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The spatial logic of fear

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Abstract

Peripersonal space (PPS) refers to the space surrounding the body. PPS is characterised by distinctive patterns of multisensory integration and sensory-motor interaction. In addition, facial expressions have been shown to modulate PPS representation. In this study we tested whether fearful faces lead to a different distribution of spatial attention, compared to neutral and joyful faces. Participants responded to tactile stimuli on the cheeks, while watching looming neutral, joyful (Experiment 1) or fearful (Experiment 2) faces of an avatar, appearing in far or near space. To probe spatial attention, when the tactile stimulus was delivered, a static ball briefly appeared central or peripheral in participant's vision, respectively ≈1° or ≈10° to the left or right of the face. With neutral and joyful faces, simple reactions to tactile stimuli were facilitated in near rather than in far space, replicating classic PPS effects, and in the presence of central rather than peripheral ball, suggesting that attention may be focused in the immediate surrounding of the face. However, when the face was fearful, response to tactile stimuli was modulated not only by the distance of the face from the participant, but also by the position of the ball. Specifically, in near space only, response to tactile stimuli was additionally facilitated by the peripheral compared to the central ball. These results suggest that as fearful faces come closer to the body, they promote a redirection of attention toward the periphery. Given the sensory-motor functions of PPS, this fear-evoked redirection of attention would enhance the defensive function of PPS specifically when it is most needed, i.e. when the source of threat is nearby, but its location has not yet been identified.

Keywords: spatial attention, peripersonal space, multisensory integration, fearful faces, joyful faces

Peripersonal space (PPS) is the multimodal sensory-motor interface (Rizzolatti, Fadiga, Fogassi, & Gallese, 1997) that mediates the interactions between the individual and the environment. PPS is characterised by an increased integration of visual or auditory stimuli with somatosensory processing (e.g. tactile stimuli), compared to farther space. Thus, PPS is multimodal in nature. In addition, it is coded in reference to specific body parts (Ladavas, 1998; Làdavas, 2002; Làdavas, Di Pellegrino, Farnè, & Zeloni, 1998). Visual or auditory stimuli presented close to, but not far from, a specific body part, enhance the excitability of neurons into the motor cortex. For example, motor responses to tactile stimuli on the hand become faster as visual or auditory stimuli are presented closer to that hand (Serino, Annella, & Avenanti, 2009). Also, reaction times to tactile stimuli delivered on a specific body part (i.e. trunk, leg, face, hand) are faster when paired with the simultaneous presentation of a visual or auditory stimulus appearing or played not directly on the body itself, but within a certain distance from the tactually stimulated body part (e.g. Làdavas & Farnè, 2004; di Pellegrino & Làdavas, 2015). Such multisensory integration in PPS has been explained according to the general principles of multisensory integration (Murray & Wallace, 2011), which state that sensory signals from two modalities in spatiotemporal proximity to one another are integrated with a gain in responsiveness. The degree of multisensory response enhancement that normally results from simultaneous presentation of visual and tactile stimuli (Van der Stoep, Nijboer, Van der Stigchel, & Spence, 2015) is found to positively correlate with the proximity of the visual stimulus to the tactually stimulated body part. Specialized brain areas with multimodal neurons, such as the ventral premotor cortex and the ventral intraparietal area, appear to underlie PPS representation (Cléry, Guipponi, Wardak, & Ben Hamed, 2015; di Pellegrino, Làdavas, & Farné, 1997; Grivaz, Blanke, & Serino, 2017).

PPS representation can expand or shrink with experience of sensory-motor interactions, such as training with a tool (Farnè, Iriki, & Làdavas, 2005; Farnè & Làdavas, 2000; Iriki, Tanaka, & Iwamura, 1996), or repeated exposure to a given sensorimotor context (Bassolino, Serino, Ubaldi,

& Làdavas, 2010), or abrupt changes in various factors (Clery, Guipponi, Odouard, Wardak, & Ben Hamed, 2015), including the individual's current state (stress, anxiety) or the valence of stimuli in the surrounding physical or social environment (Bufacchi & Iannetti, 2018; Serino, 2019). Concerning changes in the social environment, we recently showed that PPS representation is modulated by emotional facial expression of a looming 3D avatar (Ellena, Serino and Ládavas, under revision). Specifically, simple responses to tactile stimuli delivered to participants' cheeks were facilitated in the presence of a looming neutral or joyful face, as a function of their proximity to the participant, so that closer faces were associated with faster responses to tactile stimulation. Conversely, looming fearful faces facilitated responses to tactile stimuli even when the face was far from the participant, without any further modulation as the face approached.

Here we investigate the hypothesis that this modulation reflects a distinctive interaction between space and fear on attentional processing. In the presence of a threatening cue in the environment, attention is preferentially oriented towards the threat stimulus, and maintained for longer. Such attentional biases have been documented using a variety of stimuli (scenes, words, emotional faces; Yiend, 2010). Given that arousing and negative stimuli modulate spatial attention (Cisler & Koster, 2010; Koster, Crombez, Van Damme, Verschuere, & De Houwer, 2004; Yiend, 2010) and that attention influences the perception of visual or auditory stimuli, including perception of their distance (Anton-Erxleben, Henrich, & Treue, 2007), affective modulation of PPS might be based on attentional mechanisms (Cléry et al., 2015). Further, affective modulation of PPS involves long-range synchronization mechanisms between the fronto-parietal networks underlying multisensory integration and attention, and the prefrontal and limbic areas involved in action selection/inhibition and affective processing (for reviews see Cléry et al., 2015; Serino, 2019). An attentional basis for affect modulation of PPS was also suggested by De Haan and colleagues (2016). They found that spatial facilitation of tactile perception was further enhanced by an approaching threat and interpreted their results in terms of an attentional shift effect.

Fearful expressions are a particular kind of threatening stimulus. They do not constitute a direct danger (as the approaching spider in de Haan et al., 2016), but rather, they communicate the potential of an environmental risk, whose source and location are unknown. As such, fearful facial expressions might act as exogenous cues that influence the spatial distribution of selective attention. Healthy individuals covertly and reflexively orient the attentional focus to the position occupied by a fearful face, such as this will modify their behavioural performance and brain responses to a subsequent target appearing at the same location (Carlson & Aday, 2018; Carlson & Reinke, 2008; Pourtois & Vuilleumier, 2006; Vuilleumier & Pourtois, 2007). Also, fearful faces, as opposed to neutral or joyful faces, facilitate the orientation of attention onto their location (Brosch, Pourtois, Sander, & Vuilleumier, 2011; Cisler & Koster, 2010; Vogt, De Houwer, Koster, Van Damme, & Crombez, 2008). However, the capture of spatial attention by fearful faces is rapid but fleeting (Holmes, Green, & Vuilleumier, 2005; Torrence, Wylie, & Carlson, 2017), as opposed to joyful faces that hold it for longer (Fox, Russo, & Dutton, 2002; Torrence et al., 2017; Williams, Moss, Bradshaw, & Mattingley, 2005). In an array of faces, a fearful face is rapidly processed, but then attention seems to oscillate in avoidance of the face (Becker & Detweiler-Bedell, 2009); such deployment of attention, from early capture to successive redirection, would be functional to locate the actual source of threat.

We hypothesise that the attentional dynamic triggered by the presentation of fearful facial expressions may have not only a temporal but also a distinctive spatial pattern. Specifically, when a fearful face approaches the subject, attention will be redirected *from* the face to the surrounding environment, to enable identifying the location of the potential threat. That is, the distinctive effect of fear involves a wide deployment of spatial attention, as if to maximise the detection and localisation of potential threat. Fear and threat have a distinctive spatial logic, which should influence spatial attention in two ways. First, since a nearby threat is generally more important than a distant one (Bufacchi & Iannetti, 2018), fear-induced modulations of spatial attention should be stronger in near than in far space. Second, the redirection of spatial attention should not privilege the fearful face, since this is not itself threatening, but is rather an indicator of a threat located *elsewhere*. Rather, spatial attention should extend in way that covers any regions of space where the threat, that caused the fearful expression, might be located.

To our knowledge, the spatial spread of this fear-induced redirection of attention has not previously been examined. We therefore modified the paradigm described in Ellena and colleagues (under revision). Briefly, in a between-subjects design, two different groups of healthy participants made speeded responses to tactile stimuli, while watching looming avatar faces in virtual reality. The faces could show a neutral or an emotional expression, which was either joyful (Experiment 1) or fearful (Experiment 2). We chose a between-subjects design because, combining two emotions in the same task, such as joyful and fearful, would have raised the possibility of carry-over effects, or/and proactive interference effects, thus confounding or diluting the specific effect of each emotion (Paulus & Wentura, 2016). Looming emotional faces were presented in far or near space. Since PPS is centred around the specific tactually stimulated body part (Làdavas et al., 1998; Làdavas, Zeloni and Farnè, 1998; Graziano & Cooke, 2006; Duhamel et al., 1997), tactile stimulation was delivered to participants' cheeks because avatar faces were looming towards participants' face. This manipulation has been previously used in Serino and colleagues (2015). At the same time of the delivery of the tactile stimulation, a task-irrelevant visual checkerboard stimulus (a ball with a checkerboard pattern) appeared to the left or right of the face. Crucially, the ball could either be close to the face, and thus more *central* in the participant's vision, or further away from the face, and thus more *peripheral* in the participant's vision. With this paradigm, the modulation of spatial attention is not directly measured, but it is assumed to be indirectly assessed through the amount of facilitation that visual stimuli have on processing of tactile stimuli (Busse, Roberts, Crist, Weissman, & Woldorff, 2005; De Meo, Murray, Clarke, & Matusz, 2015; Eimer, Velzen, & Driver, 2002; Talsma, Senkowski, Soto-Faraco, & Woldorff, 2010). Thus, this paradigm is based on the assumption that the ball facilitates responses to tactile stimuli when it appears in a spatial location, which falls within the zone currently selected by spatial attention.

In Experiment 1, where joyful faces are contrasted to neutral faces, we expect to replicate classic PPS effect, as no specific modulation of attention is expected in the presence of joyful as opposed to neutral faces. Therefore, we expect a facilitation of response to tactile stimuli that depends on the distance of the face from the participant's body. In other words, participants are expected to respond faster to the tactile stimulation when faces are in near, as opposed to far space. In addition, neutral and joyful faces should attract attention, thus promoting processing of stimuli in their immediate surrounding (i.e. central ball) at the expense of peripheral stimuli (i.e. peripheral ball). Therefore, we expect response to tactile stimuli to be facilitated also in the presence of the central as opposed to peripheral ball. In contrast, in Experiment 2, where fearful faces are contrasted to neutral faces, we expect response to tactile stimuli to be modulated not only by the distance of the face from the participant, but also by the emotional facial expression and the position of the ball. Specifically, we expect faster response to tactile stimulation in near than in far space (classic PPS effect) and faster response in the presence of fearful than neutral faces (salience effect). Crucially, because of the specific fear-induced modulations of spatial attention described above, we also expect three-way interaction between the factors space, face emotion and ball position, such that response to tactile stimuli in near, but not far, space will be further facilitated in the presence of the peripheral, rather than central ball. This is because fearful faces will redirect attention towards the periphery and this effect should be stronger in near than far space, since a nearby threat is generally more important than a distant one (Bufacchi & Iannetti, 2018). In addition, compared to far space, in near space the peripheral (attended) rather than the central (unattended) ball will be more likely to fall within the spatiotemporal proximity window for multisensory integration. Thus, our hypothesis is based on the interactive effect of peripersonal-space multisensory processing and modulation of attention in response to fearful facial expressions.

EXPERIMENT 1

Here we tested whether looming joyful, vs. neutral, faces induce a change in PPS representation (i.e. change in RTs to tactile stimulation) by promoting a different distribution of spatial attention (probed by the ball). We hypothesize that with neutral and joyful faces, attention will be focused on the approaching face (or the space immediately surrounding it). Therefore, we expect a facilitation of response to tactile stimuli that depends on the distance of the face from the participant's body and the position of the ball. In other words, participants are expected to respond faster to the tactile stimulation when faces are in near, as opposed to far space, replicating classic PPS effect, and when in presence of the central as opposed to peripheral ball.

Methods

Participants

Twenty-three healthy participants with no history of neurological or psychiatric disorder were recruited (12 females; age: M ± SD = 29.78±3.84 years). The experiment was conducted in accordance with the principles of the Declaration of Helsinki and approved by the Bioethics Committee of the University of Bologna. Each participant gave written informed consent prior to participating and after being informed about the procedure of the experiment. The sample size was determined via a power analysis conducted in G*Power 3.1 software and based on the mean of the effect size from prior studies on PPS (Pellencin, Paladino, Herbelin, & Serino, 2018; an alpha of 0.05, and a power of 0.9.

Experimental task and procedure

The experiment was implemented in ExpyVR software (available online at http://lnco.epfl.ch/ framework for designing and running experiments in virtual reality) and ran on a Windows-based PC (Dell XPS 8930, Dell, Round rock, Texas, USA). The tactile stimuli consisted in vibrations delivered bilaterally at the participants cheeks by a pair of electrodes (Precision MicroDrives shaftless vibration motors, model 312-101, 3V, 60 mA, 150 Hz, 5 g). The motor had a surface area of 113 mm2 and reached maximal rotation speed in 50 ms. This device was activated for 100 ms during tactile stimulation. The visual stimuli were avatar joyful or neutral faces. The expression was manipulated ad hoc and validated in a preliminary study (see section below).

At the beginning of each trial (T0) an avatar face with a neutral or joyful expression appeared centrally on the visual field, either in the space near to (≈115 cm) or far from (≈220 cm) the participant, by relaying stereoscopically to the head-mounted display (HMD, Oculus Rift SDK, Oculus VR, 100° field of view, 60 Hz) worn by the participant. The face then moved toward the participant on the sagittal plane for a total of 3000 ms until its final position (Near: ≈10 cm; Far: ≈115 cm) where it remained still for 1000 ms (T2). Importantly, 2000 ms after the beginning of the trial (T1), the tactile stimulation was delivered bilaterally, and, simultaneously, a static checkerboard ball appeared for 250 ms, either ≈1° (ball central) or ≈10°(ball peripheral) to the left or right of the face (left and right sides counterbalanced among trials; *Fig. 1*). Thus at T1, touch coincides with perception of the ball and of the face, at different distances from the participant (at ≈45 cm, in the near, and ≈150 cm in the far). The ITI was set at 2100 ms (+/- 100 of jitter). Distances of near and far spaces were calibrated as previously done in Serino and colleagues (2015). During the task, participants made speeded simple responses to the tactile stimulation by pressing a button placed on the table in front of the participant with their right hand.

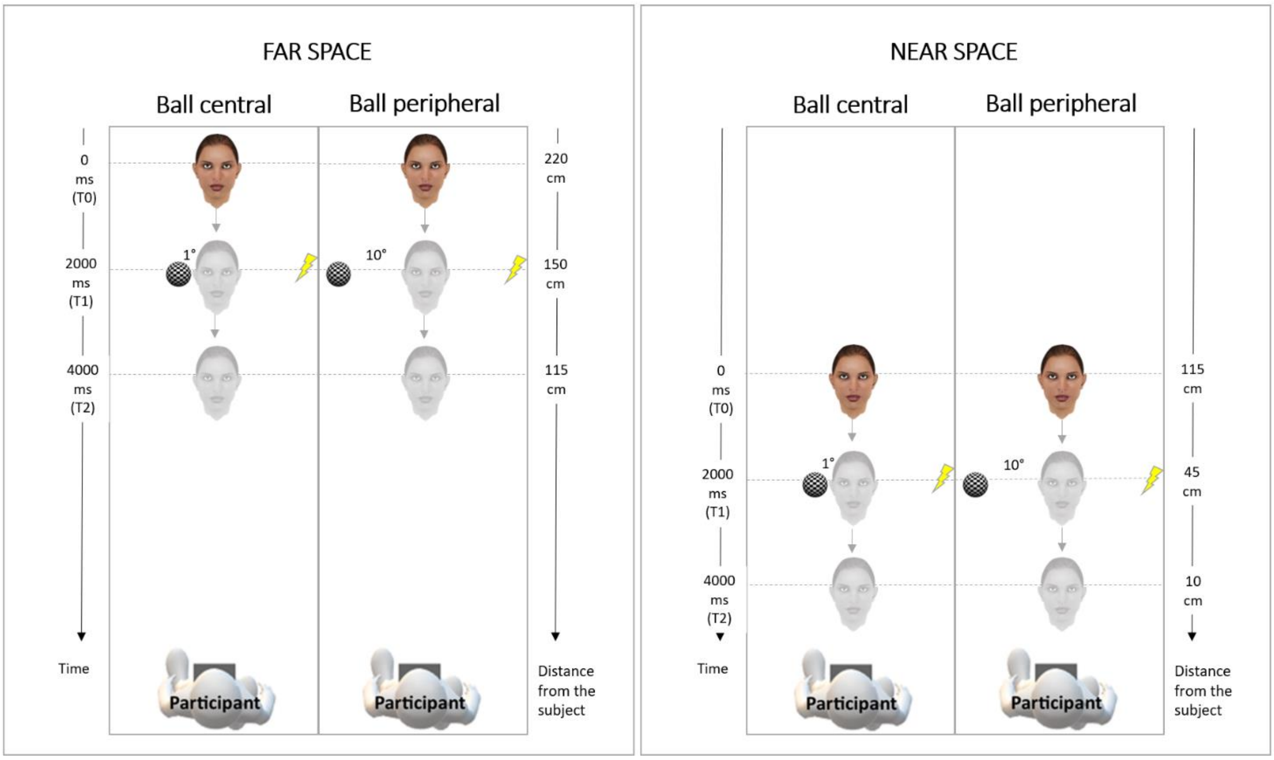

Figure1. Illustration of the experimental paradigm. Looming faces appeared in far (A) or in near (B) space with respect to the participant at T0 and approached the subject frontally until T2 at a constant speed. At T1, the tactile stimulus is delivered simultaneously to the appearance of the checkboard ball, which appeared centrally or peripherally to the left or right of the face frontal plane. To note, the ball appeared at 10° or 1° from the avatar's face both in the near than in the far space conditions.

There was a total of 320 experimental trials, equally divided among the 8 experimental conditions (i.e. 40 trials per condition): Face emotion: Neutral / Joyful; Space: Far / Near; Ball Position: central / peripheral. There were also an additional 100 trials, which were introduced to decrease task predictability: in 80 trials no vibration was delivered and in 20 trials, no ball was shown. Importantly, the only aspect of the task that was lateralized was the presentation of the ball, which could be either on the left or right. However, side of presentation is not a factor of interest for our design and left/right presentation trials were therefore pooled. The entire experiment was split in 5 blocks of 84 trials each, in which the conditions were pseudo-randomized, such that each block presented equal number of each condition. The experiment lasted approximately one hour, and participants could rest between blocks to prevent fatigue.

After signing the consent form, participants seated on a comfortable chair, in a sound attenuated room. Vibrators were then attached bilaterally on the cheeks with a medical tape, and participants then wore the virtual reality headset. Before starting the task, lens focus was adjusted for each participant to ensure clear vision.

Face stimuli creation and validation

Note that all face stimuli (joyful, fearful and neutral) were created and validated together in a pre-experimental phase of the study, thus we report here the procedure concerning all stimuli that were part of both Experiment 1 and Experiment 2. Face stimuli consisted of 3D avatar faces that displayed a joyful, fearful or neutral expression (Figure 2). The virtual faces were created with ‘Poser 10′ software (http://my.smithmicro.com/poser-3d-animation-software.html), such that their features were manipulated ad hoc to result in the desired facial expression.

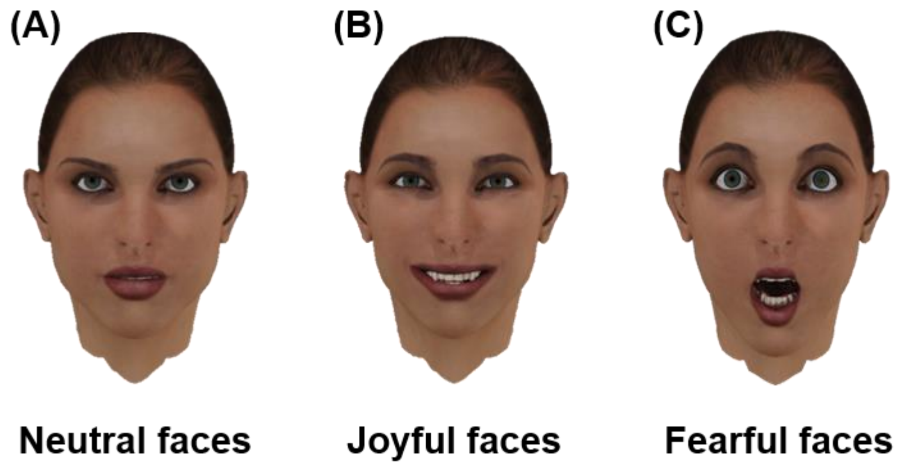

Figure2. Example of emotional faces. (A) Neutral faces used in Experiment 1 and 2. (B) Joyful faces used in Experiment 1. (C) Fearful faces used in Experiment 2.

In order to select the faces to be included in each experiment, 60 naive participants (30 females; mean age 29±10 SD) were instructed to rate 15 two-dimensional pictures constituting 5 different versions of facial expressions, namely joyful, fearful or neutral. Participants had to indicate which emotion was represented in the picture, and subsequently, to rate on a 10-points Likert scale, how strongly was expressed that emotion (0 = low intensity; 9, high intensity). Also, they had to rate the arousal level generated by each stimulus, on a 10-point Likert scale (0= not at all arousing; 9= extremely arousing).

This procedure allowed to select 2 joyful, 2 fearful, and 2 neutral facial expressions, according to the highest percentage of participants who correctly identified the emotion in the picture, then the highest perceived intensity level and the highest perceived arousing effect. The mean hit rate of the selected stimuli was 95 %, for the joyful, 80 % for the fearful and 80 % for the neutral faces. To check whether the mean ratings for intensity and arousal were significantly different between the emotions, a repeated measures ANOVA was conducted with mean intensity and mean arousal scores. The analysis on intensity level showed that ratings were different across emotions [$F(2,118) = 151.45$; $p<0.01$; $\eta p2=0.72$]. Post-hoc Bonferroni corrected showed that both joyful and fearful expressions were judged as more intense than the neutral expressions (Neutral faces: M=2.39, SEM=2.05; Joyful faces: M=5.62, SEM=1.70; Fearful faces: M=7.12, SEM=1.38; all $p<0.01$); moreover fearful expressions were judged as more intense than the joyful ($p<0.01$). The analysis on arousal level showed that ratings were different across emotions [$F(2,118) = 98.35$; $p<0.01$; $\eta p2=0.63$]. Post-hoc Bonferroni corrected showed that both joyful and fearful expressions were judged as more arousing than the neutral expressions (Neutral faces: M=1.53, SEM=1.54; Joyful faces: M=3.89, SEM=2.17; Fearful faces: M=5.08, SEM=2.32; all $p<0.01$); moreover fearful expressions were judged as more arousing than the joyful ($p<0.01$).

Dependent measure

The rate of omissions was low (M=1.6% SD=2.4). For this reason, performance was analysed in terms of reaction times (RTs) only, as previously done in e.g., Canzoneri, Magosso, & Serino(2012). Trials with RTs exceeding more than 2 standard deviations from the mean RT of each block were considered as outliers, and excluded from the analyses (M=4.5%. SD=3.01). For each participant, mean RTs were calculated for each condition, and used for analysis.

Results

A 2x2x2 RM ANOVA (Face emotion: Neutral / Joyful; Space: Far / Near; Ball Position: central / peripheral) was conducted to test whether looming joyful vs. neutral faces induced a change in PPS representation (i.e. difference in RTs to tactile stimulation) through a different distribution of spatial attention, probed by the ball appearing centrally or peripherally from the face. Results showed a significant main effect of Face Emotion [$F(1,22)=4.99$; $p=0.03$; $\eta p2=0.18$]; participants responded faster to Joyful than Neutral faces (Joyful faces: M=372.73 ms; SEM=11.35; Neutral faces: M=377.66 ms; SEM=11.84). There was also a significant main effect of Space [$F(1,22)=72.95$; $p<0.01$; $\eta p2=0.77$]; participants responded faster to faces in the Near than Far space (Near: M=360.93ms; SEM=11.68; Far: M=389.45 ms; SEM=11.32). We also found a significant main effect of Ball Position [$F(1,22)=6.32$; $p=0.02$; $\eta p2=0.22$]; participants responded faster when the ball was central as opposed to peripheral to the face (central: M=373.46 ms; SEM=11.52; peripheral: M=376.94 ms; SEM=11.68).

Moreover, there was a significant Face Emotion by Space interaction [$F (1,22) =5.59$; $p=0.03$; $\eta p2=0.20$]. Newman-Keuls post-hoc comparisons revealed that when faces appeared in Far space, participants responded faster to Joyful than Neutral faces (Joyful faces: M=384.87 ms; SEM=22.14; Neutral faces: M=394.04 ms; SEM=23.34; $p<0.01$). On the contrary, when faces appeared in Near space, there was no significant difference in RTs between Joyful and Neutral faces (Joyful faces: M=360.58ms; SEM=23.21; Neutral faces: M=361.29ms; SEM=23.76; $p=0.78$). No significant three way Face Emotion by Space by Ball position interaction was found [$F (1,22)=1.59$; $p=0.22$; $\eta p2=0.07$].

We found that response to tactile stimuli was facilitated when faces were near to, as opposed to far from, the participant (classic PPS effect). In addition, joyful faces facilitated response to tactile stimuli compared to neutral faces (classic salience effect), in the far but not in the near space.

Finally, central, as opposed to peripheral, balls facilitated response to tactile stimuli, regardless of the emotional expression of the face or the distance of the face from the participant (*see Figure3*).

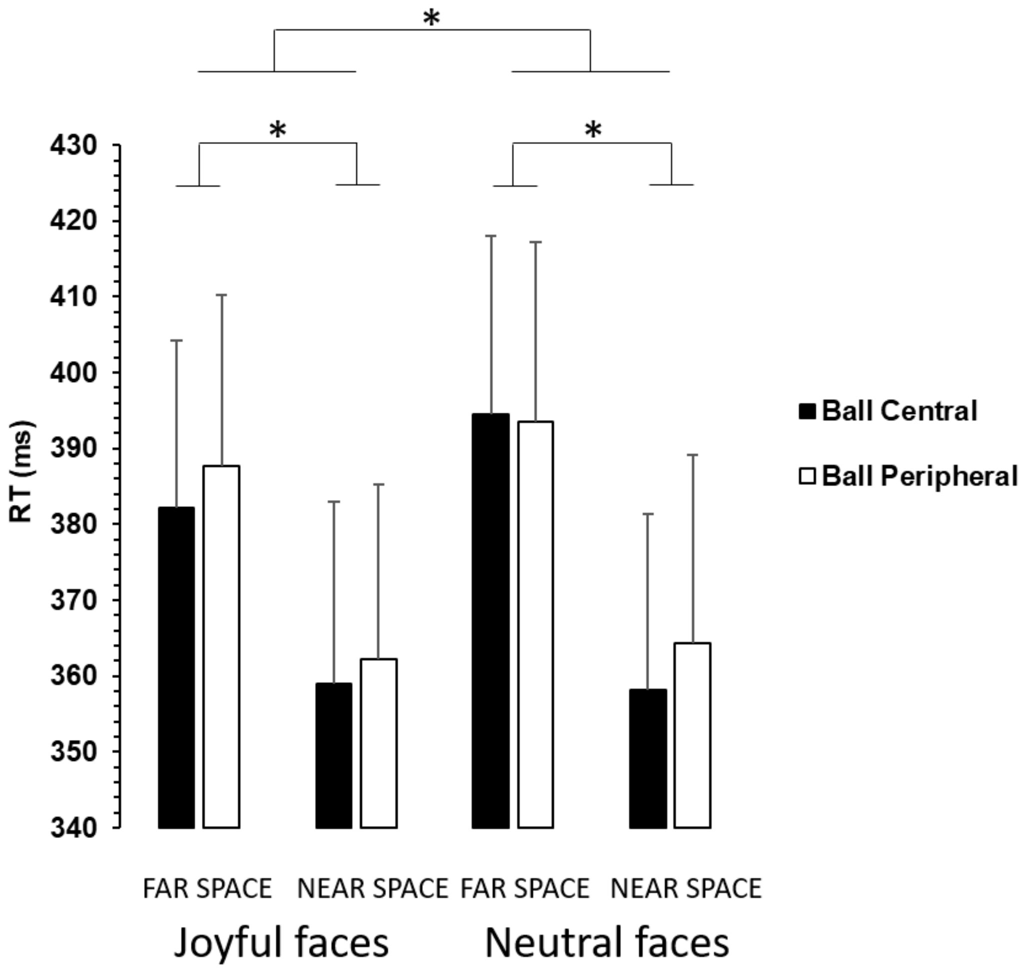

Figure3. Bar graphs showing the experimental results. The bar graph shows the main effect of space. Joyful and neutral faces facilitate response to tactile stimuli (faster RTs) when they are in near, as opposed to far space. Asterisks indicate significant comparisons. Error bars represent S.E.M..

EXPERIMENT 2

Here, whether looming fearful, vs. neutral, faces induce a change in PPS representation (i.e. change in RTs to tactile stimulation) by promoting a different distribution of spatial attention. In particular, fearful faces, as opposed to neutral, will redistribute attention towards the periphery, in order to promote scanning of the environment to find the source of threat. This mechanism should interact with the general spatial principles of multisensory integration as well as a general salience effect induced by the emotional facial expression. Such that, we expect faster responses in near than in far space (classic PPS effect) and to fearful than neutral faces (salience effect). We also expect this effect in near space to be enhanced in presence of the peripheral, rather than central ball, because that is the portion of space where the attentional modulation will be stronger and where the peripheral (attended) ball is more likely to respect the criteria of spatiotemporal proximity necessary for multisensory integration. Thus, overall, we expect a facilitation of response to tactile stimuli when faces are fearful as opposed to neutral, and in near as opposed to far space. In addition, we expect an interaction of these, as a function of ball position, such that response to tactile stimuli should be facilitated by the peripheral, vs. central, ball when the fearful face is near, rather than far, space.

Methods

Participants

Twenty-three healthy participants were recruited (12 females; mean age 27.61±4.36). None of the participants reported any history of neurological or psychiatric disorders, and all were naive to the purpose of the study. The experiment was conducted in accordance with the principles of the Declaration of Helsinki and approved by the Bioethics Committee of the University of Bologna. Each participant gave written informed consent prior to participating and after being informed about the procedure of the study. The sample size was determined via a power analysis conducted in G*Power 3.1 software and based on the mean of the effect size from prior studies on PPS (Pellencin et al., 2018;), an alpha of 0.05, and a power of 0.9.

Experimental task Procedure

Experimental stimuli, task and procedure were identical to Experiment 1, with the only difference that faces showed a neutral or a fearful expression (*Figure2 A-C*).

Dependent measure

Participants rate of omissions was low (M=1.35% SD=2.14). For this reason, performance was analysed in terms of reaction times (RTs) only, as previously done in e.g., Canzoneri and colleagues (2012). Trials with RTs exceeding more than 2 standard deviations from the mean RT of each block were considered as outliers, and excluded from the analyses (M=5.80% SD=3.12). For each participant, mean RTs were calculated for each condition, and used for analysis.

Results

A 2x2x2 RM ANOVA (Face emotion: Neutral / Fearful; Space: Far / Near; Ball Position: central / peripheral) was conducted to test whether looming fearful, vs. neutral, faces induced a change in PPS representation (i.e. difference in RTs to tactile stimulation) through a different distribution of spatial attention, probed by the ball appearing centrally or peripherally from the face.

Results showed a significant main effect of Face emotion [$F(1,22)=15.99$; $p<.01$; $\eta p2=0.42$]; participants responded faster to Fearful than Neutral faces (Fearful faces: M=374.92ms; SEM=0.89; Neutral faces: M=381.92ms; SEM=0.88). There was also a significant main effect of Space [$F(1,22)=69.60$; $p<0.01$; $\eta p2=0.76$]; participants responded faster to faces in Near than Far space (Far space: M=395.33ms; SEM=0.85; Near space: M=362.51 ms; SEM=0.87). There was no significant main effect of Ball Position [$F(1,22)=0.24$; $p=0.62$; $\eta p2=0.01$], Face emotion by Space [$F(1,22)=0.96$; $p=0.34$; $\eta p2=0.04$] or Face emotion by Ball Position [$F(1,22)=2.20$; $p=0.15$; $\eta p2=0.09$] interaction. However there was a significant Space by Ball Position [$F (1,22)=7.66$; $p=0.01$; $\eta p2=0.26$] interaction. In far space, participants responded faster to the central than peripheral ball (Peripheral: M=396.52ms, SEM=16.67; Central: M=392.15ms, SEM=16.49; $p=0.03$), while in near space, there was no difference in RT between the central and peripheral ball (Peripheral: M=361.06ms, SEM=16.56; Central: M=363.95ms, SEM=17.31; $p=0.13$).

Crucially, there was a significant three way Face emotion by Space by Ball Position interaction [$F(1,22)=4.45$; $p=0.04$; $\eta p2=0.17$]. Newman-Keuls post-hoc comparisons revealed that in presence of neutral faces, there was no difference in RT between the central and peripheral ball either in far space (central: M=396.84ms, SEM=15.95ms; peripheral: M=400.53ms; SEM=16.21ms; p=0.17) or near space (central: M=364.15ms, SEM=17.33ms; peripheral: M=366.15ms; SEM=17.32ms; p=0.45). In presence of fearful faces in far space, RTs showed a trend to be faster with the central ball compared to the peripheral one, although not significant (central: M=387.45ms, SEM=17.17; peripheral: M=392.51 ms, SEM=17.25; p=0.07). In contrast, when fearful faces appeared in near space, participants responded significantly faster to the peripheral compared to the central ball (central: M=363.75ms, SEM=17.39; peripheral: M=355.97ms, SEM=15.94; p<0.01).

We found that response to tactile stimuli was facilitated when faces were near to, as opposed to far from, the participant (classic PPS effect). We also found that fearful faces facilitate response to tactile stimuli compared to neutral faces (salience effect). Importantly, we also found that, in contrast to neutral faces, fearful faces response to tactile stimuli depending on their distance from the participant and the position of the ball. In fact, while in far response to tactile stimuli tended to be facilitated by the central rather than peripheral ball, in near space, response to tactile stimuli was significantly facilitated by the peripheral rather than central ball (*see Figure 4*).

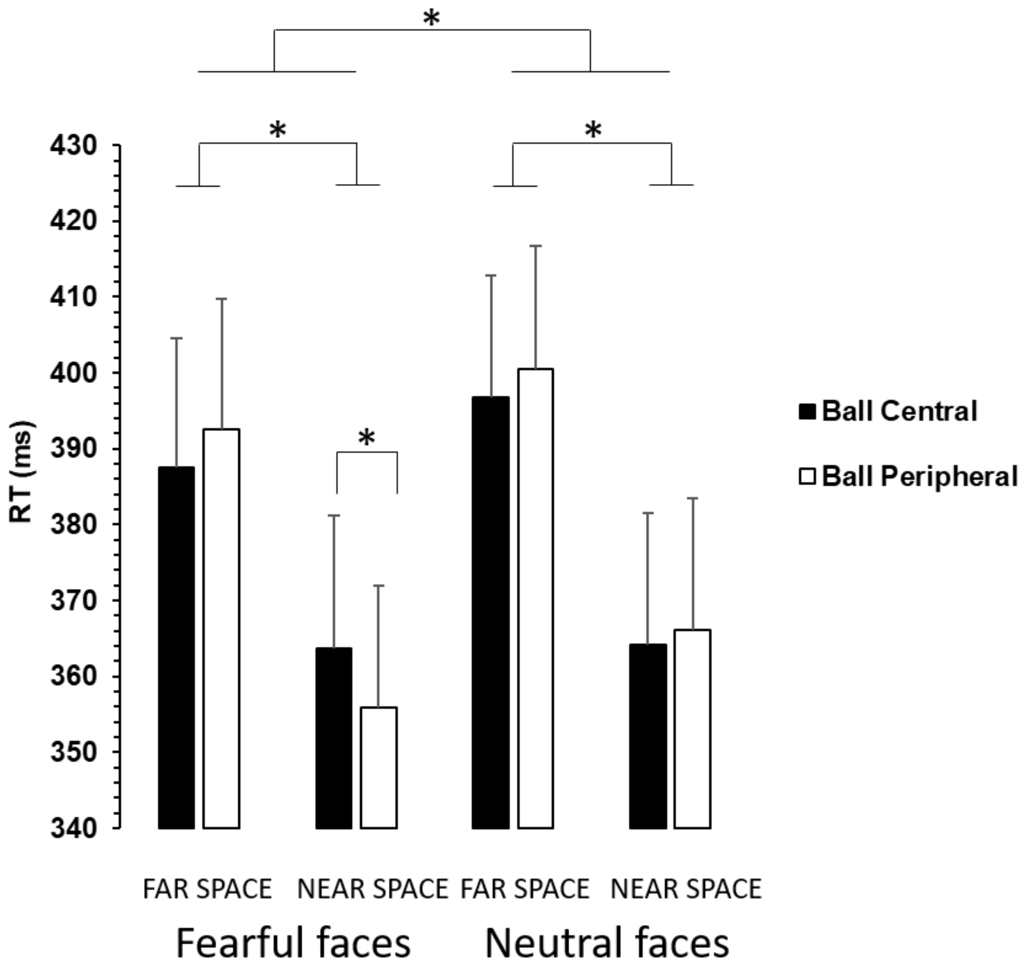

Figure 4. Bar graphs showing the experimental results. The bar graph shows the main effect of space and the face emotion by space by ball position interaction. Fearful and neutral faces facilitate response to tactile stimuli (faster RTs) when they are in near, as opposed to far space. Moreover, only when the face was fearful and in near space, response to tactile stimuli was facilitated in presence of the peripheral compared to central ball. Asterisks indicate significant comparisons. Error bars represent S.E.M..

Discussion

PPS is the representation of the space surrounding the body (Rizzolatti et al., 1997), and its extent can be defined as the portion of space in which multisensory information between somatosensory and visual and auditory stimuli has a higher probability of being integrated (Graziano & Cooke, 2006; Serino, 2019). This multisensory integration in PPS has been explained according to the general principles of multisensory integration (Murray & Wallace, 2011), which state that sensory signals from two modalities in spatiotemporal proximity to one another are integrated with a gain in responsiveness. Thus, the amount of multisensory response enhancement that normally results from simultaneous presentation of visual and tactile stimuli (Van der Stoep, Spence, Nijboer, & Van der Stigchel, 2015) is expected to positively correlate with the proximity of the visual stimulus to the tactually stimulated body part.

Emotional facial expressions have been shown to modulate PPS representation. In particular, compared to neutral and joyful faces, fearful faces facilitate response to tactile stimuli already when the face appears far from the individual without changing as the face approached (Ellena et al., under revision). The present study was designed to investigate whether the attenuation of the spatial-dependent multisensory facilitation, was due to a differential distribution of spatial attention promoted by fearful as opposed to neutral and joyful faces. To this aim, healthy participants responded to tactile stimuli at the cheeks, while watching in virtual reality looming avatar faces, that could show a neutral or an emotional expression, joyful (Experiment 1) or fearful (Experiment 2), and appear far from or near to the participant. To probe spatial attention, when the tactile stimulus was delivered, a ball (representing a static visual distractor) briefly appeared centrally or peripherally to the left or the right of the face's frontal plane. In Experiment 1, we found that response to tactile stimuli was facilitated when faces were near to, as opposed to far from, the participant (classic PPS effect). In addition, joyful faces facilitated response to tactile stimuli compared to neutral faces (classic salience effect), in the far but not in the near space. Finally, central, as opposed to peripheral, balls facilitated response to tactile stimuli, regardless of the emotional expression of the face or the distance of the face from the participant. In Experiment 2, we found that response to tactile stimuli was facilitated when faces (fear and neutral) were near to, as opposed to far from, the participant (again, classic PPS effect). We also found that fearful faces facilitate response to tactile stimuli compared to neutral faces (again, a salience effect). Importantly, we also found that, in contrast to neutral faces, fearful faces modulated response to tactile stimuli depending on their distance from the participant and the position of the ball. In fact, while in far response to tactile stimuli tended to be facilitated by the central rather than peripheral ball, in near space, response to tactile stimuli was significantly facilitated by the peripheral rather than central ball.

The facilitation of response to tactile stimuli in the near (vs. far) space, found in both experiments, is in line with the broad literature on PPS and multisensory integration. Sensory signals from two modalities in spatiotemporal proximity (e.g. visual and tactile) are integrated with a gain in responsiveness (Van der Stoep, Spence, et al., 2015) and this effect is expected to positively correlate with the proximity of the visual stimulus to the touched body part (Ladavas, 1998; Làdavas, 2002; Làdavas et al., 1998; Serino et al., 2015). In contrast with previous studies (e.g. Serino et al., 2015; Spaccasassi, Romano, & Maravita, 2019), where looming faces travelled over a constant portion of space and the near and far space conditions were determined by the time point at which the tactile stimulation was delivered (i.e. earlier stimulation = far space; later stimulation = near space), here we kept the delay between the appearance of the face and the tactile stimulation constant between far and near space conditions (Fig. 2). This manipulation enables us to exclude the possibility that the facilitation of response to tactile stimuli in near vs. far space may have resulted from a confounding effect of an increasing expectation about tactile stimulation delivery as time passes since the appearance of the face. However, by keeping the duration and face displacement constant across conditions, we could not control for the relative distance displacement: in fact, the face in the near space moves approximately the total of the distance from the observer, while the face in the far condition, moves only approximately half of its distance from the observer. Nonetheless, if the relative displacement between far and near space was equated, while keeping the duration of presentation constant, faces in near space would have to travel much slower than in far space. This would have raised another methodological limitation, as it is known that the speed of looming also affects multisensory integration relative to peripersonal space (Noel et al., 2018).

In addition to the PPS effect, we also found a salience effect, namely, the facilitation of response to tactile stimuli in far space in presence of an emotional (joyful or fearful vs. neutral) faces. This effect may have resulted from an increased arousal response elicited by the emotional face compared to the neutral face, thus fastening response times.

Crucially for the aim of the present study, by adding the central and peripheral balls we were able to show that, in addition to the PPS and the saliency effects, response to tactile stimuli, was further differentially modulated in the two experiments depending on the emotional expression of the faces, their position in space and the position of the ball in the participants' visual field. The facilitation of response to tactile stimuli by the central (vs. peripheral) ball in experiment 1, regardless of the emotion of the face and its position in space, suggests that attention may be focused in the immediate surrounding of the face and that such attentional focus does not appear to change significantly as faces come closer to participants. In fact, joyful faces appear to attract attention (Williams et al., 2005) and hold it for a longer period of time (Torrence et al., 2017), without promoting any redistribution of spatial attention. Similarly, in the spatial domain, joyful faces, not promoting any attentional shift to a specific spatial location, simply modulate tactile facilitation and PPS representation only in a spatially dependent way (central vs. peripheral and near vs. far).

Our main result is that, in contrast to neutral and joyful faces, fearful faces modulated response to tactile stimuli depending not only on their distance from the participant, but also on the position of the ball. In near space, but not in far space, response to tactile stimuli was facilitated by a peripheral ball, more than by a central one. This effect confirms the hypothesis that the attentional dynamic triggered by the presentation of fearful facial expressions has a distinctive centrifugal spatial pattern, compared to neutral and joyful. In fact, static fearful faces are known to influence the distribution of spatial attention, eliciting an early but fleeting capturing of attention (Carlson & Reinke, 2014; Pourtois & Vuilleumier, 2006, Torrence et al., 2017). Our results show for the first time that a redirection of attention is induced by looming fearful faces intruding into PPS, and also reveals the spatial logic of the redirection mechanism. Specifically, a fearful face has a centrifugal effect on attention, forcing attention towards the periphery. Even though fearful faces were presented centrally, their attentional effect was stronger when combined with a more peripheral stimulus. This redirection of attention would support the adaptive function of fearful faces, prompting a heightened perceptual processing of potential threat that could be anywhere in the observer's surroundings (Wieser & Keil, 2014). This deployment of attention to the periphery by fearful faces, in interaction with PPS sensory-motor functions, would enhance the defensive function of PPS (described by Graziano & Cooke, 2006; Lourenco, Longo, & Pathman, 2011; Sambo & Iannetti, 2013; Sambo, Liang, Cruccu, & Iannetti, 2012; De Vignemont and Iannetti, 2015). Further, this enhancement is strongest specifically when defence is most pressing, i.e. when the source of threat may be in the near space. In fact, while, in far space, response to tactile stimuli tended to be facilitated by the central ball, in near space, the peripheral ball facilitated response to tactile stimuli. This appears in line with evidence showing that the reorienting of spatial attention is more flexible for unexpected stimuli falling nearer, rather than farther in depth (Chen et al., 2012). Moreover, closer stimuli are perceived as more imminent than farther stimuli (Fanselow & Lester, 1988), and threat imminence is a decisive factor for a stimulus to provoke an attentional shift (Koster et al., 2004). Thus overall, the modulation of response to tactile stimuli may have been evident in near space because this seems the portion of space where attention is more strongly modulated by the fearful facial expression and this is also the portion of space where the peripheral (attended) ball is more likely to respect the criteria of spatiotemporal proximity necessary for multisensory integration. In fact, strength of multisensory integration is maximal in near space, because this is the portion of space where there is maximal spatiotemporal coincidence, between the visual stimulus (i.e. ball) and the tactually stimulated body part (i.e. the participant’s cheeks).

A limitation of the present study might be represented by the fact that low physical features of the emotional facial expressions could not be controlled (fearful faces presented highly contrasted eyeballs as compared to other expressions). Although this might have an influence on responses, such difference in low features seems necessary for the facial expressions to convey specific emotional information (Gray et al., 2013; Calvo and Nummenmaa, 2008). Additionally, and even more important, the highly contrasted eyeballs in fearful faces could be expected to attract attention on the face, which is the opposite of what it has been found. Thus, such difference in low physical features would not explain why fearful face resulted in a redirection of attention away from the face, and why such effect was evident in near space only. Give this, our results seemed attributable to the emotional information conveyed by the stimuli rather than their low-level features. Additionally, although an effect of the difference in retinal size between near and far stimuli cannot be excluded (near stimuli are bigger than far stimuli), this would not explain the difference in response between neutral and fearful faces in the near space, thus when the retinal size of faces was the same.

Finally, an effect of arousal in facilitating responses to tactile stimuli when the visual stimuli were in the near space cannot be excluded, and such effect may have been greatest in response to fearful faces. Although a general effect of this kind may account for the facilitation of response to fearful vs. neutral faces, this does not seem to explain the specific pattern of our main result, i.e. the facilitation of response to the peripheral vs. central ball in presence of fearful faces near the body. Similarly, we cannot exclude that higher intensity and arousal reported to fearful as opposed to joyful faces may have affected our results. Future studies could include the presentation of other negative emotional facial expressions, that are comparable in arousal and intensity to fearful expressions, such as angry faces. However, there are good reasons to suspect that this centrifugal attentional effect may be specific to fear. Looming angry faces, although negative and highly arousing, would represent a direct threat to the individual. Thus, attention may be hypothesised to be directed towards the angry face, which represents the threat per se, leaving any peripheral event (i.e. the ball) unattended, to favour the processing of events in the proximity of the face.

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