Neuropsychologia 51 (2013) 1823–1828

Contents lists available at ScienceDirect

Neuropsychologia

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

Heightened motor and sensory (mirror-touch) referral induced by nerve block or topical anesthetic

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ARTICLE INFO

Article history:
Received 5 April 2013
Received in revised form
25 May 2013
Accepted 10 June 2013
Available online 17 June 2013

Keywords:
Sensory referral
Motor referral
Mirror neurons
Mirror-touch synesthesia
Simulation
Anesthetic

ABSTRACT

Mirror neurons allow us to covertly simulate the sensation and movement of others. If mirror neurons are sensory and motor neurons, why do we not actually feel this simulation- like "mirror-touch synesthetes"? Might afferent sensation normally inhibit mirror representations from reaching consciousness? We and others have reported heightened sensory referral to phantom limbs and temporarily anesthetized arms. These patients, however, had experienced illness or injury of the deafferented limb. In the current study we observe heightened sensory and motor referral to the face after unilateral nerve block for routine dental procedures. We also obtain double-blind, quantitative evidence of heightened sensory referral in healthy participants completing a mirror-touch confusion task after topical anesthetic cream is applied. We suggest that sensory and motor feedback exist in dynamic equilibrium with mirror representations; as feedback is reduced, the brain draws more upon visual information to determine- perhaps in a Bayesian manner- what to feel.

1. Introduction

Mirror neurons – a subset of motor neurons – fire when a primate watches another primate move its hand—as if these neurons were simulating the movements and intentions of the primate's conspecific (Rizzolatti, Fogassi, & Gallese, 2001). Mirror neurons have also been recorded in humans (Mukamel, Ekstrom, Kaplan, Iacoboni, & Fried, 2010). Mirror regions that activate during both observed and performed movement are consistently identified in areas including the inferior parietal lobule, inferior frontal gyrus, and ventral premotor cortex (Molenberghs, Cunnington, & Mattingley, 2012). There are also mirror neurons for touch; primary cortical somatosensory areas respond both when you are touched and when you watch someone else being touched (Blakemore, Bristow, Bird, Frith, & Ward, 2005; Keysers et al., 2004). If motor and sensory neurons fire during the observation of movement or touch, why don't we actually move our own hand, or feel touch on it?

In a rare form of congenital synesthesia called "mirror-touch synesthesia," individuals do experience touch that they observe (Banissy, Kadosh, Maus, Walsh, & Ward, 2009). If mirror-touch synesthesia occurred only in these synesthetes, it might be written off as an interesting genetic quirk. Yet we (Ramachandran & Brang, 2009), as well as Goller, Richards, Novak, and Ward (2011), have reported that mirror-touch synesthesia also occurs in phantom limbs after amputation, as well as in arms temporarily anesthetized for orthopedic surgery (Case, Abrams, & Ramachandran, 2010). We conjecture that under normal sensory conditions, the firing rate of tactile receptors in the skin provides a source of information to somatosensory cortex that you are not being touched. This information that you are not being touched keeps the mirror neuron system (MNS) signal of observed touch from reaching conscious experience (either by inhibition, or failure to contribute corroboratory sensory evidence to achieve threshold activation). This "sensory inhibition" hypothesis suggests that sensory referral and mirroring are heightened when sensory feedback is reduced. However, these were observational studies performed under limited conditions, with injured or ill patients whose limbs had undergone surgical trauma.

In Experiment 1, we attempt to replicate the finding of enhanced sensory referral under unilateral nerve block, and also investigate motor referral, by using patients undergoing relatively minor dental procedures. In addition, we wish to obtain quantitative evidence of heightened sensory referral under deafferentation, *without the participant being aware of the anesthetic state*. In Experiment 2 we therefore experimentally manipulate anesthetic state by administering an anesthetic cream or control cream in a double-blind fashion and employ a mirror-touch confusion task to test for sensory referral. Both experiments were approved by the University of California, San Diego Human Research Protections Program.

2. Experiment 1: Heightened referral induced by nerve block

2.1. Materials and methods

Experiment 1 was designed to provide additional clinical evidence of heightened sensory and motor referral under local anesthesia. We studied dental

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http://dx.doi.org/10.1016/j.neuropsychologia.2013.06.010

patients because they were easily accessible, had no underlying injury or disease process, and had undergone minimally invasive, routine procedures such as filling replacement for which a block of the inferior alveolar nerve was required. Because Experiment 1 could not be run in a blind manner, as dental participants were aware that they had received a dental nerve block (and most reported feeling numb, swollen, or tingly on the blocked side), we also studied control participants with an unknown skin cream applied to their face to try and control for effects of attention and expectation to one side of the face.

2.1.1. Participants

Fourteen patients (10 female; mean age=36.9, *range*=21–68, 11 right-handed) were recruited in the waiting room of a local dental office after their appointment. 8 participants had a filling placed or replaced, 5 had crowns placed or replaced, and 1 had wisdom teeth removed. All patients had received a unilateral inferior alveolar nerve block, which anesthetizes the ipsilateral teeth, lip, and chin. In addition, 14 control participants (UCSD undergraduates; 8 female) were included who had not received any dental work that week. We applied a layer of Vaseline® to one side of their face and told them that we were applying a skin product with a variety of possible properties.

2.1.2. Task

Participants were asked to watch four 20-s videos that depicted, respectively, (1) an experimenter touching her chin, (2) moving the distal portion of her mouth, or (3) applying a cold compress or (4) a hot cup to her chin (see Fig. 1). Each video displayed repeated touch or movement of the left and right sides of the face, in alternating order. After each touch or movement trial participants were prompted by text on the computer screen to verbally rate whether they felt any faint sensation or movement in their OWN face on a scale from 1 to 5 (1=nothing; 5=feels like own face actually being touched or moving). Participants were assured that we were only asking about any sensations *as* if they were being touched or moving. Participants were asked to report only sensations that occurred (or increased) when they observed the motion or touch in the movie. This task resembles that used by Holle, Banissy, Wright, Bowling, and Ward (2011), who report the effectiveness of video stimuli depicting touch to real bodies to induce touch referral in mirror-touch synesthetes. Thermal stimuli (implied heat and cold) were included to test relative referral of thermal properties; studies examining sensory referral of thermal qualities have thus far reported very low rates of this type of sensory referral (e.g. Holle et al., 2011; Ramachandran & Brang, 2009).

2.1.3. Data analysis

Ratings from each of the three trials on each side of the face were averaged for each video. Regardless of whether the model had touched her right or left face, referral was coded according to the side of the face the participant felt sensation on. Based on predictions from our brachial block study (Case et al., 2010) and from our pilot work, we predicted heightened referral to the numbed side of the face in all four conditions in the dental patients (less for thermal sensations), but not in the controls.

2.2. Results

Participants reported mean sensory referral of 1.3 ($\pm$0.4) on the numb side of their face and 1.0 ($\pm$0.0) on the other side. Participants reported mean motor referral of 1.5 ($\pm$0.5) to their numb side and 1.1 ($\pm$0.4) to the other side. Sensory referral was greater to the numbed side of the face (paired $t(13)=2.24$; two-tailed $p=0.04$; Cohen's $d=1.24$). Motor referral was also greater to the numbed side of the face (paired $t(13)=2.90$; two-tailed $p=0.01$; Cohen's $d=1.61$). Nonsignificant trends in the predicted direction were observed for both cold (paired $t(13)=1.71$; two-tailed $p=0.11$) and hot ($t(11)=1.91$; two-tailed $p=0.08$) stimuli. Only one participant ever reported greater referral to the unblocked side; this referral occurred during the motion condition.

In the control participants, no condition showed statistically significant differences between the sides of the face ($p=0.14$, 0.82, 0.15, and 0.34 for sensory, motor, hot, and cold, respectively), and four participants experienced greater referral to the unaffected side of the face. While dental patients had an average of 0.28 more sensory referrals to the numb side than the other side and controls had only 0.1 more referrals to the cream side than the other side, the statistical difference between control participants and dental participants was not statistically significant (unpaired $t(25)=1.25$; two-tailed $p=0.22$).

2.3. Discussion

In Study 1 we find that anesthesia due to temporary nerve block does elicit heightened reports of sensory and motor referral. To rule out the possibility that this effect was caused by attention or expectation, we ran a control group with an inert skin product applied to their face. This group did *not* show higher referral to the side with the skin product, demonstrating that attention and expectation, at least as modulated in the current study, are insufficient to explain the heightened referral observed under nerve block. We further believe that the dental participant findings are not accounted for by attention or expectation because many participants claimed during debriefing that they would have expected to be unable to experience vicarious

Fig. 1. Video stimuli depicted the model touching her chin, moving the distal portion of her mouth, applying a cold compress to her chin, or applying a cup containing a hot drink to her chin.