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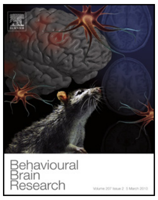

Research report

Illusory self-identification with an avatar reduces arousal responses to painful stimuli

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HIGHLIGHTS

- We experimentally induced the full body illusion through a robotic device.
- We collected SCRs and ratings following acute pain stimulation during bodily illusion.
- Reduced arousal responses were detectable under illusory states of self-consciousness.
- Reduced SCR was related to the degree of ownership experienced for the virtual body.
- Virtual body must be in anatomical configuration to be effective.

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ABSTRACT

Looking at one's own body has been shown to induce analgesia. In the present work we investigated whether illusory self-identification with an avatar, as induced experimentally through visuo-tactile stimulation, modulates the response to painful stimuli.

In 30 healthy volunteers, a robotic device was used to stroke the participants' back, while they viewed either the body of an avatar, a non-body object (control object), or a body avatar with scrambled body parts (control body). All were visually stimulated in either congruent or incongruent fashion with the participant's body. We collected physiological responses (skin conductance response: SCR) to painful stimuli delivered to the participant's hand and responses to a questionnaire inquiring about self-identification with the avatar. We expected reduced physiological responses to pain during the observation of a body avatar only during synchronous visuo-tactile stroking and no reduction for the control object and the control body.

Results showed a reduced SCR to painful stimuli when participants observed the normal body avatar being stroked synchronously that was also associated with largest self-identification ratings recordable already during the pain anticipation. Moreover, a negative correlation between self-identification and SCR was observed, suggesting that a greater degree of self-identification with the avatar was associated with larger decreases in SCR. These results suggest that during states of illusory self-identification with the avatar, the vision of an alien body (anatomically compatible for the vision and congruently stroked for the touch) is effective in modulating physiological responses to painful stimuli.

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1. Introduction

Bodily self-consciousness is not considered anymore a unitary inviolable concept. Recent experimental evidences suggest that it is rather a result of multisensory bodily signal integration in the brain. Bodily self-consciousness has been proposed to comprise self-identification (the experience that 'I' identify with a body), self-location (the experience of where 'I' am located), and a first-person perspective (from where 'I' experience the world), but also relating to the sense of agency (the experience that 'I' am the agent causing 'my' actions) [1–3]. Since the first experimental induction of changes in limb-ownership and location in the rubber-hand illusion [4], further studies have demonstrated that it is possible to extend one's own body representation to different external objects such as a prosthetic hand [4] or different fake body parts [5–8] but

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also to entire bodies [9,10]. In the rubber hand illusion (RHI), the visuo-tactile congruent stimulation of one's own hidden hand and a visible anatomical compatible fake hand induces the sensation that the prosthetic limb belongs to oneself [4,11]. Similarly, the full body illusion (FBI) can be induced; thus, congruent visuo-tactile stimulation at the trunk can induce self-identification and self-location changes with respect to a virtual or fake body [12,13,9,14].

Multisensory body representation has been proposed to be crucial for self-identification with the body and for other aspects of bodily self-consciousness [4,15,9,16,17,11]; however, it has also been shown to be critical for any sensory perception including pain.

Recent studies from cognitive neuroscience show that although pain is highly subjective, it is affected by certain bodily states and experimentally modulated multisensory signals [18–20]. Thus, although nociceptive stimuli are processed through specific sensory pathways [18,21], similar to non painful stimuli, pain can be critically modulated by vision.

Previous work has shown that looking at one's own body but not to an object or at another person's body, while receiving a painful stimulus, produces analgesic effects [22,20]. Starting from this observation, we aimed at investigating the relationship between pain processing and body ownership; here, we sought for evidence that reduced responses to nociceptive stimuli can be obtained not only by looking at one's own body [20] but also when looking at another person's body or avatar, especially under conditions of self-identification with the virtual body. Thus, we asked whether changes in illusory self-identification following the induction of an FBI would be associated with a reduction of pain responses.

In two experiments, we combined robotic stimulation and virtual reality technology in order to induce the FBI [23–25]. We then investigated the response to acute noxious stimuli delivered to the participant's hand, through the recording of the SCR, corresponding to the activation of the autonomic nervous system (ANS) [26–28]. Since the response to a noxious stimulus starts before skin contact, as a consequence of anticipatory evaluation of the sensory consequence to the approaching stimulus [29], we also studied the modulation of such an anticipatory response to pain following FBI. We induced the FBI by manipulating the congruency of visuo-tactile stroking between the virtual body and participants' own body (stroking factor) and we manipulated whether the participants saw a virtual body or a control object on their head-mounted display (visual feedback configuration factor).

2. Experiment 1

2.1. Materials and methods

2.1.1. Participants

Fourteen right-handed healthy volunteers took part in Experiment 1 (mean age ±standard deviation: 24.87±2.82 years; 3 females). 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 Medicine de l'Université de Lausanne,and was conducted in accordance with the ethical standards of the Declaration of Helsinki [30].

2.1.2. Experimental setup

The experiment was conducted in a light-shielded room where a robotic device for tactile stroking was installed [23]. The robotic device had 200 cm × 90 cm × 10 cm dimensions and a soft foam cover that permitted participants to lie comfortably on their back. Stroking units were integrated in the robotic device that allowed to separately stroke the left and right upper back of participants. A stroking unit consisted of an ultrasonic motor (Shinsei, USR60-E3 N, Japan, http://www.shinsei-motor.com) that actuated via a pinion-hole mechanism movable end parts on which a spring blade and a plastic sphere were mounted. Plastic spheres reached through gaps in the foam cover of the robotic device to touch the upper back of a participant and via the spring blades adapted to the curvature of participants' back during stroking.

Visual stimuli were presented on a head-mounted display (Virtual Realities, Virtual Viewer 3D, Houston, Texas, www.vrealities.com/virtualviewer3d.html) with 800 × 600 pixel resolution and 35 degrees of visual angle. On headphones white noise was presented to participants in order to prevent them from hearing acoustic cues from the robotic stroking.

A serial keypad (Targus Numeric Keypad AKP10US, Anaheim, CA, www.targus.com) was used to record participants' button press responses, which were given with participant's right hand.

In-house software (ExpyVR, Lausanne, Switzerland, http://lnco.epfl.ch/expyvr) was used for visual and acoustic stimulus presentation and recording of responses and LABview software (National Instruments Corporation, version 2010b, Austin Texas, www.ni.com/labview) was used for robotic device control.

2.1.3. Stimuli

Tactile stroking by the robotic device was specified by pre-programmed stroking sequences. A total of four random sequences were created before the experiment with Matlab software (MathWorks, version R13, Massachusetts US, http://www.mathworks.ch). These sequences specified the position of a stroking unit at 100 Hz sampling rate, within 0–20 cm distance range, and 2–12 cm/s velocity range. Within these limits, the four sequences had respectively random direction, timing, relative position, and speed.

The head-mounted display showed an image of a human body (male or female, according to participant's gender) wearing a white t-shirt and blue jeans against a gray background (virtual body, Fig. 1a) or a white rectangle, as a control condition (virtual object, Fig. 1b). The virtual body held a prone posture and was seen in bird's eye view [25].

2.1.4. SCR device

The BioSemi ActiveTwo system (ActiveTwo, BioSemi B.V., Amsterdam, Netherlands) was used as signal amplifier with specific GSR sensors consisting of 2 passive Nihon Kohden electrodes to induce an oscillator signal synchronized with the sample-rate. The sensors were applied on the distal phalanx of the index and middle finger of the left hand, while the two references electrodes were applied to the left forearm. A saline conductive paste was applied to the electrodes, in order to improve the signal-to-noise ratio.

Data were digitalized on a dedicated computer through optic connection with a sample rate of 2048 Hz and then data were re-sampled offline at 200 Hz.

2.1.5. Procedure

An experimental run consisted of an FBI-induction phase, followed by a pain-stimulation phase, questionnaire ratings, and a resting period (Fig. 1d)

The FBI-induction phase consisted of 50 s visuo-tactile stroking in synchronous or asynchronous fashion (stroking factor) seen on an avatar or object (visual feedback factor).

A total of 8 trials were presented during the pain-stimulation phase. A trial began with visually presenting a needle that moved toward the body/object eventually contacting the target ("virtual puncture") during 5 s and was followed by a fixed interstimulus interval of 5 s after which the next trial was presented. During the pain-stimulation phase, visuo-tactile stroking was continuously presented. The picture of a big static needle was displayed

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