Neuropsychologia 70 (2015) 468–475

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Emotion-inducing approaching sounds shape the boundaries of multisensory peripersonal space

Francesca Ferri [a,*], Ana Tajadura-Jiménez [b], Aleksander Väljamäe [c], Roberta Vastano [d,e], Marcello Costantini [a,e,f]

[a] Mind, Brain Imaging and Neuroethics, University of Ottawa, Institute of Mental Health Research, Ottawa, ON, Canada
[b] UCL Interaction Centre (UCLIC), University College London, University of London, London WC1E 6BT, UK
[c] Department of Behavioural Sciences and Learning, Linköping University, Linköping, Sweden
[d] Fondazione Istituto Italiano di Tecnologia, Department of Robotics, Brain and Cognitive Sciences, Genova, Italy
[e] Department of Neuroscience, Imaging and Clinical Science, University G. d'Annunzio, Chieti, Italy
[f] Institute for Advanced Biomedical Technologies-ITAB, University G. d'Annunzio, Chieti, Italy

ARTICLE INFO

Article history:
Received 9 May 2014
Received in revised form
16 February 2015
Accepted 1 March 2015
Available online 3 March 2015

Keywords:
Peripersonal space
Multisensory integration
Emotion
Auditory sources
Approaching
looming sounds

ABSTRACT

In order to survive in a complex environment, inhabited by potentially threatening and noxious objects or living beings, we need to constantly monitor our surrounding space, especially in the vicinity of our body. Such a space has been commonly referred to as one's ‘peripersonal space’ (PPS). In this study we investigated whether emotion-inducing approaching sound sources impact the boundaries of PPS. Previous studies have indeed showed that the boundaries of PPS are not fixed but modulate according to properties of stimuli in the surrounding environment. In Experiment 1, participants performed a simple tactile detection task of targets presented to their right hand. Concurrently, they were presented with intensity-changing task-irrelevant artificial sound sources perceived as approaching toward their body. The physical properties of the sound elicited emotional responses of either neutral or negative valence. Results showed larger PPS when the approaching stimulus had negative as compared to neutral emotional valence. In Experiment 2, we used ecological sounds which content (i.e., psychological associations to the sound producing source), rather than physical properties, elicited emotional responses of negative, positive or neutral valence. In agreement with results from experiment 1, we found larger PPS when the approaching stimuli had negative emotional valence as compared to both neutral and positive ones. Results are discussed within the theoretical framework that conceives PPS as a safety zone around one's body.

1. Introduction

The term Peripersonal space (PPS), as used in cognitive neuroscience research, commonly refers to as a multisensory space around our body (Rizzolatti et al., 1997). In the field of social psychology the term “Personal space” is often used to define the emotionally-tinged zone around the human body that people experience as “their space” (Sommer, 1959) and which others cannot intrude without arousing discomfort (Hayduk, 1983). Evidence of the multisensory coding of PPS was firstly provided by electrophysiological single cell recording in the monkey brain (Rizzolatti et.al., 1981). In 1981 Rizzolatti et al. (1981) described visuo–tactile neurons in the periarcuate cortex that selectively responded to stimuli presented in the space immediately around the animal. Later studies of PPS coding identified neurons integrating somatosensory information with either visual or acoustical information within PPS in the ventral premotor cortex (Rizzolatti et al., 1981), including the polysensory zone PZ (Graziano and Gandhi, 2000), in the ventral intraparietal sulcus (Avillac et al., 2005; Duhamel et al., 1997), in the parietal areas 7b, and in the putamen (Graziano and Gross, 1993). The existence of a similar fronto-parietal system for the multisensory coding of PPS in the human brain has been shown by different neuroimaging and neurophysiological studies (Bremmer et al., 2001; Brozzoli, 2011, Gentile et al., 2011; Cardini et al., 2011; Gentile et al., 2011; Makin, et all., 2007; Serino et al., 2011).

It is largely accepted that the brain specialisation for PPS has several functions in both animals and humans. These functions include the definition of the position of objects located near the body (Chieffi et al., 1992; Moseley et al., 2012) and the sustaining of a margin of safety around one's body (Graziano and Cooke, 2006; Niedenthal, 2007). This understanding of the PPS suggests

* Correspondence author.
E-mail address: Francesca.Ferri@theroyal.ca (F. Ferri).

http://dx.doi.org/10.1016/j.neuropsychologia.2015.03.001
0028-3932/

that its boundaries can be defined in two different ways, that is, using either a metric or a functional approach (Costantini et al., 2010). According to the metric hypothesis, all the objects located within a given physical distance (e.g., 50–60 cm) from the body will fall into the PPS. Conversely, if the functional understanding of the PPS holds, PPS boundaries will dynamically change according to contingent factors. Currently, there seems to be a consensus reached that supports the functional hypothesis. Indeed, several studies have demonstrated that PPS boundaries can shrink or expand as a function of the properties of stimuli in the surrounding environment, for example, when the stimuli are approaching the body vs. receding it or being static (Tajadura-Jiménez et al., 2010b), or when the stimuli have the capability to elicit emotional responses or not (Vagnoni et al., 2012).

Regarding the sensitivity of PPS boundaries to dynamic stimuli, it has been shown that PPS is more sensitive to approaching as compared to static objects. In this regard, Neuhoff and colleagues demonstrated that the terminal distance of approaching sound sources is underestimated (Neuhoff et al., 2009). In the same vein, Serino and colleagues proposed a method for capturing the boundaries of PPS which involves using intensity-changing sounds and testing their influence on the detection of tactile stimuli due to audio-tactile interaction processes (Canzoneri et al., 2012). In their study, participants responded to tactile stimuli delivered to the right hand at different delays from the onset of task-irrelevant intensity-changing sounds. These sounds, which were presented via a pair of loudspeakers placed near the hand, gave an impression of a moving sound source either approaching or receding from the participant's hand. Results showed that auditory stimuli speeded up the processing of a tactile stimulus at the hand as long as it was perceived at a limited distance from the hand, thus capturing the boundaries of PPS representation. This multisensory enhancement observed for sound sources inside the bounds of PPS was stronger for approaching than receding auditory stimuli, perhaps due to the larger biological salience of approaching stimuli (Tajadura-Jiménez et al., 2010b).

The impact of looming stimuli on PPS boundaries seems to be even stronger for emotion-inducing stimuli, as shown for threatening stimuli. This effect has been demonstrated by Vagnoni et al. (2012). Participants were required to judge the time-to-collision for looming visual stimuli that expanded in size before disappearing. It was found that time-to-collision was underestimated for threatening stimuli (e.g., a spider) as compared to non-threatening stimuli (e.g., a butterfly).

It is currently unknown whether auditory emotion-inducing looming stimuli, rather than visual, can similarly alter PPS boundaries. If we think on our everyday life, we can easily find examples suggesting that this is the case, especially, given the omnidirectional nature of spatial hearing. For instance, sounds of a growling dog are immediately perceived as threatening, and these are perceived even more threatening when the dog is running towards us and sounds are becoming louder (Tajadura-Jiménez et al., 2010b). In fact, we can react emotionally even when the dog is still far away and we are still not seeing it. This behaviour is likely to be paralleled by an alteration of the PPS boundaries. This example is in line with one of the functions ascribed to PPS, which can be referred to as defining a defence space (Cooke and Graziano, 2004). According to this understanding of PPS function, its boundaries would change as the surrounding environment changes, i.e., whether there are perceived sources of threat or not.

From the perspective of PPS as "defence space" it is worth investigating whether approaching threatening sound stimuli will influence PPS boundaries. Experimental evidence supporting the hypothesis that negative looming sounds can shape PPS comes from two previous studies by Tajadura-Jiménez et al. (2011, 2010b). In a first study they showed that unpleasant approaching sound sources evoke more intense emotional responses than receding ones (Tajadura-Jiménez et al., 2010b) as revealed by electrodermal responses, electromyography and self-reported emotional experiences. This approaching-receding difference was found, however, only for negative emotion-inducing sound sources and not for neutral or positive sounds. In a second study, Tajadura-Jiménez et al. (2011) investigated changes in personal space boundaries caused by listening to either positive or negative emotion-inducing music. In this study, personal space was defined as the comfort interpersonal distance between a participant and an experimenter approaching the participant. They found that, in contrast with the negative condition, listening to positive emotion-inducing music shrank the representation of the participants' personal space, thus allowing others to come closer to them. The study by Tajadura-Jiménez and colleagues, however, tested the impact of emotional auditory stimuli on personal space, as defined in social psychology, which not necessarily corresponds to the PPS, as defined in cognitive neuroscience. Moreover, the auditory stimuli in that study were only used to change the emotional context in which a different stimulus (i.e., the experimenter) approached the participant.

In the present study we investigated whether emotion-inducing looming sound sources affect PPS representation. In two experiments participants were exposed to artificial and ecological sounds simulating looming (i.e., approaching) sound sources. Rising intensity level simulated the approaching nature of sound sources. Previous research has shown that the most salient cue for auditory motion perception is intensity change (Lutfi and Wang, 1999), and therefore, sounds rising in intensity are generally perceived as approaching sound sources (for similar procedures see: Maier and Ghazanfar, 2007; Neuhoff, 2001; Rosenblum et al., 1987; Tajadura-Jiménez et al., 2010b).

In a first experiment, participants performed a simple tactile detection task of stimuli presented to their right hand, while listening to concurrently presented task-irrelevant artificial sound sources approaching toward their body (a similar procedure was used in (Canzoneri et al., 2012; Finisguerra et al., 2014; Teneggi et al., 2013). The spectral properties of the sounds induced affective responses of either neutral or negative emotional valence. In agreement with the perspective of PPS as "defence space, we expected larger PPS when the approaching sound stimulus was negative as compared to neutral. In Experiment 2, we used ecological sounds, which content (i.e., psychological associations to the sound producing source), rather than physical properties, elicited emotional responses of negative, positive or neutral valence. Again, according to the defence space perspective, we expected to find a larger PPS when the approaching stimulus was a negative, threatening sound as compared to neutral or positive.

2. Methods

2.1. Experiment 1

2.1.1. Participants

Twenty healthy subjects (17 females, mean age 21 years, range: 18–23) participated in Experiment 1 and twenty-five (23 females, mean age 21 years, range: 18–23) in Experiment 2. All participants were right-handed and had normal hearing, as self- reported. All subjects (students at the University of Chieti) gave their written informed consent to participate in the study, which was approved by the Ethical Committee of University "G. d'Annunzio", and was performed in accordance with the Declaration of Helsinki.

2.1.2. Artificial sounds selection and validation

The experimental stimuli were various power-law shaped