American Pain Society
RESEARCH
EDUCATION
TREATMENT
ADVOCACY
PUBLISHED BY ELSEVIER

The Journal of Pain, Vol 17, No 3 (March), 2016: pp 350-358
Available online at www.jpain.org and www.sciencedirect.com

Size and Viewpoint of an Embodied Virtual Body Affect the Processing of Painful Stimuli

Daniele Romano,[*,†,‡,§] Joan Llobera,[‡,§,¶] and Olaf Blanke[‡,§]

**University of Milan-Bicocca, Department of Psychology, Milan, Italy.*
[†]NeuroMi, Milan Center for Neuroscience, Milan, Italy.
[‡]Laboratory of Cognitive Neuroscience, [§]Center for Neuroprosthetics, and the [¶]Immersive Interaction Group, École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland.

Abstract: Looking at one's own body might induce visual analgesia. However, the cognitive and physiological mechanisms underlying such visual analgesia are unknown. Because body and pain representations in the brain are multisensory, and have been reported to partially overlap, we herein investigated whether experimentally-induced changes in bodily self-consciousness (BSC) modulate pain. We measured physiological responses to pain (skin conductance response [SCR]) and the subjective experience of pain, under conditions of manipulated BSC. First we investigated whether looking at a virtual body that was associated with BSC (embodiment) reduced responses to pain, which revealed the effect of BSC on pain processing. Second, we manipulated the visual size of the virtual body during painful stimulation, a procedure known to modulate pain processing when used with biological bodies, but never studied with embodied avatars. We found reduced SCR in conditions of illusory embodiment, and a negative correlation between virtual body size and SCR, whereas subjective pain ratings were not affected by these manipulations. These results suggest that pain processing is modulated during illusory states of BSC and that these changes are greater for larger virtual bodies, which sustains that pain and its physiological mechanisms are associated with the bodily self, opening promising avenues for future pain treatments.

Perspective:* *We show that BSC affects the processing of painful stimuli with induction of different levels of pain responses for embodied virtual bodies of different sizes. Our data reveal novel links between pain and self and suggest that embodied virtual bodies are a promising technique for future pain treatments.

Key words: *Full body illusion, pain, analgesia, body representation, skin conductance response.*

Nociceptive stimuli are processed through specific sensory pathways.[22,33] Nonetheless, pain perception is highly subjective and it has been shown to be modulated by different bodily states, including the experimental manipulation of visual and multisensory signals.[22,28,34,52] In particular, it has been shown that looking at one's own body is associated with analgesia. However, this effect does not occur when looking at nonbodily objects or at another person's body (ie, visual analgesia).[34,35] It has also been shown that the visual magnification of one's own hand leads to increased pain thresholds[37] and reduced arousal responses[52] to nociceptive stimuli. Moreover, visual analgesia when looking at one's own body is modulated by the degree of ownership felt towards the seen body,[53] for healthy participants[24,38,53] and neurological patients with abnormal ownership.[51,54] Less is known about how visual magnification affects changes in analgesia related to body ownership[37,42,44,52] and whether visual magnification-related effects on analgesia are associated with the sense of body ownership and body representation.

Body representation refers to the many distributed processing systems in the brain that encode a person's body.[25] Next to somatosensory and motor functions, body representation has also been associated with

Received July 21, 2015; Revised October 22, 2015; Accepted November 17, 2015.
The study was supported by a grant from the International Foundation for Research in Paraplegia to Olaf Blanke.
The authors have no conflicts of interest to declare.
Address reprint requests to Daniele Romano, Università degli studi di Milano Bicocca, Department of Psychology, Piazza Ateneo Nuovo 1, Milano 20126, Italy. E-mail: daniele.romano@unimib.it
1526-5900/$36.00

http://dx.doi.org/10.1016/j.jpain.2015.11.005

cognitive functions necessary for proper interaction with external objects,[14] and for anticipating sensory consequences of approaching stimuli,[55] as well as the sense of self. Concerning the sense of self, the study of bodily aspects of the sense of self or self-consciousness (bodily self-consciousness [BSC]) has been extensively investigated in the past years.[5,14,16,59] A fundamental component of BSC is body ownership (ie, the feeling that a given body part belongs to us),[14] and is formed on the basis of the integration of specific multisensory bodily stimuli. The feeling of ownership toward our own body parts is such a common experience that people tacitly take it for granted,[54] although it has been shown that it can be experimentally manipulated in healthy volunteers,[7,17,32] and there have been numerous reports of neurological patients who experience pathological forms of body ownership.[19,51] Body ownership is on the basis of nonconceptual processing of body-related information[6,13,14,18] and supported by a continuous stream of multisensory brain signals including tactile, proprioceptive, visual, and interoceptive cues. Recent works using video, virtual reality, and robotic technologies have allowed the study of the multisensory mechanisms of BSC in a fine-grained manner.[7,17,32] These studies revealed that congruent visuotactile stimulation at the trunk can induce changes in self-identification and self-location with respect to a virtual or fake body.[17,32,40] This illusion, known as the full body illusion, is induced by looking at the virtual body from a posterior third-person viewpoint (eg, participants see a virtual body in front space as being located 2 m ahead),[32,47] or from a first-person viewpoint (eg, participants see a virtual body from an embodied congruent viewpoint).[30,39,40,57]

In the current study we took advantage of virtual reality and manipulated the sense of ownership toward a virtual body. We investigated the physiological responses (skin conductance response [SCR])[2,21,23,53] to acute noxious stimuli delivered to the participant's body while body ownership was manipulated by showing a virtual body from a first-person and third-person viewpoint. We also tested visual magnification and showed the virtual body in 3 different size conditions: a standard body of normal size, a magnified body (30%), and a smaller body (30%). We predicted reduced responses to nociceptive stimuli under conditions of stronger illusory ownership, thus especially when the virtual body was seen from the first-person viewpoint. We also predicted an effect of virtual body size, namely a larger body should induce weaker responses than a smaller body, again only when seen from the first-person viewpoint.

Methods

Participants

Twenty-one right-handed healthy volunteers took part in the experiment (mean age $\pm$ SD = 23.0 $\pm$ 2.0 years; 9 women). All participants had normal vision and were naive to the purpose of the experiment. All participants gave their written informed consent before the inclusion in the study. The study was approved by the local ethics committee—La Commission d'Ethique de la Recherche Clinique de la Faculté et de Médecine de l'Université de Lausanne—and was conducted in accordance with the ethical standards of the Declaration of Helsinki.[60]

The general aim of the study and the procedure were explained to participants before collecting the informed consent; at the end of the experimental session the specific scope of the study was also explained. Participants were informed that the experiment was aimed to study the relation between body perception and pain perception. They were informed that they would receive noxious stimuli on 1 leg and that they could stop the experiment at any time, and withdraw their consent whenever they wanted. Specific expectations about the different conditions and the hypothesis related to the body size and analgesia were never mentioned before the experimental procedure to reduce potential bias in their responses, particularly in the questionnaires. These were explained at the end of the session.

Experimental Setup

The experiment was conducted in a light-shielded room.

Visual stimuli were presented on a head-mounted display (Virtual Viewer 3D; Virtual Realities, Houston, TX) with 1280 $\times$ 1024 pixel resolution and a 60° diagonal field of view. White noise was delivered to volunteers through headphones to prevent them from hearing acoustic cues from the external environment.

A serial keypad (Targus Numeric Keypad AKP10US; Anaheim, CA [www.targus.com]) was used to record participants' responses to the questionnaire. In-house software (ExpyVR; Lausanne, Switzerland [http://lnco.epfl.ch/expyvr]) was used for visual stimuli presentation and recording ratings.

SCR Hardware

The BioSemi ActiveTwo system (ActiveTwo; BioSemi BV, Amsterdam, The Netherlands) was used, together with 2 passive Nihon Kohden electrodes, to record galvanic skin response. The sensors were applied to the distal phalanx of the index and middle finger of the left hand, and the 2 reference electrodes were applied to the left forearm. A saline conductive paste was applied to the electrodes to improve the signal to noise ratio. Data were digitalized at a sample rate of 2,048 Hz, sent through an optic connection, and stored on a dedicated computer. The data were downsampled offline at 200 Hz.

Visual Stimuli

The head-mounted display showed the image of a human body, perceived from a first-person viewpoint, wearing a gray t-shirt and blue jeans (Fig 1). Critically, the body was presented in 2 possible orientations (factor: viewpoint). In the 0° rotated condition the virtual body was viewed in such a way that when participants looked down, they saw the virtual legs in place of their own