NeuroImage 139 (2016) 360–367

Contents lists available at ScienceDirect

NeuroImage

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

Temporal dynamics of brain activation during 40 minutes of pleasant touch

Uta Sailer [a,b,*], Chantal Triscoli [a,c], Gisela Häggblad [d], Paul Hamilton [e], Håkan Olausson [c,e], Ilona Croy [e,f]

[a] Dept. of Psychology, University of Gothenburg, Gothenburg, Sweden
[b] Faculty of Medicine, Institute of Basic Medical Sciences, Dept. of Behavioural Sciences in Medicine, University of Oslo, Oslo, Norway
[c] Dept. of Clinical Neurophysiology, Sahlgrenska University Hospital, Gothenburg, Sweden
[d] Dept. of Pedagogical, Curricular and Professional Studies, University of Gothenburg, Sweden
[e] Center for Social and Affective Neuroscience, Department of Clinical and Experimental Medicine, Linköping University, Linköping, Sweden
[f] Clinic for Psychosomatic Medicine, Technical University of Dresden, Germany

ARTICLE INFO

Article history:
Received 29 January 2016
Revised 16 May 2016
Accepted 17 June 2016
Available online 20 June 2016

Keywords:
Touch
Reward
Stroking
Inferior frontal gyrus
Putamen
Secondary somatosensory cortex

ABSTRACT

Introduction: Touch is important for individuals' subjective well-being, is typically rewarding, and is one of few sensory stimuli which are experienced as pleasant for a rather long time. This study tracked brain activation during slow stroking stimulation of the arm that was applied continuously for 40 min - a much longer time than what previous studies have investigated.
Methods: 25 subjects were stroked for 40 min with a soft brush while they were scanned with functional Magnetic Resonance Imaging, and rated the perceived pleasantness of the brush stroking. Two resting baselines were included. Whole brain-based analyses investigated the neural response to long-lasting stroking.
Results: Stroking was perceived as pleasant throughout scanning and activated areas that were previously found to be involved in the processing of pleasant touch. Activation in primary somatosensory cortex (S1) and S2, subdivision OP1, decreased over time, whereas activation in orbito-frontal gyrus (OFC) and putamen strongly increased until reaching a plateau after approximately 20 min. Similarly, functional connectivity of posterior insula with middle cingulate and striatal regions increased over time.
Discussion: Long-lasting stroking was processed in similar areas as shorter-lasting stroking. The decreased activation in somatosensory cortices over time may represent stimulus habituation, whereas increased activation in OFC and putamen may relate to the stimulation's subjective reward value. This involvement of reward-related brain circuits can facilitate maintenance of long-lasting social touch interactions.

Introduction

Affective touch plays an important role in individuals' subjective well-being and is assumed to form the basis for affiliate behavior and social bonding (McGlone et al., 2014; Morrison et al., 2010). People touch and stroke each other frequently and by that express affection, security and positive attention (for overview, see Gallace and Spence, 2010). Affective touch varies from short tapping or touching the hand, as is common for contact between strangers, to stroking and massaging that endures for minutes and hours. Such long-lasting touch spontaneously happens between intimate partners, family members, and in parent-child interactions (Suvilehto et al., 2015) and often signals deep emotion and affection. Indeed, pleasant touch seems to be one of few sensory stimuli which is experienced as pleasant for a rather long time (Triscoli et al., 2014). However, although many studies (Francis et al., 1999; Rolls et al., 2003; Rolls, 2010), identified the neural correlates of short-lasting pleasant touch, there has never been any attempt of investigating brain activation during prolonged touch.

The importance of pleasant touch is underlined by the finding that such stimulation is transmitted by a separate sensory system of low-threshold mechanoreceptive tactile C-afferents (CT-afferents). These CT-afferents innervate all hairy parts of human skin and exhibit the highest firing frequency when the skin is gently stroked at speeds corresponding to a caress. Furthermore, the firing rate of CTs highly correlates with subjective ratings of pleasantness of stroking (Ackerley et al., 2014; Löken et al., 2009). CT afferents project to the posterior insula (Morrison et al., 2011a; Olausson et al., 2002), as shown by results from fMRI investigations of brain areas activated by slow touch in patients lacking Aβ afferents. Whereas slow stroking activated somatosensory areas and insular cortex in healthy subjects; only the

* Corresponding author at: University of Oslo, Faculty of Medicine, Institute of Basic Medical Sciences, Department of Behavioural Sciences in Medicine, PO Box 1111, Blindern, 0317 Oslo, Norway.
E-mail address: uta.sailer@medisin.uio.no (U. Sailer).

http://dx.doi.org/10.1016/j.neuroimage.2016.06.031

posterior insula was activated in subjects lacking Aβ afferents (Olausson et al., 2008; Olausson et al., 2002).

In addition to the insula, slow stroking commonly activates orbitofrontal cortex (OFC) (Lamm et al., 2015a; Mc Glone et al., 2012; Morrison et al., 2011a; Olausson et al., 2002; Rolls et al., 2003). Even more, activation in the orbitofrontal cortex correlates with the subjective pleasantness of touch (as reviewed by Rolls and Grabenhorst, 2008). Since the OFC is activated by a large number of rewarding and punishing stimuli such as taste (Kringelbach et al., 2003; Veldhuizen et al., 2010), odors (e.g., Rolls et al., 2010), money (e.g., O'Doherty et al., 2001) and erotic stimuli (e.g., Sescousse et al., 2010), it appears to generally track rewards regardless of modality.

A further region coding for the hedonic aspect of touch is the ventral striatum (May et al., 2014). Previous work showed a correlation between activation in the ventral striatum and pleasantness ratings when participants were touched on their forearm with a “rich” vs “thin” body cream (McCabe et al., 2008). In addition to these regions, the posterior superior temporal sulcus (Bennett et al., 2013; Voos et al., 2013), the medial prefrontal cortex (Gordon et al., 2013; Voos et al., 2013), and the pregenual anterior cingulate cortex (Lindgren et al., 2012) have been implicated in processing slow pleasant touch.

To the best of our knowledge, neural processing of pleasant touch has only been examined on time scales shorter than several minutes (Morrison et al., 2011a; Olausson et al., 2002; Rolls et al., 2003). However, the willingness of people to pay for longer-lasting touch in the form of massage, the intimate quality of long-term stroking and the long duration of experienced pleasantness suggests that long-lasting stroking has rewarding effects in humans which may evolve over time. Alongside a rich literature about short-lasting pleasant touch, the present study is the first to investigate which brain regions code hedonic experience during long-lasting pleasant touch.

To this end, brain activation and subjective evaluation of continuous touch were monitored over an extended period of time (around 40 min). Tactile stimulation was performed with the slow stroking velocity of 3 cm/s. This velocity is typically experienced as most pleasant and is the optimal speed to elicit CT-fibres discharge (Ackerley et al., 2014; Löken et al., 2009). BOLD changes over time were monitored in the whole brain and related to subjective ratings of pleasantness. In addition, changes of connectivity during long-term stroking were explored.

Methods

Participants

25 healthy subjects (15 women), right-handed, with normal or corrected-to-normal vision by contact lenses, aged between 19 and 38 years (Mean age = 23; SD = 3.85) were recruited locally. The majority of the participants were students.

All subjects gave written informed consent and received financial compensation of 200 SEK/h (~25 dollars) for participation in the study.

The study was performed in agreement with the Declaration of Helsinki and has been approved by the regional medical research ethics committee.

Experimental setting and procedure

Acquisition parameters for fMRI

Images were acquired with a 3-Tesla PHILIPS Achieva scanner fitted with a 32 channel head coil. Changes in blood oxygen level dependence (BOLD) were obtained from T2*-weighted scans using a gradient-echo single shot EPI sequence (repetition time: 3000 ms; echo time: 35 ms). Volumes were acquired in 40 transverse ascending slices without gap with an in-plane resolution of 2.8 mm and a reconstructed voxel size of 2.50 × 2.55 × 2.80 mm. Field of view was 20 × 24 cm, matrix size 144 × 144 and flip angle 90°. Two dummy volumes were acquired at the beginning of the first block to reduce possible saturation effects. An anatomical T1 volume with slice thickness 0.9 mm (170 slices) and in-plane resolution of 0.94 × 0.94 mm (matrix size 256 × 256) was additionally acquired for anatomical mapping of activation.

Setup

Participants lay in the scanner with their left arm comfortably stabilized with medical cushions. To minimize head movements participants' heads were stabilized with foam padding and adhesive tape.

Altogether, subjects were scanned during 18 blocks of two minutes duration each. During all these blocks, the computer screen in front of the subjects was black. 37 volumes were acquired during each block (666 volumes in total). The first and the last of these blocks constituted a baseline, during which the subjects were instructed to lie still and “do nothing”. The remaining 16 blocks in-between represented the active tactile stimulation condition. The subjects' left dorsal forearm was stroked with a custom-built MR-compatible robotic device which delivers highly replicable force (linear tactile stimulator, LTS; Dancer Design; St Helen's, UK, driven by LabVIEW software (National Instruments; Austin, TX)) (see Fig. 1). The subjects were informed that they would be brushed by a robot both in the consent-form and the verbal instruction given before the experiment, and they saw the machine already when entering the scanner room. A 60 mm wide flat water-colour brush made of fine, smooth goat's hair was attached to the robot. Continuous back-and-forth brush strokes on the participant's left dorsal forearm were given at a predefined force of 0.4 N ± 0.05 and a velocity of 3 cm/s. The brush traversed a distance on the skin of ~10 cm for each direction.

Stroking was performed continuously and without interruption during the whole session for an average duration of 39 min (range 38–40 min). In our previous study on long-lasting touch (Triscoli et al., 2014), brushing was applied for 50 min and was paused during the time the subjects gave their rating. In the present study, we did not want to keep the subjects in the scanner for too long and therefore reduced brushing time for 40 min. At the same time, we were interested in the decrease in ratings. Therefore, we decided to speed up the “satiation process” by brushing continuously. After every 2 min, fMRI acquisition stopped and participants rated the sensation on a subsequently presented visual analogue scale (VAS) using a response box attached to the subject's left leg. The visual analogue scale was presented on a computer-controlled screen which the subjects could see via a mirror on the head coil. Participants were asked to answer the question: “How pleasant was the brushing?” on a scale with the endpoints “not at all pleasant” (−10) and “very pleasant” (+10). After the subjects had given their rating the VAS disappeared, and fMRI measurement started again for another 2-min interval (see Fig. 2). This was repeated for 16 blocks in total. The average time in-between blocks was 15 s (range 7–19 s). Prior to the experiment, subjects were trained to use the button press for VAS rating.

Fig. 1. Linear tactile stimulator for high-precision brush stroking of the left forearm.