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23 Abstract

24 Peripersonal space (PPS) corresponds to the space around the body and it is defined by the location in space where  
25 multimodal inputs from bodily and external stimuli are integrated. Its extent varies according to the characteristics of  
26 external stimuli, e.g. the salience of an emotional facial expression.

27 In the present study, we investigated the psycho-physiological correlates of the extension phenomenon. Specifically, we  
28 investigated whether an approaching human face showing either an emotionally negative (fearful) or positive (joyful)  
29 facial expression would differentially modulate PPS representation, compared to the same face with a neutral  
30 expression. To this aim, we continuously recorded the skin conductance response (SCR) of 27 healthy participants  
31 while they watched approaching 3D avatar faces showing fearful, joyful or neutral expressions, and then pressed a  
32 button to respond to tactile stimuli delivered on their cheeks at three possible delays (visuo-tactile trials).

33 The results revealed that the SCR to fearful faces, but not joyful or neutral faces, was modulated by the apparent  
34 distance from the participant's body. SCR increased from very far space to far and then to near space. We propose that  
35 the proximity of the fearful face provided a cue to the presence of a threat in the environment and elicited a robust and  
36 urgent organization of defensive responses. In contrast, there would be no need to organize defensive responses to  
37 joyful or neutral faces and, as a consequence, no SCR differences were found across spatial positions. These results  
38 confirm the defensive function of PPS.

39 Keywords: *peripersonal space, fearful faces, joyful faces, skin conductance response*

40

## Introduction

Peripersonal space (PPS) is the multimodal sensory-motor interface that mediates the interaction between an individual and their environment, which generally corresponds to the space around that individual's body. Numerous studies in non-human primates have shown that multisensory cues, specifically those recruiting the body through touch, are integrated by a specialized neural system representing PPS. Specific populations of multisensory neurons respond to both tactile information on the body (i.e., the arm, face or trunk) and visual or auditory stimuli occurring in PPS (i.e., close to the body). These multisensory neurons were first described in the macaque brain, in a network composed of specialized parietal and frontal areas, such as the ventral premotor cortex (vPM, Rizzolatti et al. 1981; or polysensory zone, Graziano et al. 1999), the ventral intraparietal area on the fundus of the intraparietal sulcus (VIP, Duhamel et al. 1997; Duhamel et al. 1998), and parietal area 7b, as well as subcortical regions such as the putamen (Graziano and Gross 1993; see Grivaz et al. 2017; di Pellegrino and Ládavas 2015, for reviews).

PPS representations serve to encode the location of nearby sensory stimuli to generate suitable motor acts, such as goal-directed, approaching actions toward objects (Rizzolatti et al 1997; Rizzolatti et al. 1981) or involuntary, defensive/avoidant reactions in response to close threats (Graziano et al. 2002). In fact, neural and behavioral responses to approaching stimuli increase as a function of the vicinity of the stimulus to the body, the so-called proximity effect (Bufacchi and Iannetti 2018; Cléry et al. 2014; Van der Stoep et al. 2015). In addition to proximity to the body, several other factors affect PPS representation including stimulus movement parameters, such as direction and speed. Regarding direction, the majority of bimodal neurons in the VIP respond more than twice as much to stimuli moving in a preferred direction compared with a non-preferred direction (Colby et al. 1993), even when the responses are elicited by identical visual stimuli. Regarding speed, the firing rate of a portion of these neurons in VIP increases as function of the velocity of the looming stimulus, suggesting that they might be computing the time to impact on the body (Fogassi et al. 1996). The influence of speed on PPS representation has also been observed behaviorally, as the velocity of looming audio stimuli has been shown to dynamically resize PPS (Noel et al. 2018).

Another important factor influencing PPS representation is the salience of the approaching stimulus. Stimuli that are behaviorally relevant for actions aiming to create or avoid contact between the stimulus and the body modulate the proximity effect. For example, the proximity effect is enhanced by an approaching threat (e.g., a spider; de Haan et al. 2016). Within the realm of salient threatening stimuli, fearful facial expressions are a particular kind of threatening stimulus that does not constitute a direct danger (as did the approaching spider used by de Haan et al. 2016, or the angry faces used by Cartaud et al. 2018, and Ruggiero et al. 2017), but, rather, communicates a potential environmental risk whose source and location are unknown (Fanselow and Pennington 2018). Thus, if one fundamental element that

71 triggers the chain of transformations required for defensive purposes is the capability to read threat signals in the  
72 environment, we should find that a fearful facial expression, but not a joyful one, modulates the proximity effect.

73           The capability to read threat signals in the environment and trigger appropriate behavioral responses is  
74 supported by neural circuitries involving sub-cortical and cortical structures, in strict connection with the autonomic  
75 nervous system. In particular, the amygdala plays a crucial part in emotion-related processes (Öhman 2005) and is  
76 involved in modulating autonomic nervous system responses to threat (Gläscher et al. 2003; Phelps et al. 2001; Laine et  
77 al. 2009), such as the skin conductance response (SCR) (Wang et al. 2018). In this regard, fearful faces seem to elicit a  
78 robust skin conductance response and amygdala activation (Anderson et al. 2003; Britton et al. 2008; Hariri and  
79 Tessitore 2002; Cushing et al. 2018).

80           Here, we investigated the role of approaching emotional facial expressions (fearful and joyful) in modulating  
81 autonomic arousal as a function of the distance of the faces from the observer. To this aim, healthy subjects underwent a  
82 PPS task (responding to tactile stimuli delivered to the cheeks) while their SCR was recorded, and they watched task-  
83 irrelevant fearful or joyful faces approaching them from very far to near space in an immersive virtual environment.  
84 Neutral faces were also administered to control for the effects of stimulus movement parameters, such as speed and  
85 stimulus size, which are known to influence proximity effects.

86           Note that the impact of emotional faces on proximity effects was previously addressed by Cartaud et al. (2018),  
87 who demonstrated that an angry avatar elicited a stronger physiological activation than joyful or neutral avatars when it  
88 was presented within reaching distance (at 65 cm), but not outside of reaching distance (at 250 cm). In their study, PPS  
89 was conceptualized as an in-or-out space, assumed to yield a discrete response. However, the PPS representation is  
90 based on a sequence of graded rather than discrete receptive fields (Bufacchi and Iannetti 2018). Thus, we wondered  
91 whether the modulation of arousal by spatial proximity may be gradual rather than discrete. For this reason, in this  
92 study, the face approached participants from three different spatial distances, namely Ultra-far, Far and Near, and we  
93 expected a gradual modulation of SCR as a function of these distances. Moreover, Cartaud et al. (2018) explicitly asked  
94 participants to consider the spatial position of the emotional avatar (in the reachability judgment and interpersonal  
95 comfort distance tasks), possibly tapping into more cognitive processes. Here, participants were not required to make  
96 any such estimations, enabling us to investigate the effect of space in an implicit way. Furthermore, in the present study,  
97 we investigated the effect of fearful faces on PPS, which, as discussed before, have different characteristics than angry  
98 faces.

99           In order to quantify the modulation of autonomic arousal by fearful faces as a function of their distance from  
100 the observer—while controlling for confounding stimulus movement parameters, such as speed and stimulus size—we

101 subtracted the mean SCR elicited by fearful and joyful faces from that elicited by neutral faces and then contrasted  
102 fearful SCR indices with joyful SCR indices. Thus, any difference between joyful and fearful faces would reflect the  
103 relative enhancements in arousal elicited by those emotions, compared to the arousal elicited by the neutral face, as a  
104 function of distance from the participant. More precisely, we expected that approaching fearful faces, by signalling an  
105 upcoming environmental threat, would elicit a gradual increase in SCR as the face become closer to the participant. In  
106 contrast, we did not expect approaching joyful faces to increase SCR magnitude.

## 107 **Material and methods**

### 108 **Participants**

109 Twenty-seven healthy participants with no history of neurological or psychiatric disorders were recruited (17 females;  
110 mean age  $\pm$  SD = 25 $\pm$ 2.5 years). This study was performed in line with the principles of the Declaration of Helsinki.  
111 Approval was granted by the Bioethics Committee of the University of Bologna (Date 8-8-2019 /No. 178302). All  
112 participants gave informed written consent to participate after being informed about the experiment. The sample size  
113 was determined via a power analysis conducted in G\*Power 3.1 software and based on the mean effect size from prior  
114 studies on PPS and SCR responses (Cartaud et al. 2018; Rossetti et al. 2015), with an alpha of 0.05 and a desired power  
115 of 0.9.

### 116 **Stimuli and Materials**

117 The experiment was implemented in ExpyVR software (a framework for designing and running experiments in virtual  
118 reality, available online at <http://Inco.epfl.ch/>) and run on a Windows PC (XPS 8930, Dell, Round Rock, Texas, USA).  
119 The tactile stimuli consisted of vibrations delivered bilaterally to the participants cheeks by a pair of shaftless vibration  
120 motors (Precision MicroDrives, model 312-101, 3V, 60 mA, 150 Hz, 5 g). Each motor had a surface area of 113 mm<sup>2</sup>  
121 and reached maximal rotation speed in 50 ms. The devices were activated for 100 ms during tactile stimulation.

122 The visual stimuli were avatar faces showing a fearful, joyful or a neutral expression and were presented by  
123 relaying to the head mounted display (HMD, Oculus Rift SDK, Oculus VR, 100° field of view, 60 Hz). Stereoscopic  
124 vision was obtained by projecting the stimulus in a slightly different angle to the left and right eye (for more details see  
125 <https://developer.oculus.com/design/bp-vision/>). The angular size, which is the size of the image that an object produces  
126 on the retina of the observer, was not corrected, thus, far faces were perceived as smaller than closer faces.

127 The avatar emotional facial expressions were manipulated ad hoc to render the desired features with Poser  
128 software (vers. 10; Smith Micro Software, Aliso Viejo, California, USA). Stimuli implemented in the study were  
129 chosen through a validation procedure (see section below).

130 At T0 (see Fig. 1), the beginning of each trial, a black fixation dot appeared centrally in the participant's visual  
131 field, on a grey background, for 500 ms, at an apparent distance of 400 cm from the participant. At T1, an avatar face  
132 with a neutral, fearful or joyful expression appeared centrally in the visual field, in one of three different positions: Near  
133 space (~70 cm away), Far space (~210 cm away) or Ultra-far space (~350 cm away) from the participant (see Fig. 2).  
134 Faces moved toward the participant on the sagittal plane for a total of 3000 ms. The end point of the looming face was  
135 always fixed near the participant (~10 cm away), where the face remained still for 1000 ms before stimulus offset.  
136 Therefore, stimuli in each condition covered different lengths of space in the same amount of time, resulting in different  
137 travelling speeds: 20 cm/s, 66,7 cm/s and 113,3 cm/s, for the Near, Far and Ultra-Far conditions respectively. At T2,  
138 1500 ms after the presentation of the face, the tactile stimulus was delivered. Thus, touch coincided with perception of  
139 the face at different distances from the participant (Serino et al., 2018; 40 cm in the Near condition, 110 cm in the Far  
140 condition and 180 cm in the Ultra-far condition). Lastly, at T3, at the face offset, the fixation dot reappeared, at the  
141 previous location, for 500 ms. Note that, in the 15% of trials, the color of the fixation dot changed from black to red at  
142 T3. Participants were asked to detect the color change and signal it to the experimenter. The change in fixation dot color  
143 always happened at the end of the trial, when the face disappeared. The inter-trial interval (ITI) was a grey empty  
144 environment, with a variable duration ranging from 11 to 14 s (+/- 1 s of jitter).

145 <<Please insert Fig. 1 near here>>

146 This design allowed us to exclude a potential confounding effect of temporal expectation on tactile facilitation,  
147 since the tactile stimulation was always delivered with the same delay after the appearance of the face in each spatial  
148 condition. In fact, when a moving object approaches the body, it does not only trigger the multisensory PPS neurons  
149 that influence tactile processing, but also the impending contact with the approaching object creates an expectation of  
150 an upcoming tactile event that influences the response time to the tactile stimuli. Also, the expectation increases as time  
151 elapses and it approached the body (Kandula et al. 2017).

152 <<Please insert Fig. 2 near here>>

153 **Visual stimulus validation**

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

160 This procedure allowed us to select 2 joyful, 2 fearful and 2 neutral facial expressions, according to the highest  
161 percentage of participants who correctly identified the emotion in the picture, then the highest perceived intensity level  
162 and the highest perceived arousal. The mean hit rate of the selected stimuli was 95 %, for the joyful faces and 80 % for  
163 the fearful and neutral faces. To check whether the mean ratings of intensity and arousal were significantly different  
164 between the emotions, repeated measures analyses of variance (ANOVAs) were conducted with mean intensity and  
165 mean arousal scores. The analysis of intensity level showed that ratings were different across emotions [ $F(2,118) =$   
166  $151.45; p < 0.01; \eta_p^2=0.72$ ]. Post-hoc Bonferroni tests showed that both joyful and fearful expressions were judged as  
167 more intense than the neutral expressions (Neutral faces:  $M = 2.39$ ,  $SEM = 2.05$ ; Joyful faces:  $M = 5.62$ ,  $SEM = 1.70$ ;  
168 Fearful faces:  $M = 7.12$ ,  $SEM = 1.38$ ; all  $p < 0.01$ ); moreover, fearful expressions were judged as more intense than the  
169 joyful expressions ( $p < 0.01$ ). The analysis of arousal level also showed that ratings were different across emotions  
170 [ $F(2,118) = 98.35; p < 0.01; \eta_p^2=0.63$ ]. Post-hoc Bonferroni tests showed that both joyful and fearful expressions were  
171 judged as more arousing than the neutral expressions (Neutral faces:  $M = 1.53$ ,  $SEM = 1.54$ ; Joyful faces:  $M = 3.89$ ,  
172  $SEM = 2.17$ ; Fearful faces:  $M = 5.08$ ,  $SEM = 2.32$ ; all  $p < 0.01$ ); moreover, fearful expressions were judged as more  
173 arousing than the joyful expressions ( $p < 0.01$ ).

#### 174 **Task and procedure**

175 There was a total of 27 trials, evenly distributed among the 9 experimental conditions defined by facial expression  
176 (Neutral/Fearful/Joyful) and spatial position (Ultra-far/Far/Near; i.e., 3 trials per condition). The number of repetitions  
177 per condition was kept low, due to the fast decay of the SCR to a stimulus presented repeatedly (i.e., the habituation  
178 phenomenon; Bradley et al. 1993). Trial order was randomized. After signing the consent form, participants sat on a  
179 comfortable chair in a sound-attenuated room. Vibrators were then attached bilaterally on the cheeks with medical tape,  
180 and a virtual reality headset was mounted onto the head of the participant. Before the task began, the lens focus of the  
181 Oculus VR was manually adjusted by each participant until clear vision was reported and the SCR activity recording



182 was verified. During the task, participants made speeded simple responses to the tactile stimulation by pressing a button  
183 placed on the table in front of them with their right hand.

184 At the end of the experimental phase, participants were invited to fill out a form in which they were asked to  
185 recognize the emotions represented in VR and to rate their intensity and arousal levels with two separate 10-point Likert  
186 scales. For intensity, the anchors were 0 (mild-neutral) to 9 (very intense), and, for arousal, they were 0 (not exciting at  
187 all-relaxing) to 9 (highly arousing-exciting). Moreover, participants were invited to rate the pleasantness of their general  
188 experience in the VR environment with a 10-point Likert scale that ranged from 0 (not pleasant at all) to 9 (very  
189 pleasant).

### 190 **SCR recording and data processing**

191 SCR was recorded with a Biopac MP-150 (BIOPAC Systems, Inc., Goleta, California, USA) at a 200-Hz sampling rate,  
192 and collected with AcqKnowledge 3.9 software (BIOPAC Systems) for offline analysis. SCR was acquired with two  
193 Ag/AgCl electrodes (TSD203; BIOPAC Systems) filled with isotonic hypo-saturated conductant gel and attached to the  
194 distal phalanges of the second and third fingers of the participant's non-dominant hand. A Biopac EDA100C (BIOPAC  
195 Systems) was used to measure SCR (gain switch set to 5  $\mu\text{S}/\text{V}$ , low pass to 35 Hz, high pass to DC).

196 SCR data were analyzed offline using MATLAB (Version R2018b; The MathWorks, Inc., Natick,  
197 Massachusetts, USA), and all statistical analyses were performed with STATISTICA (StatSoft, v. 13.0, Round Rock,  
198 Texas, USA). Each trial (see Fig. 3 as an example of single SCR traces) was extracted from the entire SCR signal and,  
199 to reduce inter-individual variability, a baseline correction was applied using the mean value of the signal 1000 ms  
200 before each stimulus presentation as a baseline (Alpers et al. 2011; Banks et al. 2012; Shibani et al. 2015). Then, for  
201 each baseline-corrected trial, the peak-to-peak value was calculated as the amplitude during the 500 to 4500 ms time  
202 window after emotional face onset. The minimum response criterion was 0.02  $\mu\text{S}$ , and smaller responses were encoded  
203 as zero. Raw SCR scores were square root-transformed to normalize the data distribution (Boucsein et al. 2012; Schiller  
204 et al. 2008).

205 <<Please insert Fig. 3 near here>>

### 206 **Results**

207 Concerning the psychophysiological data, the assumption of a normal distribution of data was verified, and mixed-  
208 design ANOVAs were used to investigate modulations of arousal (SCR) during the experimental task. Post-hoc

209 analyses were conducted with Bonferroni corrections, and the significance threshold was set at  $p < 0.05$ . The effect size  
210 was calculated as partial eta-squared ( $\eta_p^2$ ). Three participants, considered SCR non-responders, were excluded from the  
211 analysis due to the minimal level of recorded responses (Boucsein et al. 2012).

212 In order to quantify the mere effect of the emotion (fear, joy, neutral) at each distance, we created an index  
213 ( $\Delta$ SCR) by subtracting the mean value of the phasic response to neutral faces from the phasic responses to the fearful  
214 and joyful expressions, for each distance (Ultra-far, Far, Near). Thus,  $\Delta$ SCR allowed us to control for possible effects of  
215 both the stimulus speed and size. Indeed, it is important to highlight that the looming faces started at different distances  
216 from the participant, but the end point was always the same. This means that the stimuli covered different distances in  
217 the same amount of time, resulting in different travel speeds, as well as faces presented at different distances appearing  
218 in different sizes.

219 A repeated measures ANOVA was performed to investigate the effect of the Emotion (two levels:  $\Delta$ SCR Fear,  
220  $\Delta$ SCR Joy), the effect of the Distance (three levels: Ultra-far, Far, Near) and their interaction. There was neither a main  
221 effect of the Emotion ( $F(1,26) = 1.25$ ;  $p = 0.27$ ;  $\eta_p^2 = 0.05$ ), nor of the Distance ( $F(2,52) = 2.63$ ;  $p = 0.08$ ;  $\eta_p^2 = 0.09$ ).  
222 Crucially, an Emotion\*Distance interaction was found ( $F(2,52) = 6.76$ ;  $p < 0.01$ ;  $\eta_p^2 = 0.21$ ). Bonferroni-corrected post-  
223 hoc comparisons revealed that, for the joyful faces condition, there was no difference between the Ultra-far, Far and  
224 Near conditions ( $\Delta$ SCR Joy Ultra-far:  $M = 0.00$ ;  $SEM = 0.03$ ;  $\Delta$ SCR Joy Far:  $M = 0.03$ ;  $SEM = 0.02$ ;  $\Delta$ SCR Joy Near:  
225  $M = 0.01$ ;  $SEM = 0.02$ ; all  $p = 1$ ). In the fearful faces condition, instead, values in the Ultra-far condition were  
226 significantly lower than values in the Far and Near conditions ( $\Delta$ SCR Fear Ultra-far:  $M = -0.04$ ;  $SEM = 0.03$ ;  $\Delta$ SCR  
227 Fear Far:  $M = 0.04$ ;  $SEM = 0.03$ ;  $\Delta$ SCR Fear Near:  $M = 0.09$ ;  $SEM = 0.03$ ; all  $p < 0.02$ ).  $\Delta$ SCR Fear in the Far  
228 condition did not differ from  $\Delta$ SCR Fear in the Near condition ( $p = 0.49$ ). Importantly,  $\Delta$ SCR Fear was higher than  
229  $\Delta$ SCR Joy in the Near condition ( $p = 0.01$ ; see Fig. 4).

230 <<Please insert Fig. 4 near here>>

231 Finally, we also analyzed the latencies of the peaks, computed as the period between the stimulus onset (T1;  
232 the appearance of the face) and the SCR maximal peak elicited by the visuo-tactile compound. Largest deflections of  
233 the SCR signal, except for one subject in one condition, were always following the time of the touch delivery (T2; 1500  
234 ms), at latencies that were around 4130 ms on average ( $SEM=60$ ). As a sanity check, analysis on the SCR peaks, were  
235 rerun with the exclusion of the mentioned subject, and similar results were obtained. Moreover, we checked whether  
236 latencies of the peaks were modulated by our experimental conditions (Emotion and Distance). Results from the

237 repeated measures ANOVA confirmed that latencies were not modulated by the main effect Emotion ( $F(2,52) = 0.67$ ;  $p$   
238  $= 0.51$ ;  $\eta^2 = 0.03$ ), nor by the main effect of Distance ( $F(2,52) = 0.80$ ;  $p = 0.45$ ;  $\eta^2 = 0.03$ ), nor by their interaction  
239 ( $F(4,104) = 1.03$ ;  $p = 0.39$ ;  $\eta^2 = 0.04$ ).

240 Concerning the behavioral data, all participants detected 100% of the attentional probes and were also accurate  
241 at detecting the tactile stimulus, as the rate of the omissions was low ( $< 1\%$ ). Due to the limited number of trials per  
242 conditions ( $n = 3$ ), response times to tactile stimuli were not analyzed.

243 Concerning the final rating results, the totality of the subjects correctly reported the identity of the emotional  
244 faces (mean hit rate 100%). Intensity and arousal levels, rated at the end of the experimental session, were analyzed  
245 separately. A repeated measures ANOVA was used to evaluate differences in the intensity ratings of the stimuli. Results  
246 showed a main effect of Emotion ( $F(2,52) = 17.95$ ;  $p < 0.001$ ; Fear:  $M = 7.40$ ;  $SEM = 0.27$ ; Joy:  $M = 4.85$ ;  $SEM =$   
247  $0.44$ ; Neutral:  $M = 4.26$ ;  $SEM = 0.51$ ). Bonferroni-corrected post-hoc comparisons revealed that fearful faces were  
248 rated as more intense than joyful and neutral faces (all  $p < 0.01$ ). Another repeated measures ANOVA was used to  
249 evaluate differences in the arousal ratings of the stimuli. Results showed a main effect of Emotion ( $F(2,52) = 6.91$ ;  $p =$   
250  $0.002$ ; Fear : $M = 5.44$ ;  $SEM = 0.27$ ; Joy:  $M = 5.11$ ;  $SEM = 0.35$ ; Neutral:  $M = 4.44$ ;  $SEM = 0.37$ ). Bonferroni-corrected  
251 post-hoc comparisons revealed that fearful faces were rated as more arousing than neutral faces ( $p < 0.01$ ) but not  
252 significantly different from joyful faces ( $p = 0.06$ ). Finally, participants rated their general experience in VR as mildly  
253 pleasant ( $M = 6.66$ ;  $SEM = 0.42$ ).

254

## Discussion

255 Multisensory neurons mapping PPS are sensitive to the spatio-temporal dynamics of objects in the environment, and it  
256 is known that stimuli related to the body (in this case, a tactile vibration) and external events that occur near the body  
257 (in this case, an approaching avatar face) are highly likely to be jointly processed (Serino 2019). The information from  
258 this joint processing is directly transferred to the motor system to prompt appropriate responses, which are positively  
259 correlated with the proximity of the visual stimulus to the touched body part. In addition to proximity to the body,  
260 several other factors affect PPS representation, including stimulus movement parameters such as direction and speed,  
261 and, more relevant to the aim of the present study, the salience of the stimulus.

262 In the present study, we investigated the role of the salience of approaching emotional facial expressions in  
263 modulating the autonomic nervous system as a function of their distance from the observer. Thus, the aim of the present  
264 study was to verify whether SCR—an index of transient responses of the autonomic nervous system in response to a

265 stimulus, —is differentially modulated by emotional facial expressions (fear and joy) according to how close the  
266 looming face is to the participant. We predicted a modulatory effect only for stimuli with high salience and importance  
267 to the individual, like a fearful face, which signals the presence of an unknown threat in the environment. This effect  
268 was expected to gradually increase as the visual stimulus approached the participant, i.e. when the source of threat may  
269 be inescapable, and the need for defense is most pressing. In light of the defensive purpose of peripersonal space, joyful  
270 faces—which have low salience and little importance for an individual’s defense and avoidance behavior—should not  
271 modulate the proximity effects.

272 To this aim, we created a novel version of a well validated behavioral task used to assess PPS (Pellencin et al.  
273 2018; Serino et al. 2015). In this task, participants were asked to respond, as quickly as they could, to tactile stimuli  
274 administered on their cheeks while an emotional or neutral face appeared to approach them from three different  
275 distances (ultra-far, far and near). To eliminate the time expectancy effect, which is known to influence the proximity  
276 effect (Kandula et al. 2017), tactile stimulation was always delivered 1500 ms after the beginning of the trial, so that  
277 touch coincided with perception of the faces at different distances from the participant. In order to quantify the pure  
278 modulatory effects of the emotions on the proximity effect, we subtracted the mean value of the phasic SCR response to  
279 the neutral faces from the phasic responses to the fearful and joyful faces, at each distance condition. This correction  
280 returned an index of the relative arousal response enhancement due to the presentation of emotional faces, compared to  
281 the presentation of the neutral, and allowed us to control for confounding stimulus parameters, such as speed (fast vs  
282 slow movement) and stimulus size (big vs small faces). Previous literature has shown that speed of travelling affects  
283 PPS (Fogassi et al. 1996; Noel et al. 2018), in particular, as the velocity of incoming visual stimulus increases, the size  
284 of the receptive fields of multisensory neurons also increases, as if to initiate the computation for PPS representation  
285 earlier and integrate the speed of the incoming stimuli (Fogassi et al. 1996). Consequently, by using such index we did  
286 not expect an absolute main effect of the distance, but, instead, we predicted that only in the fearful condition, responses  
287 would be relatively modulated as the fearful face was perceived as closer to the participant. The results confirmed our  
288 predictions; approaching fearful faces triggered particularly intense emotional responses which depended on the  
289 distance between the stimulus and the observer. Approaching fearful faces, but not joyful faces, elicited a gradual  
290 increase in SCR magnitude as the face became closer to the observer. Greater physiological responses to fearful faces  
291 were obtained in the near condition (~40 cm away) compared to the far (~110 cm away) and ultra-far conditions (~180  
292 cm away). Distance did not modulate the physiological responses to joyful faces.

293 The difference in the physiological response to fearful faces, on the one hand, and joyful faces, on the other, is  
294 not surprising if we consider that the stimuli are not equally salient and have different impacts on motor corticospinal

295 excitability (Schutter et al. 2008). Given the sensory-motor function of PPS to protect the body from potentially  
296 dangerous stimuli, it is not surprising that PPS is influenced by the salience of stimuli and by their differential impacts  
297 on the motor system. These two factors will be discussed in turn, in the following paragraphs.

298         Regarding stimulus salience, joyful and neutral faces have very little relevance to threat detection, compared to  
299 fearful faces, and they are probably unable to activate the emotional neural circuits, involving the amygdala, which play  
300 an important role in evaluating stimulus salience and generating physiological responses, such as SCR. In addition,  
301 previous studies have demonstrated that the amygdala shows greater activation when a stimulus is presented in  
302 ambiguous and uncertain environmental circumstances, in the presence of ambiguous threat (Adams and Kleck 2003) or  
303 during an unpredictable series of auditory tones (Herry et al. 2007). A fearful face, unlike other negative emotions such  
304 as anger, signals an environmental threat whose source and location are unknown (Fanselow and Pennington 2018) and,  
305 as such, it can be conceived of as an ambiguous stimulus (Hortensius et al. 2016). Consequently, after fearful face  
306 presentation, enhanced amygdala-mediated vigilance and arousal are necessary for scanning the environment and  
307 dealing with the uncertainty of the upcoming danger. Thus, the gradual increase in SCR magnitude found in the present  
308 study, as the fearful face approached the participant, could be explained by the greater amount of attentional resources  
309 required to search for the source and location of the threat that generated that fearful expression.

310         Regarding the differential impacts of fearful and joyful expressions on the motor system, previous research has  
311 demonstrated that joyful and neutral scenarios, unlike threatening scenarios, do not selectively induce an early increase  
312 in motor corticospinal excitability, suggesting a lack of action preparedness when the participant is confronted with  
313 these emotions. In contrast, an early modulation of the motor cortex has been found when participants face threatening  
314 scenarios (Borgomaneri et al. 2014). The same results have been obtained with emotional faces: a selective impact on  
315 the motor system was found for fearful faces, but not for neutral or joyful faces (Schutter et al. 2008). These results  
316 show that the emotional system and the motor system are closely related, and fearful faces, but not neutral or joyful  
317 faces, act as cues that rapidly prepare the organism for action critical to survival (Anderson and Phelps 2001). This  
318 observation is particularly relevant for PPS, which has been conceived of as a sensory-motor interface for body  
319 protection.

320         The results of the present study are in line with neurophysiological findings (see Bufacchi and Iannetti 2018;  
321 Colby et al. 1993; Graziano et al. 1997, for a review) showing that peripersonal space seems to reflect a relevant area in  
322 which the salience of the stimulus interacts with the distance between the stimulus and the observer. The perceived  
323 salience of an emotional expression gradually increases as the face approaches the observer, as documented by the

324 gradual increase in physiological activation from ultra-far to far and then to near space; it is worth remembering that the  
325 more the face expresses fear, the higher the SCR in the observer (Alpers et al. 2011; Fusar-Poli et al. 2009). Given the  
326 sensory-motor functions of PPS, a fearful face would enhance the defensive function of PPS specifically when it is most  
327 needed, i.e., when the source of threat is nearby, and its location has not yet been identified. We cannot exclude that  
328 also the valence of the emotional expression, a construct that refers to its pleasantness or unpleasantness (Kensinger and  
329 Schacter 2006), may have played a role in determining our results. In fact, fearful faces, that are carrying important  
330 information about presence of threats in the environment, are not only more salient stimuli than joyful faces, but have  
331 also more negative valence. This aspect needs to be clarified by tailored future studies.

332 We do not know whether the results of the present study can be extended to other definition of PPS, i.e.,  
333 action-based peripersonal space (APS), defined as the space within which we can act (~70 cm), and interpersonal space  
334 (IPS), defined as the space within which any intrusion by others may cause discomfort. These PPS definitions seem to  
335 be based on different mechanisms, since it has been shown that they are differentially sensitive to social modulation  
336 (Patané et al. 2016; see also Coello and Iachini 2015; Iachini et al. 2014). On the other hand, those studies on the APS  
337 and IPS relied on explicit processing, which may tap into more cognitive processes. In the present study, we used a  
338 multisensory integration paradigm where the visual stimulus producing the effect was irrelevant to the tactile detection  
339 task. In such a task, processing may be based on bottom-up factors and might tap into the defensive motor system  
340 promptly by asking for a binary response (action or no action; de Gelder et al. 2012). In addition, neurophysiological  
341 studies in monkeys have shown a functional dissociation between multisensory PPS neurons in the premotor cortex  
342 (VIP and F4) and the reaching neurons in the parietal lobe (MIP/Parietal reaching region and F2; see, e.g.: Grefkes and  
343 Fink 2005; Matelli and Luppino 2001; Rizzolatti et al. 1997; Rizzolatti et al. 2002). A similar dissociation is evident in  
344 humans (see, e.g., Gallivan and Culham 2015; Grivaz et al. 2017). Considering the functional dissociations between the  
345 different types of PPS, we might expect different results when other paradigms, relying on different neural circuits, are  
346 used. Further investigation is needed to clarify this point.

347 Thus, the results of the present study confirm the defensive functional definition of peripersonal space; they  
348 show that fearful facial expressions are physiological salient cues whose activation of the autonomic system depends  
349 upon the region of space where they are perceived. In other words, the salience of the face changes with its proximity to  
350 the body; an approaching fearful face, by signalling an upcoming environmental threat, elicits a gradual increase in SCR  
351 as the face comes closer to the participant, where the source of threat may be inescapable and the need for defense is  
352 most pressing.

353 **Declarations**

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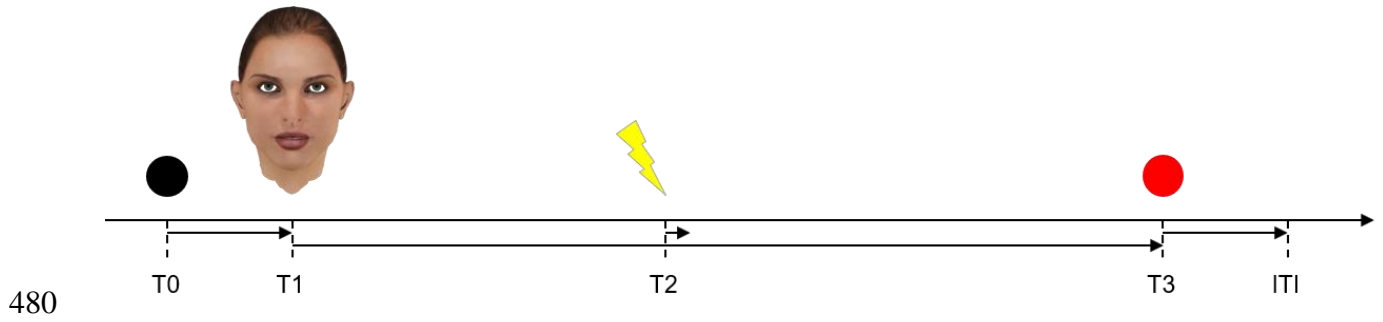
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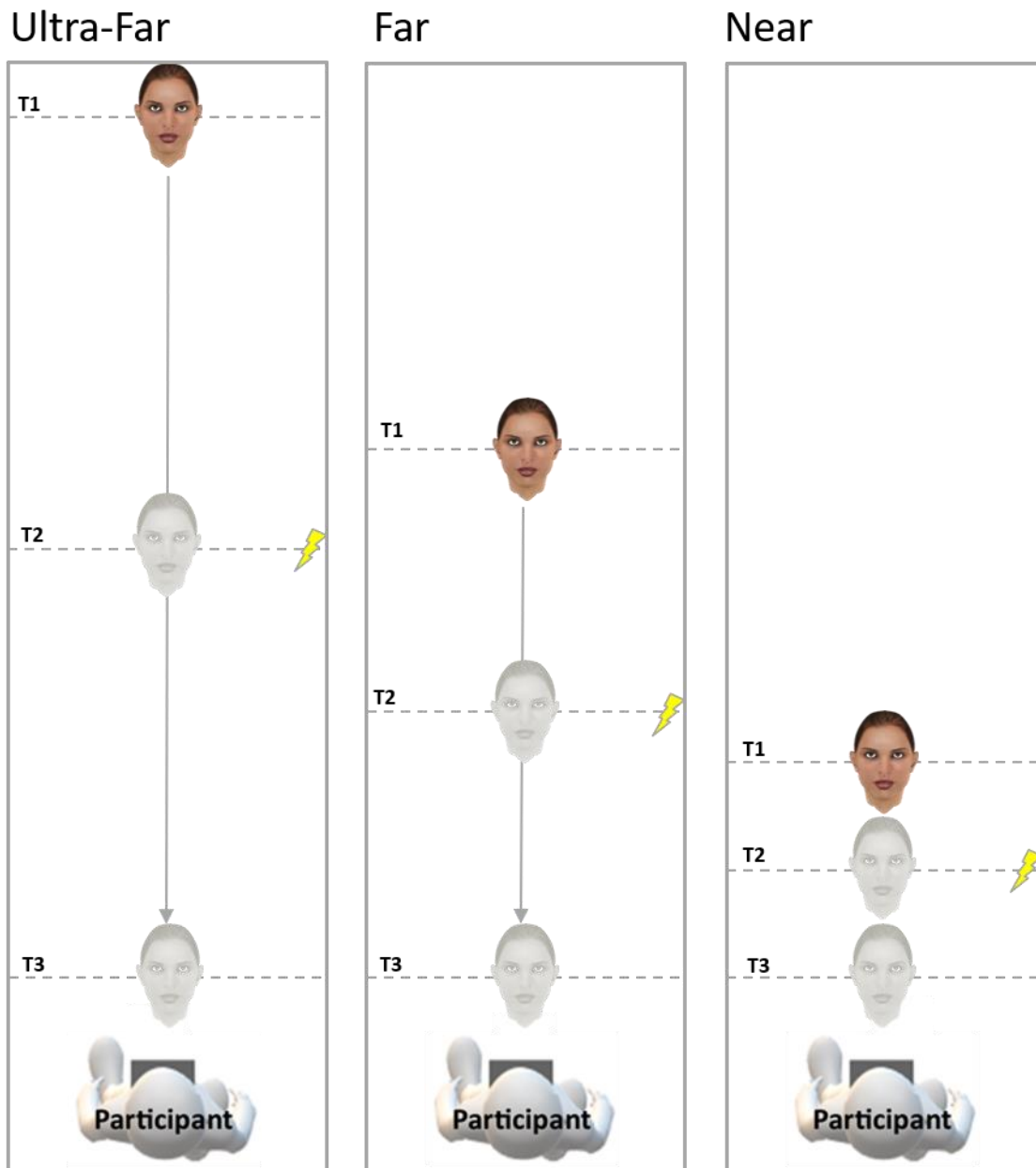
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- 478

479 **Figures**

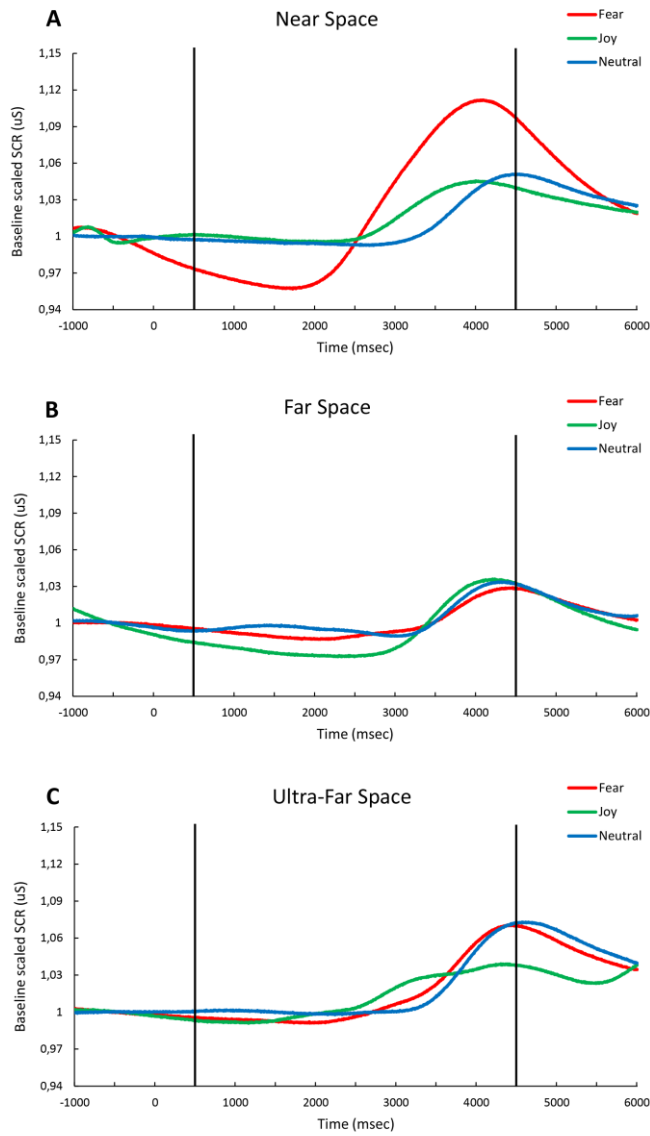


480  
481 **Fig. 1** Experimental timeline. At T0, the fixation dot (black) appeared for 500 ms. At T1, the face moved for 3000 ms  
482 toward a location near the participant, where it remained still for 1000 ms (T3). At T2, tactile stimulation was delivered.  
483 At T3, the face disappeared and the fixation dot (black/red) re-appeared for 500 ms. The ITI was set at 11 to 14 s



484

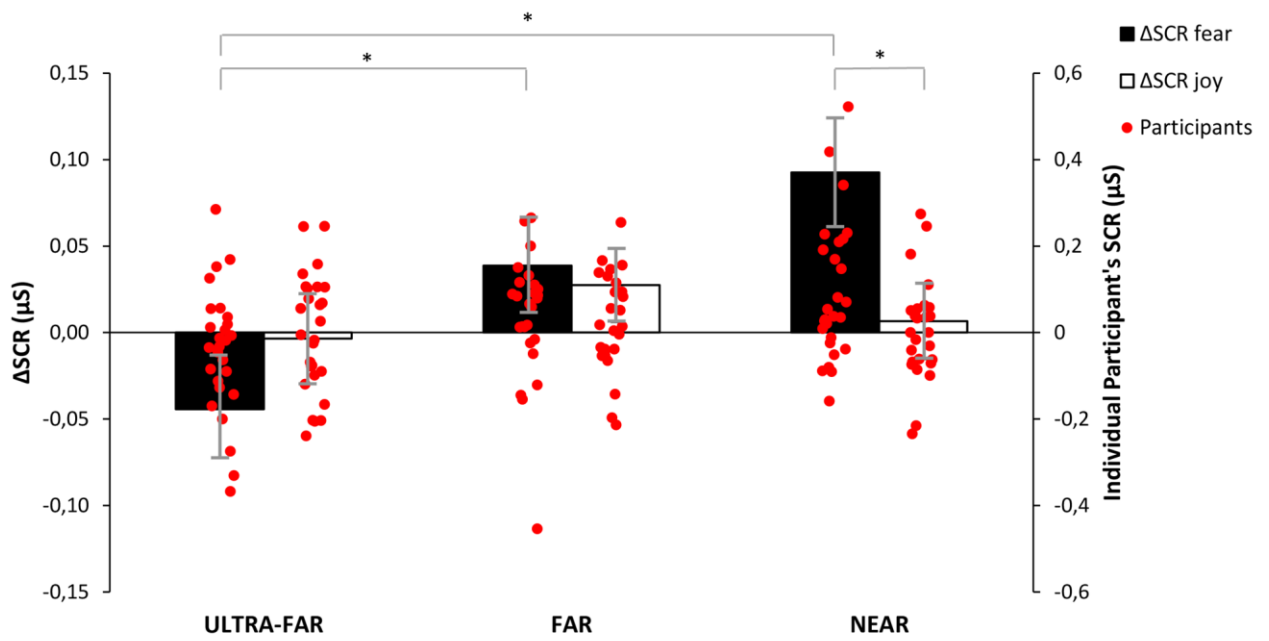
485 **Fig. 2** Spatial conditions. In each spatial condition, the end point was fixed at a location near the participant (10 cm),  
 486 while the starting point differed, resulting in a distance from the participant of approximately 350 cm in the Ultra-far  
 487 condition, 210 cm in the Far condition and 70 cm in the Near condition. At T2, when tactile stimulation was delivered,  
 488 the face appeared to be 180 cm away in the Ultra-far condition, 110 cm away in the Far condition and 40 cm away in  
 489 the Near condition. The face was always displayed for 4000 ms (from T1 to T3)



490

491 **Fig. 3** Plots showing an example of single trial SCR from a single participant. Each panel reports the plot of three trials,  
 492 one per each emotion condition, in the Near space (upper panel A), in the Far space (middle panel B) and in the Ultra-  
 493 Far space condition (lower panel C). Lines intercepting the x-axis are delimiting the time-window chosen for the  
 494 analysis (500 – 4500 ms after stimulus onset).

495



496

497 **Fig. 4** Bar graph showing the experimental results. In particular, the graph shows the interaction between Emotion and  
 498 Distance. In the joyful faces condition, ΔSCR did not differ between spatial conditions, whereas ΔSCR for the fearful  
 499 faces was significantly modulated by spatial distance. Asterisks indicate significant comparisons. Error bars represent  
 500 S.E.M. Overlaid dots show the individual subjects' data per each condition.