in near peripheral vision (e.g., Calvo & Lang, 2004; Calvo et al., 2015; Nummenmaa et al., 2006), this study is the first to show that it persists at very large eccentricity (60°), at least for pleasant scenes. Some critical features are therefore processed to allow discrimination between emotional and neutral scenes in peripheral vision, despite its low spatial resolution. As suggested by Calvo et al. (2015), the use of an explicit measure shows that affective significance is encoded. In the present study, the fact that the performance significantly exceeds the chance level at 60° only for pleasant scenes clearly suggests that valence is processed. This is consistent with the idea that the valence encoding at extrafoveal locations is based on an emotional gist processing (Calvo et al., 2015): a coarse visual impression would be sufficient to determine whether the scene has a positive or a negative affective value (Calvo et al., 2008; Calvo, 2006; Gutiérrez, Nummenmaa, & Calvo, 2009), even at far eccentricities. Moreover, Boucart et al. (2013) observed that classification of global scene properties (e.g., naturalness, openness) can be accomplished with a performance highly above chance even in the far periphery (up to 70° of eccentricity), showing that scene gist recognition can be accomplished by the low resolution of peripheral vision. Thus, explicit emotional processing appears to be efficient in peripheral vision, up to 60° at least for pleasant scenes, and may be based on a coarse impression of the visual input.

It has also been proposed that the emotional gist in peripheral vision would be sufficient to attract attention (e.g.D'Hondt et al., 2013 McSorley & van Reekum, 2013; Nummenmaa et al., 2006). This may explain why performance of the neutral group was not different from the chance level in the current study. As we hypothesized, given their privileged adaptive status over neutral scenes, emotional scenes in peripheral vision may capture attentional resources leading to numerous errors when the participants had the explicit instruction to saccade toward neutral scenes. This is supported by results reported by Nummenmaa et al. (2006) who found that, when pairs of lateralized scenes, one emotional and one neutral, are presented, the probability of the first fixation toward the emotional stimulus is higher, even when participants are told to look first at the neutral stimulus. In line with this observation, Kissler and Keil (2008) found more anti-saccade errors toward emotional pictures (pleasant and unpleasant) than neutral pictures during an anti-saccade task. Unlike the results of Nummenmaa et al. (2006), those of the present study did not suggest that emotional scenes were more likely to attract the first fixation when participants had to saccade toward neutral scenes since this would have led to a performance significantly lower than the chance level in this group. Nevertheless, we can conclude that the emotional content of visual scenes is encoded in peripheral vision and captures attentional resources.

4.2. Implicit emotional processing in peripheral vision

The results of the implicit task further suggest that emotional processing in peripheral vision persists even when emotion is not relevant to the task, up to 30° of eccentricity, at least for pleasant scenes. Two conclusions can be drawn from these results. First, the fact that the performance differs between emotional and neutral targets suggests that the emotional content of the scenes was processed even though it was not the primary focus of attention. Second, the better performance for emotional targets than for neutral targets suggests that a selective initial orienting toward emotional scenes benefited to the discrimination of the shape. This result agrees with those of studies using dot-probe tasks showing that the visual selection of a parafoveal probe is facilitated by the emotional value of the preceding visual stimulus (usually an emotional facial expression) on the basis of a common spatial location (Brosch, Sander, Pourtois, & Scherer, 2008; Pourtois, Grandjean, Sander, & Vuilleumier, 2004). This attentional capture in peripheral vision is consistent with the necessity to react to relevant stimuli for the well-being and the survival, independently of the ongoing task.

The categorization of the shape was also more accurate and faster when emotional scenes were presented in the left rather than in the right visual field, regardless of whether these emotional scenes were targets or not. One way to explain this result is that attentional capture by the emotional scenes may have helped to discriminate their shape and by inference, the ones of the neutral scenes presented in the right visual field. This result is in agreement with the hypothesis according to which the right hemisphere dominates in the processing of emotional information (e.g., Demaree et al., 2005; Gainotti, 2012; Heller et al., 1998). Previous studies on emotional processing in near peripheral vision have provided evidence for a right-hemisphere dominance, either during passive viewing (Alpers, 2008; at 11.2° eccentricity), in implicit conditions (De Cesarei et al., 2009; at 8.2° eccentricity while no emotional effects were observed at a 16.4° eccentricity; Keil et al., 2005; at 3.9° eccentricity) or in explicit conditions (Calvo et al., 2015; at 12.75° eccentricity). In the present study, the fact that we observed a right hemisphere dominance only in implicit conditions supports the idea that cerebral correlates of explicit and implicit emotional processing are partly dissociable (e.g., Critchley et al., 2000; Habel et al., 2007; Hariri et al., 2000; Scheuerecker et al., 2007) and further studies are needed to investigate this issue in peripheral vision.

4.3. Emotional effects and eccentricity

The emotional effects observed on accuracy measures suggest that emotional stimuli benefit from a privileged status compared to neutral stimuli in peripheral vision, where they are more likely to capture attentional resources. However, we did not find any emotional benefits in the saccade latencies while one could have expected that attentional capture would have induced shorter saccade latencies for emotional compared to neutral scenes in both tasks. In fact, this kind of effect has been observed by Calvo et al. (2007) during a recognition task where emotional-neutral pairs of scenes (presented at 11.8° eccentricity) were used as primes. Thus, even though it is plausible that the higher visual eccentricities used in the present study have constrained the speed at which emotional compared to neutral stimuli trigger the orientation mechanism, we should have found a significant interaction between eccentricity and group (emotional or neutral) in the explicit task and between eccentricity and target (emotional or neutral) in the implicit task: the saccade latencies should have been faster toward emotional than toward neutral scenes at least at a 10° eccentricity. This discrepancy in the results is, therefore, likely to be due to other methodological differences: in the present study, pictures were presented for a longer duration (1 s vs 450 ms for Calvo et al., 2007) and no speeded saccadic response was required, which may have made the saccadic latency measure less sensitive (Calvo et al., 2007). Moreover, mean latencies in our study, which ranged from 252 to 377 ms in the explicit task and from 260 to 368 ms in the implicit task, are relatively longer than those typically observed for reflexive saccades (i.e., between 150 and 175 ms; e.g., Rayner, 1998). Thus, one can assume that some endogenous control, reflected by the longer latencies and linked to the achievement of the task, has prevented the emergence of emotional differences in saccade latencies (Nummenmaa et al., 2006).

From the results of the present study, we cannot state that attentional capture by emotional scenes is automatic, notably since shape discrimination is a relatively easy task to perform and a more resources-consuming task may cancel emotional effects evidenced here (e.g., Pessoa, McKenna, Gutierrez, & Ungerleider, 2002). Moreover, the results from the implicit task suggest that attentional capture by emotional scenes depends on their valence and the visual eccentricity at which they are presented. For pleasant-neutral pairs, performance in the shape categorization task was not modulated by visual eccentricity when the targets were pleasant but was reduced at 10° and at 30° compared to 60° when the targets were neutral. This result as well as the fact that the performance was higher for pleasant than for neutral targets only at 10° and at 30° suggest that: (1) performance was reduced for neutral targets at 10° and at 30° probably due to the capture of some attentional resources by the pleasant scenes presented concurrently; (2) in more difficult visual conditions, i.e. at the farthest eccentricities explored in the present study (at 60° eccentricity), implicit emotional processing was not possible because attentional resources were only dedicated to the categorization of shape. While there was also no emotional effect for unpleasant-pairs at 60° in the implicit task, this latter explanation appears more plausible for pleasant scenes than for unpleasant scenes, which are not explicitly discriminated with a performance higher than the chance level at 60°. Furthermore, there was no emotional effect (i.e. a significant difference between emotional and neutral targets) for unpleasant-neutral pairs in the implicit task at 30°, where performance was also worse than at 10° and at 60° whatever the target (unpleasant or neutral). One possibility to explain this unforeseen result is that at 30° eccentricity, implicit discrimination between unpleasant and neutral scenes was still possible but was more resources-consuming than at 10° eccentricity and did not lead to a specific attentional capture by negative information. In line with this idea, the results of the emotional categorization task show that explicit processing of unpleasant scenes in the emotional group, although still significantly higher than the chance level, strongly decreased between 10° and 30° eccentricity. Thus, rather than modulating differentially the processing of unpleasant and neutral targets, implicit emotional processing may have interfered with the task by consuming resources dedicated to the shape discrimination of both kinds of targets. This explanation remains highly speculative and further studies are needed to explore in greater detail the specific characteristics of explicit and implicit emotional processing at that eccentricity.

The privileged status of pleasant scenes (vs unpleasant scenes) in both tasks is also somewhat surprising. Indeed, while the results observed at 10° eccentricity are consistent with those of previous studies showing that both pleasant and unpleasant scenes are efficiently processed in near peripheral vision (e.g., Calvo & Lang, 2004, 2005; Calvo et al., 2007, 2008; D'Hondt et al., 2013; Nummenmaa et al., 2006), the investigation of emotional processing at higher eccentricities suggests that: (1) it persists up to 60° in explicit conditions and up to 30° in implicit conditions only for pleasant scenes; (2) the ability to explicitly categorize emotional scenes decreases with increasing eccentricities only for unpleasant-neutral pairs. Actually, rather than a privileged status of pleasant scenes, one could have supposed that, in line with the negativity bias hypothesis (e.g., Carretié et al., 2001; Carretié et al., 2013; Hansen & Hansen, 1988; Ohman et al., 2001; Pratto & John, 1991; Smith et al., 2003), the discrimination performance would have been better with unpleasant scenes than pleasant scenes, whatever the part of visual field that is stimulated, given the high adaptive value of the negative stimuli in an evolutionary perspective. Nevertheless, De Cesarei and Codispoti (2006) also found a privileged status for pleasant scenes during an animal/person categorization task, even in conditions where discriminability was decreased because of the loss of fine details: only pleasant scenes induced an emotional modulation of an early ERP component, which was still present with decreasing picture size, even though reduced in amplitude and delayed. Rather than a negativity bias, the present results may reflect a positivity offset, based on the Evaluative Space Model (ESM; Cacioppo & Berntson, 1994, 1999; Cacioppo, Gardner, & Berntson, 1997, 1999). According to the ESM, the positive motivational system is more activated in response to low levels of emotional cues yielding a positivity offset while the negative motivational system is activated more in response to high levels of emotional cues yielding a negativity bias. Interestingly, Robinson, Storbeck, Meier, and Kirkeby, 2004 observed that participants were faster to categorize pleasant than unpleasant scenes when these were low in arousal while the reverse pattern was observed for high arousal stimuli. Given that the sets of pleasant and unpleasant scenes selected for the present study were on average equally arousing but with levels that can be considered as relatively moderated (around six on a scale ranging from one to nine), one can assume that, at these arousal levels, the positivity offset predominates over the negativity bias leading to the preferential processing of positive stimuli observed here. Moreover, this preferential processing could also be due to the nature of the saccadic task itself, requiring the participants to saccade toward target stimuli, which can be associated with an approach behavior. Indeed, positive stimuli are supposed to facilitate approach behavior while negative stimuli are more likely to induce an avoidance orientation (Cacioppo, Gardner, & Berntson, 1999) and several studies have observed these different attentional patterns according to emotional valence (e.g., Bradley, Mogg, & Millar, 2000; Bradley et al., 1997). This explanation appears also suitable to elucidate the decrease of performance in the explicit categorization of unpleasant scenes with eccentricity: negative stimuli in far eccentricity may be more likely to be avoided, leading to a saccade in the opposite direction and thus poorer performance in the saccadic choice task. Further research is needed to clarify this issue, and the impact of anxiety in the emotional processing of peripherally presented visual scenes may be particularly relevant (D'Hondt, Honore, Williot, & Sequeira, 2014).

To conclude, the results show evidence for explicit and implicit processing of emotional scenes in peripheral vision which are both modulated by the eccentricity and the valence of stimuli. Present research also brings interesting perspectives about the status of peripheral vision as a potential paradigm to analyze the balance between attentional vs. emotional power to capture and share cognitive resources.

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Conflict of interest

All other authors declare that they have no conflicts of interest.

Author contributions

FDH and MB developed the study concept. FDH, SS, and MB contributed to the study design. Testing and data collection were performed by SS, FDH and MB. FDH and SS performed the data analysis and interpretation under the supervision of MB. FDH and MB drafted the manuscript, and HS provided critical revisions. All authors approved the final version of the manuscript for submission.

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