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The spatial logic of fear

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The spatial logic of fear

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Abstract

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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 $\approx 1^\circ$ or $\approx 10^\circ$ 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

38 Peripersonal space (PPS) is the multimodal sensory-motor interface (Rizzolatti, Fadiga, Fogassi, &
39 Gallese, 1997) that mediates the interactions between the individual and the environment. PPS is
40 characterised by an increased integration of visual or auditory stimuli with somatosensory
41 processing (e.g. tactile stimuli), compared to farther space. Thus, PPS is multimodal in nature. In
42 addition, it is coded in reference to specific body parts (Làdavas, 1998; Làdavas, 2002; Làdavas, Di
43 Pellegrino, Farnè, & Zeloni, 1998). Visual or auditory stimuli presented close to, but not far from, a
44 specific body part, enhance the excitability of neurons into the motor cortex. For example, motor
45 responses to tactile stimuli on the hand become faster as visual or auditory stimuli are presented
46 closer to that hand (Serino, Annella, & Avenanti, 2009). Also, reaction times to tactile stimuli
47 delivered on a specific body part (i.e. trunk, leg, face, hand) are faster when paired with the
48 simultaneous presentation of a visual or auditory stimulus appearing or played not directly on the
49 body itself, but within a certain distance from the tactually stimulated body part (e.g. Làdavas &
50 Farnè, 2004; di Pellegrino & Làdavas, 2015). Such multisensory integration in PPS has been
51 explained according to the general principles of multisensory integration (Murray & Wallace,
52 2011), which state that sensory signals from two modalities in spatiotemporal proximity to one
53 another are integrated with a gain in responsiveness. The degree of multisensory response
54 enhancement that normally results from simultaneous presentation of visual and tactile stimuli (Van
55 der Stoep, Nijboer, Van der Stigchel, & Spence, 2015) is found to positively correlate with the
56 proximity of the visual stimulus to the tactually stimulated body part. Specialized brain areas with
57 multimodal neurons, such as the ventral premotor cortex and the ventral intraparietal area, appear to
58 underlie PPS representation (Cléry, Guipponi, Wardak, & Ben Hamed, 2015; di Pellegrino,
59 Làdavas, & Farné, 1997; Grivaz, Blanke, & Serino, 2017).

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

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

73 Here we investigate the hypothesis that this modulation reflects a distinctive interaction
74 between space and fear on attentional processing. In the presence of a threatening cue in the
75 environment, attention is preferentially oriented towards the threat stimulus, and maintained for
76 longer. Such attentional biases have been documented using a variety of stimuli (scenes, words,
77 emotional faces; Yiend, 2010). Given that arousing and negative stimuli modulate spatial attention
78 (Cisler & Koster, 2010; Koster, Crombez, Van Damme, Verschuere, & De Houwer, 2004; Yiend,
79 2010) and that attention influences the perception of visual or auditory stimuli, including perception
80 of their distance (Anton-Erxleben, Henrich, & Treue, 2007), affective modulation of PPS might be
81 based on attentional mechanisms (Cléry et al., 2015). Further, affective modulation of PPS involves
82 long-range synchronization mechanisms between the fronto-parietal networks underlying
83 multisensory integration and attention, and the prefrontal and limbic areas involved in action
84 selection/inhibition and affective processing (for reviews see Cléry et al., 2015; Serino, 2019). An
85 attentional basis for affect modulation of PPS was also suggested by De Haan and colleagues
86 (2016). They found that spatial facilitation of tactile perception was further enhanced by an
87 approaching threat and interpreted their results in terms of an attentional shift effect.

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

105 We hypothesise that the attentional dynamic triggered by the presentation of fearful facial
106 expressions may have not only a temporal but also a distinctive spatial pattern. Specifically, when a
107 fearful face approaches the subject, attention will be redirected *from* the face to the surrounding
108 environment, to enable identifying the location of the potential threat. That is, the distinctive effect
109 of fear involves a wide deployment of spatial attention, as if to maximise the detection and
110 localisation of potential threat. Fear and threat have a distinctive spatial logic, which should
111 influence spatial attention in two ways. First, since a nearby threat is generally more important than
112 a distant one (Bufacchi & Iannetti, 2018), fear-induced modulations of spatial attention should be
113 stronger in near than in far space. Second, the redirection of spatial attention should not privilege

114 the fearful face, since this is not itself threatening, but is rather an indicator of a threat located
115 *elsewhere*. Rather, spatial attention should extend in way that covers any regions of space where
116 the threat, that caused the fearful expression, might be located.

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

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

163

164

EXPERIMENT 1

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

173

Methods

174 **Participants**

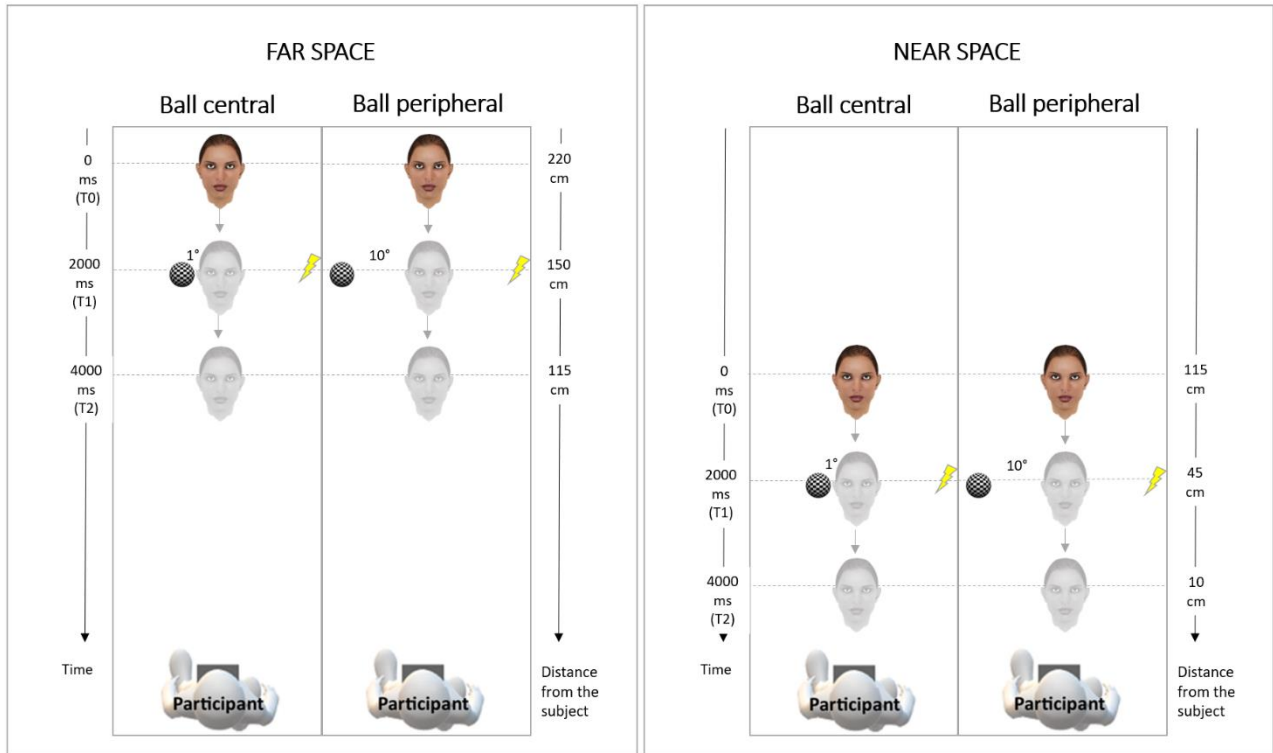
175 Twenty-three healthy participants with no history of neurological or psychiatric disorder were
176 recruited (12 females; age: $M \pm SD = 29.78 \pm 3.84$ years). The experiment was conducted in
177 accordance with the principles of the Declaration of Helsinki and approved by the Bioethics
178 Committee of the University of Bologna. Each participant gave written informed consent prior to
179 participating and after being informed about the procedure of the experiment. The sample size was
180 determined via a power analysis conducted in G*Power 3.1 software and based on the mean of the
181 effect size from prior studies on PPS (Pellencin, Paladino, Herbelin, & Serino, 2018; an alpha of
182 0.05, and a power of 0.9).

183 **Experimental task and procedure**

184 The experiment was implemented in ExpyVR software (available online at <http://Inco.epfl.ch/>
185 framework for designing and running experiments in virtual reality) and ran on a Windows-based
186 PC (Dell XPS 8930, Dell, Round rock, Texas, USA). The tactile stimuli consisted in vibrations
187 delivered bilaterally at the participants cheeks by a pair of electrodes (Precision MicroDrives

188 shaftless vibration motors, model 312-101, 3V, 60 mA, 150 Hz, 5 g). The motor had a surface area
189 of 113 mm² and reached maximal rotation speed in 50 ms. This device was activated for 100 ms
190 during tactile stimulation. The visual stimuli were avatar joyful or neutral faces. The expression was
191 manipulated ad hoc and validated in a preliminary study (see section below).

192 At the beginning of each trial (T0) an avatar face with a neutral or joyful expression
193 appeared centrally on the visual field, either in the space near to (≈ 115 cm) or far from (≈ 220 cm)
194 the participant, by relaying stereoscopically to the head-mounted display (HMD, Oculus Rift SDK,
195 Oculus VR, 100° field of view, 60 Hz) worn by the participant. The face then moved toward the
196 participant on the sagittal plane for a total of 3000 ms until its final position (Near: ≈ 10 cm; Far:
197 ≈ 115 cm) where it remained still for 1000 ms (T2). Importantly, 2000 ms after the beginning of the
198 trial (T1), the tactile stimulation was delivered bilaterally, and, simultaneously, a static
199 checkerboard ball appeared for 250 ms, either $\approx 1^\circ$ (ball central) or $\approx 10^\circ$ (ball peripheral) to the left
200 or right of the face (left and right sides counterbalanced among trials; *Fig. 1*). Thus at T1, touch
201 coincides with perception of the ball and of the face, at different distances from the participant (at ≈ 45 cm,
202 in the near, and ≈ 150 cm in the far). The ITI was set at 2100 ms (+/- 100 of jitter). Distances of near
203 and far spaces were calibrated as previously done in Serino and colleagues (2015). During the task,
204 participants made speeded simple responses to the tactile stimulation by pressing a button placed on
205 the table in front of the participant with their right hand.



206

207 *Figure 1.* Illustration of the experimental paradigm. Looming faces appeared in far (A) or in near (B) space with respect
 208 to the participant at T0 and approached the subject frontally until T2 at a constant speed. At T1, the tactile stimulus is
 209 delivered simultaneously to the appearance of the checkboard ball, which appeared centrally or peripherally to the left
 210 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
 211 the far space conditions.

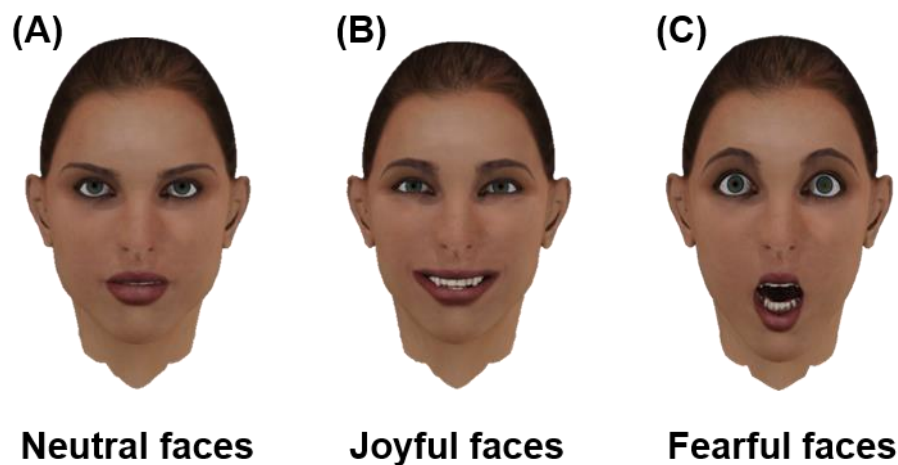
212 There was a total of 320 experimental trials, equally divided among the 8 experimental
 213 conditions (i.e. 40 trials per condition): Face emotion: Neutral / Joyful; Space: Far / Near; Ball
 214 Position: central / peripheral. There were also an additional 100 trials, which were introduced to
 215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

222 After signing the consent form, participants seated on a comfortable chair, in a sound
 223 attenuated room. Vibrators were then attached bilaterally on the cheeks with a medical tape, and

224 participants then wore the virtual reality headset. Before starting the task, lens focus was adjusted
225 for each participant to ensure clear vision.

226 **Face stimuli creation and validation**

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



233

234 *Figure 2.* Example of emotional faces. (A) Neutral faces used in Experiment 1 and 2. (B) Joyful faces used in
235 Experiment 1. (C) Fearful faces used in Experiment 2.

236

237 In order to select the faces to be included in each experiment, 60 naive participants (30 females;
238 mean age 29 ± 10 SD) were instructed to rate 15 two-dimensional pictures constituting 5 different
239 versions of facial expressions, namely joyful, fearful or neutral. Participants had to indicate which
240 emotion was represented in the picture, and subsequently, to rate on a 10-points Likert scale, how
241 strongly was expressed that emotion (0 = low intensity; 9, high intensity). Also, they had to rate the

242 arousal level generated by each stimulus, on a 10-point Likert scale (0= not at all arousing; 9=
243 extremely arousing).

244 This procedure allowed to select 2 joyful, 2 fearful, and 2 neutral facial expressions, according to
245 the highest percentage of participants who correctly identified the emotion in the picture, then the
246 highest perceived intensity level and the highest perceived arousing effect. The mean hit rate of the
247 selected stimuli was 95 %, for the joyful, 80 % for the fearful and 80 % for the neutral faces. To
248 check whether the mean ratings for intensity and arousal were significantly different between the
249 emotions, a repeated measures ANOVA was conducted with mean intensity and mean arousal
250 scores. The analysis on intensity level showed that ratings were different across emotions [$F(2,118)$
251 $= 151.45$; $p < 0.01$; $\eta^2 = 0.72$]. Post-hoc Bonferroni corrected showed that both joyful and fearful
252 expressions were judged as more intense than the neutral expressions (Neutral faces: $M = 2.39$,
253 $SEM = 2.05$; Joyful faces: $M = 5.62$, $SEM = 1.70$; Fearful faces: $M = 7.12$, $SEM = 1.38$; all $p < 0.01$);
254 moreover fearful expressions were judged as more intense than the joyful ($p < 0.01$). The analysis on
255 arousal level showed that ratings were different across emotions [$F(2,118) = 98.35$; $p < 0.01$;
256 $\eta^2 = 0.63$]. Post-hoc Bonferroni corrected showed that both joyful and fearful expressions were
257 judged as more arousing than the neutral expressions (Neutral faces: $M = 1.53$, $SEM = 1.54$; Joyful
258 faces: $M = 3.89$, $SEM = 2.17$; Fearful faces: $M = 5.08$, $SEM = 2.32$; all $p < 0.01$); moreover fearful
259 expressions were judged as more arousing than the joyful ($p < 0.01$).

260 **Dependent measure**

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

266

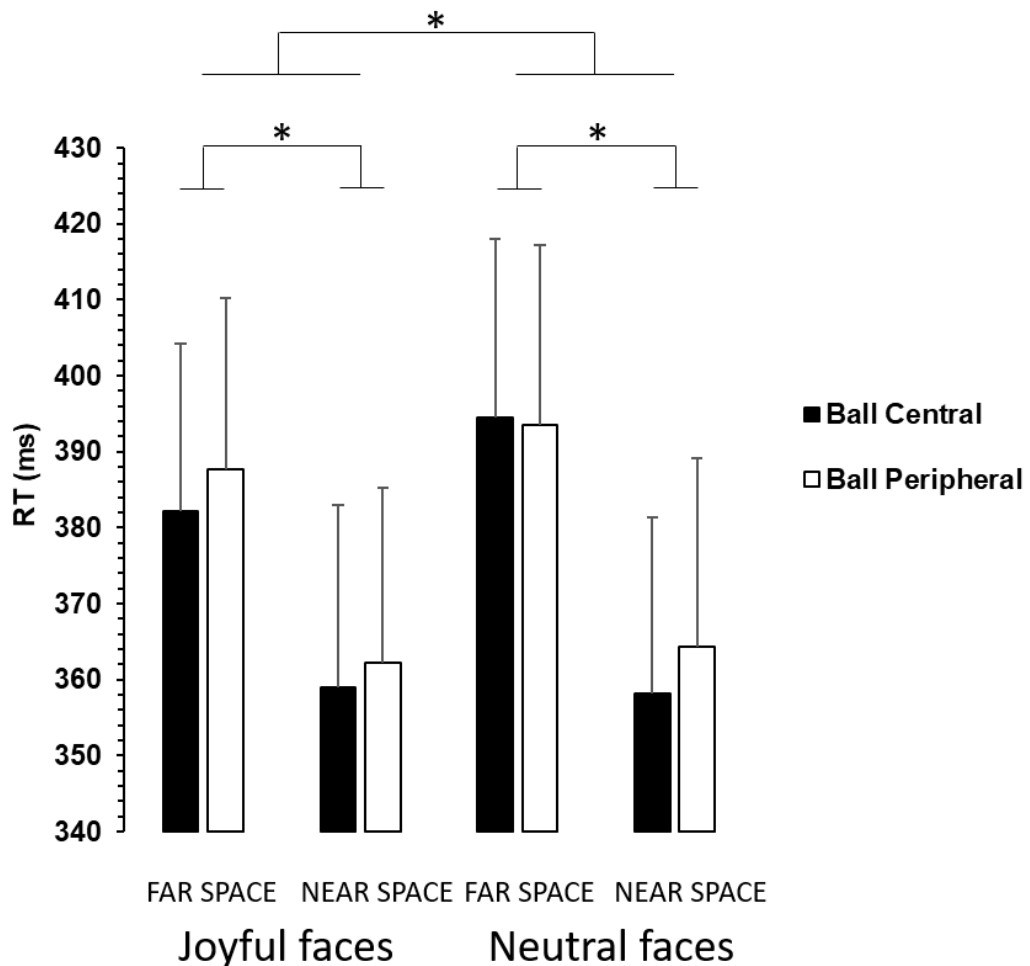
Results

267 A 2x2x2 RM ANOVA (Face emotion: Neutral / Joyful; Space: Far / Near; Ball Position: central /
268 peripheral) was conducted to test whether looming joyful vs. neutral faces induced a change in PPS
269 representation (i.e. difference in RTs to tactile stimulation) through a different distribution of spatial
270 attention, probed by the ball appearing centrally or peripherally from the face. Results showed a
271 significant main effect of Face Emotion [$F(1,22)=4.99$; $p=0.03$; $\eta^2=0.18$]; participants responded
272 faster to Joyful than Neutral faces (Joyful faces: $M=372.73$ ms; $SEM=11.35$; Neutral faces:
273 $M=377.66$ ms; $SEM=11.84$). There was also a significant main effect of Space [$F(1,22)=72.95$;
274 $p<0.01$; $\eta^2=0.77$]; participants responded faster to faces in the Near than Far space (Near:
275 $M=360.93$ ms; $SEM=11.68$; Far: $M=389.45$ ms; $SEM=11.32$). We also found a significant main
276 effect of Ball Position [$F(1,22)=6.32$; $p=0.02$; $\eta^2=0.22$]; participants responded faster when the
277 ball was central as opposed to peripheral to the face (central: $M=373.46$ ms; $SEM=11.52$;
278 peripheral: $M=376.94$ ms; $SEM=11.68$).

279 Moreover, there was a significant Face Emotion by Space interaction [$F(1,22)=5.59$;
280 $p=0.03$; $\eta^2=0.20$]. Newman-Keuls post-hoc comparisons revealed that when faces appeared in Far
281 space, participants responded faster to Joyful than Neutral faces (Joyful faces: $M=384.87$ ms;
282 $SEM=22.14$; Neutral faces: $M=394.04$ ms; $SEM=23.34$; $p<0.01$). On the contrary, when faces
283 appeared in Near space, there was no significant difference in RTs between Joyful and Neutral faces
284 (Joyful faces: $M=360.58$ ms; $SEM=23.21$; Neutral faces: $M=361.29$ ms; $SEM=23.76$; $p=0.78$). No
285 significant three way Face Emotion by Space by Ball position interaction was found [$F(1,22)=1.59$;
286 $p=0.22$; $\eta^2=0.07$].

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

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



292

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

296

EXPERIMENT 2

297 Here, whether looming fearful, vs. neutral, faces induce a change in PPS representation (i.e. change
 298 in RTs to tactile stimulation) by promoting a different distribution of spatial attention. In particular,
 299 fearful faces, as opposed to neutral, will redistribute attention towards the periphery, in order to
 300 promote scanning of the environment to find the source of threat. This mechanism should interact
 301 with the general spatial principles of multisensory integration as well as a general salience effect

302 induced by the emotional facial expression. Such that, we expect faster responses in near than in far
303 space (classic PPS effect) and to fearful than neutral faces (salience effect). We also expect this
304 effect in near space to be enhanced in presence of the peripheral, rather than central ball, because
305 that is the portion of space where the attentional modulation will be stronger and where the
306 peripheral (attended) ball is more likely to respect the criteria of spatiotemporal proximity necessary
307 for multisensory integration. Thus, overall, we expect a facilitation of response to tactile stimuli
308 when faces are fearful as opposed to neutral, and in near as opposed to far space. In addition, we
309 expect an interaction of these, as a function of ball position, such that response to tactile stimuli
310 should be facilitated by the peripheral, vs. central, ball when the fearful face is near, rather than far,
311 space.

312 **Methods**

313 **Participants**

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

322 **Experimental task Procedure**

323 Experimental stimuli, task and procedure were identical to Experiment 1, with the only difference
324 that faces showed a neutral or a fearful expression (*Figure 2 A-C*).

325 **Dependent measure**

326 Participants rate of omissions was low ($M=1.35\%$ $SD=2.14$). For this reason, performance was
327 analysed in terms of reaction times (RTs) only, as previously done in e.g., Canzoneri and colleagues
328 (2012). Trials with RTs exceeding more than 2 standard deviations from the mean RT of each block
329 were considered as outliers, and excluded from the analyses ($M=5.80\%$ $SD=3.12$). For each
330 participant, mean RTs were calculated for each condition, and used for analysis.

331 **Results**

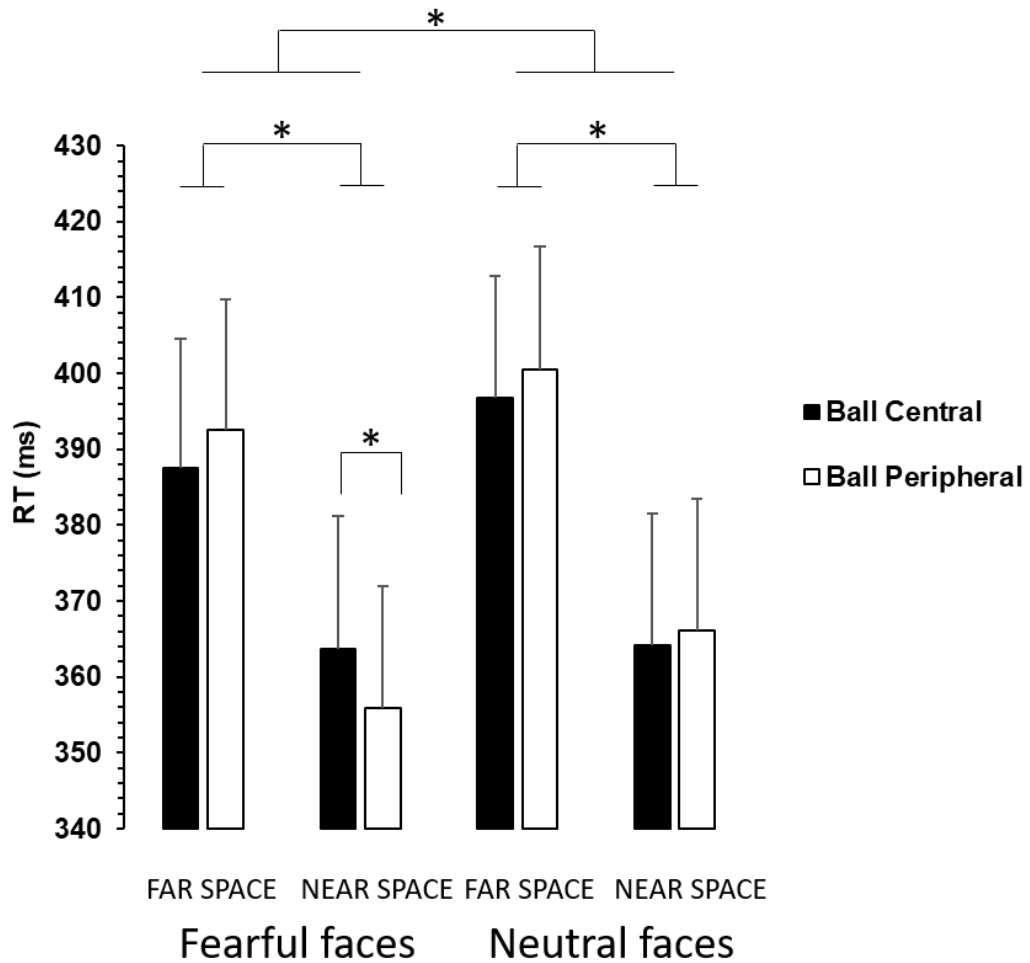
332 A 2x2x2 RM ANOVA (Face emotion: Neutral / Fearful; Space: Far / Near; Ball Position: central /
333 peripheral) was conducted to test whether looming fearful, vs. neutral, faces induced a change in
334 PPS representation (i.e. difference in RTs to tactile stimulation) through a different distribution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

336 Results showed a significant main effect of Face emotion [$F(1,22)=15.99$; $p<.01$; $\eta^2=0.42$];
337 participants responded faster to Fearful than Neutral faces (Fearful faces: $M=374.92\text{ms}$; $SEM=0.89$;
338 Neutral faces: $M=381.92\text{ms}$; $SEM=0.88$). There was also a significant main effect of Space
339 [$F(1,22)=69.60$; $p<0.01$; $\eta^2=0.76$]; participants responded faster to faces in Near than Far space
340 (Far space: $M=395.33\text{ms}$; $SEM=0.85$; Near space: $M=362.51\text{ms}$; $SEM=0.87$). There was no
341 significant main effect of Ball Position [$F(1,22)=0.24$; $p=0.62$; $\eta^2=0.01$], Face emotion by Space
342 [$F(1,22)=0.96$; $p=0.34$; $\eta^2=0.04$] or Face emotion by Ball Position [$F(1,22)=2.20$; $p=0.15$;
343 $\eta^2=0.09$] interaction. However there was a significant Space by Ball Position [$F(1,22)=7.66$;
344 $p=0.01$; $\eta^2=0.26$] interaction. In far space, participants responded faster to the central than
345 peripheral ball (Peripheral: $M=396.52\text{ms}$, $SEM=16.67$; Central: $M=392.15\text{ms}$, $SEM=16.49$;
346 $p=0.03$), while in near space, there was no difference in RT between the central and peripheral ball
347 (Peripheral: $M=361.06\text{ms}$, $SEM=16.56$; Central: $M=363.95\text{ms}$, $SEM=17.31$; $p=0.13$).

348 Crucially, there was a significant three way Face emotion by Space by Ball Position interaction
349 [$F(1,22)=4.45$; $p=0.04$; $\eta^2=0.17$]. Newman-Keuls post-hoc comparisons revealed that in presence

350 of neutral faces, there was no difference in RT between the central and peripheral ball either in far
351 space (central: $M=396.84\text{ms}$, $SEM=15.95\text{ms}$; peripheral: $M=400.53\text{ms}$, $SEM=16.21\text{ms}$; $p=0.17$) or
352 near space (central: $M=364.15\text{ms}$, $SEM=17.33\text{ms}$; peripheral: $M=366.15\text{ms}$, $SEM=17.32\text{ms}$;
353 $p=0.45$). In presence of fearful faces in far space, RTs showed a trend to be faster with the central
354 ball compared to the peripheral one, although not significant (central: $M=387.45\text{ms}$, $SEM=17.17$;
355 peripheral: $M=392.51\text{ms}$, $SEM=17.25$; $p=0.07$). In contrast, when fearful faces appeared in near
356 space, participants responded significantly faster to the peripheral compared to the central ball
357 (central: $M=363.75\text{ms}$, $SEM=17.39$; peripheral: $M=355.97\text{ms}$, $SEM=15.94$; $p<0.01$).

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



365

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

371

Discussion

372 PPS is the representation of the space surrounding the body (Rizzolatti et al., 1997), and its extent
 373 can be defined as the portion of space in which multisensory information between somatosensory
 374 and visual and auditory stimuli has a higher probability of being integrated (Graziano & Cooke,
 375 2006; Serino, 2019). This multisensory integration in PPS has been explained according to the
 376 general principles of multisensory integration (Murray & Wallace, 2011), which state that sensory
 377 signals from two modalities in spatiotemporal proximity to one another are integrated with a gain in

378 responsiveness. Thus, the amount of multisensory response enhancement that normally results from
379 simultaneous presentation of visual and tactile stimuli (Van der Stoep, Spence, Nijboer, & Van der
380 Stigchel, 2015) is expected to positively correlate with the proximity of the visual stimulus to the
381 tactually stimulated body part.

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

404 space, response to tactile stimuli was significantly facilitated by the peripheral rather than central
405 ball.

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

427 In addition to the PPS effect, we also found a salience effect, namely, the facilitation of response to
428 tactile stimuli in far space in presence of an emotional (joyful or fearful vs. neutral) faces. This

429 effect may have resulted from an increased arousal response elicited by the emotional face
430 compared to the neutral face, thus fastening response times.

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

443 Our main result is that, in contrast to neutral and joyful faces, fearful faces modulated
444 response to tactile stimuli depending not only on their distance from the participant, but also on the
445 position of the ball. In near space, but not in far space, response to tactile stimuli was facilitated by
446 a peripheral ball, more than by a central one. This effect confirms the hypothesis that the attentional
447 dynamic triggered by the presentation of fearful facial expressions has a distinctive centrifugal
448 spatial pattern, compared to neutral and joyful. In fact, static fearful faces are known to influence
449 the distribution of spatial attention, eliciting an early but fleeting capturing of attention (Carlson &
450 Reinke, 2014; Pourtois & Vuilleumier, 2006, Torrence et al., 2017). Our results show for the first
451 time that a redirection of attention is induced by looming fearful faces intruding into PPS, and also
452 reveals the spatial logic of the redirection mechanism. Specifically, a fearful face has a centrifugal
453 effect on attention, forcing attention towards the periphery. Even though fearful faces were

454 presented centrally, their attentional effect was stronger when combined with a more peripheral
455 stimulus. This redirection of attention would support the adaptive function of fearful faces,
456 prompting a heightened perceptual processing of potential threat that could be anywhere in the
457 observer's surroundings (Wieser & Keil, 2014). This deployment of attention to the periphery by
458 fearful faces, in interaction with PPS sensory-motor functions, would enhance the defensive
459 function of PPS (described by Graziano & Cooke, 2006; Lourenco, Longo, & Pathman, 2011;
460 Sambo & Iannetti, 2013; Sambo, Liang, Cruccu, & Iannetti, 2012; De Vignemont and Iannetti,
461 2015). Further, this enhancement is strongest specifically when defence is most pressing, i.e. when
462 the source of threat may be in the near space. In fact, while, in far space, response to tactile stimuli
463 tended to be facilitated by the central ball, in near space, the peripheral ball facilitated response to
464 tactile stimuli. This appears in line with evidence showing that the reorienting of spatial attention is
465 more flexible for unexpected stimuli falling nearer, rather than farther in depth (Chen et al., 2012).
466 Moreover, closer stimuli are perceived as more imminent than farther stimuli (Fanselow & Lester,
467 1988), and threat imminence is a decisive factor for a stimulus to provoke an attentional shift
468 (Koster et al., 2004). Thus overall, the modulation of response to tactile stimuli may have been
469 evident in near space because this seems the portion of space where attention is more strongly
470 modulated by the fearful facial expression and this is also the portion of space where the peripheral
471 (attended) ball is more likely to respect the criteria of spatiotemporal proximity necessary for
472 multisensory integration. In fact, strength of multisensory integration is maximal in near space,
473 because this is the portion of space where there is maximal spatiotemporal coincidence, between the
474 visual stimulus (i.e. ball) and the tactually stimulated body part (i.e. the participant's cheeks).

475 A limitation of the present study might be represented by the fact that low physical features
476 of the emotional facial expressions could not be controlled (fearful faces presented highly
477 contrasted eyeballs as compared to other expressions). Although this might have an influence on
478 responses, such difference in low features seems necessary for the facial expressions to convey
479 specific emotional information (Gray et al., 2013; Calvo and Nummenmaa, 2008). Additionally,

480 and even more important, the highly contrasted eyeballs in fearful faces could be expected to attract
481 attention on the face, which is the opposite of what it has been found. Thus, such difference in low
482 physical features would not explain why fearful face resulted in a redirection of attention away from
483 the face, and why such effect was evident in near space only. Given this, our results seemed
484 attributable to the emotional information conveyed by the stimuli rather than their low-level
485 features. Additionally, although an effect of the difference in retinal size between near and far
486 stimuli cannot be excluded (near stimuli are bigger than far stimuli), this would not explain the
487 difference in response between neutral and fearful faces in the near space, thus when the retinal size
488 of faces was the same.

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

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