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Mirror-touch Synaesthesia in the Phantom Limbs of Amputees

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Abstract

In mirror-touch synaesthesia merely observing another person being touched will cause the observer to experience a touch sensation on their own body. The current study investigates whether this, normally a developmental condition, might be acquired following amputation. Twenty-eight amputees observed 67 videos of touch events and indicated a) whether the video elicited tactile sensations, b) where on the body this was located, c) the intensity of the sensation, and d) whether it was painful. Almost a third of amputees report a tactile sensation on their amputated phantom limb when watching someone else being touched. In this particular group the sensations tend to be localised on the phantom limb or stump, but are rarely reported elsewhere on the body. This occurs irrespective of the body part seen. The synaesthetic sensations were more intense when real bodies were observed relative to dummies or objects, and when the observed touch is mildly painful relative to non-painful. Although frequency, intensity and cause of phantom limb pain do not appear to determine whether an amputee will report mirror-touch sensations, those who do report it show greater empathic emotional reactivity. These results suggest that acquired synaesthesia may be linked with sensory loss, arising after amputation, and that highly empathic individuals could be predisposed to strengthening existing pathways between observed touch and felt touch.

Keywords: mirror system, synaesthesia, amputation, touch, empathy.
1. Introduction

Following amputation, 98% of amputees report a ‘phantom’ feeling that the missing limb still exists (e.g. Ramachandran and Hirstein, 1998). This is typically explained by assuming that the brain’s representation of the body is maintained after amputation (as a sensory-motor ‘memory’ of the missing limb) and may still be activated from various other inputs that are modified, via plasticity, when the normal somatosensory and proprioceptive inputs from the limb are lost (e.g. Melzack, 1990; Flor et al., 2006). Much of this research has concerned intra-modal plasticity such that adjacent regions of somatosensory cortex may send inputs into the ‘silent’ region representing the missing limb giving rise to phantom limb pain (Flor et al., 1995) or referred tactile sensations (Halligan et al., 1993). However, there has also been a significant body of research on the role of cross-modal inputs, notably from vision, on phantom limb experiences. For example, if touch is applied to the left hand of a right-arm amputee but such that a mirror reflects the sight of touch into the space of the missing limb, then tactile sensations are reported on the phantom right hand in addition to the intact left hand (Ramachandran and Rogers-Ramachandran, 1996). Phenomena such as this have often been labelled as examples of synaesthesia induced in phantom limbs because a visual input is needed to create the tactile sensation. The present study is also concerned with synaesthesia experienced in phantom limbs, but it differs from the previous example in a number of important respects. It concerns inter-personal sensations induced by watching touch to another human (rather than touch observed within one’s own body space) and it is elicited solely from vision without the need for additional touching of the participant’s intact limb (Ramachandran and Rogers-Ramachandran, 1996) or stump (Ehrsson et al., 2008).

Mirror systems have been hypothesised to provide a general mechanism for inter-personal sensory and motor correspondences (e.g. Rizzolatti and Craighero, 2004). In the original discovery of mirror neurons, these neurons were found to respond both when a monkey performed an action and when a monkey observed another person performing the same action (Rizzolatti et al., 1996). In humans, evidence for a comparable system has been obtained from increased motor excitability during action observation using TMS (Transcranial Magnetic Stimulation; e.g. Fadiga et al., 1995), from fMRI studies (e.g. Buccino et al., 2001) and from single cell recordings (Mukamel et al., 2010). The studies on action observation have been extended in a number of important ways. It has been argued that comparable mirror systems exist in other domains such as for touch, pain and emotion. Observing others being touched activates, during fMRI, somatosensory regions of the brain (Keysers et al., 2010) and observing others in pain activates the so-called ‘pain matrix’ including the anterior
insula and anterior cingulate (Singer et al., 2004). The same regions are also active when ‘real’ touch
and pain are experienced. Similarly, perceived threat to a rubber hand is also associated with neural
activity in the ‘pain matrix’ but only during conditions of illusory ownership (Ehrsson et al., 2007).
Moreover, it has been argued that this inter-personal sharing of feelings may provide a neural basis
for certain aspects of empathy (Carr et al., 2003; Leslie et al., 2003). Several lines of evidence
support this. In fMRI studies, self-reported levels of trait empathy may correlate with level of brain
activity when watching others in pain (Singer et al., 2004). Avenanti et al. (2009) showed
participants images of a body part being injected with a needle and measured cortico-spinal activity.
They found a decrease in cortico-spinal activity that was correlated with the pain they believed was
being experienced by the person being injected, and was specific to the body part observed. This
effect was greater in participants who scored highly on an empathy questionnaire. Similarly, they
found in research investigating racial bias that empathically cortico-spinal excitability was reduced
when observing pain to a member of the in-group, but not when seeing a member of the out-group
in pain (Avenanti et al., 2010).

For most people, observing touch activates the somatosensory system (e.g. Keysers et al.,
2004; Ebisch et al., 2008) and may lead to behavioural facilitation/interference of felt touch (e.g.
Schaefer et al., 2005; Serino et al., 2008), but this activity is not normally associated with conscious
experiences of being touched. However, some people do report tactile experiences on their own
body in response to observing touch on others and this has been termed mirror-touch synaesthesia
(Banissy and Ward, 2007). Synaesthesia occurs when the stimulation of one sensory modality, such
as vision, automatically and immediately induces a conscious sensory experience in another
modality, such as touch. The developmental form of synaesthesia, persisting over the lifespan, is
thought to have a genetic component (e.g. Asher et al., 2009). Mirror-touch synaesthesia occurs
when observing touch to humans but not objects (Blakemore et al., 2005b; Banissy and Ward, 2007)
and not dummies (Hölle et al., in press). It has been linked, using fMRI, to hyper-activity in the
somatosensory system in response to observing touch (Blakemore et al., 2005b). These individuals
have heightened tactile acuity (Banissy et al., 2009b) and a higher level of self-reported empathy
(Banissy and Ward, 2007). It may have a prevalence of around 1.5% (Banissy et al., 2009a) and is
believed to have a developmental rather than acquired origin. However, comparable symptoms
may be acquired under certain circumstances. For example, some brain-damaged patients with
reduced tactile sensitivity report tactile sensations from observed touch (Halligan et al., 1996;
Halligan et al., 1997). The present study will consider whether mirror-touch synaesthesia may be
acquired in some people following amputation.
Ramachandran and Brang (2009) empirically investigated mirror-touch synaesthesia in amputees. They reported the cases of four upper limb amputees who observed an assistant’s arm being stroked at 0°, 90° and 180° in front of them. Unlike previous studies (e.g. Ramachandran and Rogers-Ramachandran, 1996; Ehrsson et al., 2008), no actual touch was applied anywhere on their body. They report that phantom mirror-touch sensations were experienced in 61 of the 64 trials, and that mirror-touch sensations were never experienced in the intact limb. If the observed hand wiggled the sensations were enhanced, and one of their patients experienced cold sensations when observing the assistant’s arm being touched by an ice cube. It has been suggested that the mirror system in general may play a role in maintaining a ‘normal’ representation of the body following amputation (for a review see Giummarra et al., 2007) or in individuals with congenitally missing limbs and phantom sensations who may acquire a ‘normal’ body representation via inter-personal observation alone (Brugger et al., 2000; Price, 2006).

It is possible that in mirror-touch synaesthesia (e.g. Blakemore et al., 2005a) and hyperalgesia (e.g. Bradshaw and Mattingley, 2001) the mirror systems for touch and pain, respectively, exceed the threshold for conscious tactile perception to the extent that individuals report tactile experiences in response to the observation of touch or pain. A review by Fitzgibbon et al. (2010b) put forward that the amputees’, so called, “synaesthesia for pain” may be the consequence of the removal of the inhibition from a “normal” pain empathy mirror system caused by a painful or traumatic experience such as an amputation. In a preliminary questionnaire on pain synaesthesia, Fitzgibbon et al. (2010a) asked amputees to reflect on past experiences and found that nearly a sixth of amputees surveyed (12/74) recalled experiencing phantom pain when observing or imagining another person in pain. Of these, 91% reported that synaesthesia for pain was not specific to corresponding limb or cause of pain, and 75% claimed that the synaesthetic pain occurred in the phantom regardless of the site of seen or imagined pain.

It is possible that synaesthesia for pain might be relatively common in the general population. Osborn and Derbyshire (2010) presented participants with painful images and movie clips, and found that nearly 30% (31/108) had experienced pain in response to at least one of the images. They classified these participants as ‘responders’ and compared them in an fMRI study to ‘non-responders’ who never reported a sensory feeling in response to observing the painful stimuli. When observing noxious events as opposed to equivalent neutral events, the responders showed activation in brain regions associated with emotional and sensory pain, whilst the non-responders showed little activation.

In this study, we explore whether amputees report tactile (or painful) sensations in response to observing touch on others. Movie clips showing touch to limbs and faces were recorded and
presented on a computer screen. Participants were asked if they felt anything on their own body (or phantom), and were subsequently prompted to report where the sensation was felt, how intense it was, and whether it was painful or not. The visual stimuli were either non-painful or mildly painful (e.g. touch with the tip of a knife) but not strongly painful (as in Osborn and Derbyshire, 2010). This paradigm was adapted from a similar one recently used with normal-bodied mirror-touch synaesthetes (Holle et al., in press) but the stimuli and questions were adapted to be more appropriate to amputees (e.g. by having more images of limbs, asking participants if the feeling was on the phantom).

2. Methods

2.1. Participants

Thirty-two individuals with at least one missing limb took part in this study of which three were excluded for not completing the survey and one was excluded because his responses indicated difficulties in understanding the task. The remaining participants (23 male, 5 female) ranged in age from 21 to 71 years (Mean = 54.82 years; SD = 11.86), and consisted of 4 upper limb amputees and 24 lower limb amputees. All but three have experienced phantom sensations at some point, and 23 of the amputees still do. The characteristics of these amputees are given in Table 1. Participants were recruited through the Sussex Rehabilitation Centre in Brighton, and had previously completed a questionnaire regarding limb deficiency and phantom limb sensations. Thirty-three controls took part in a modified version of the experiment (that did not mention phantom limbs) and two were excluded for not understanding the instructions. The control group (15 Male, 16 Female) ranged in age from 26 to 73 (Mean = 49.42 years; SD = 14.11). The experiment was approved by the Life Sciences Ethics Committee at the University of Sussex and by the Brighton East Research Ethics Committee of the National Health Service.

2.2. Materials

This study required participants to watch videos which portrayed touch to a real body part, a dummy or an object. In total 34 videos were produced that showed this touch. All (excluding one) of the videos were mirror reversed so that the touch shown in the videos was seen to be applied to both the right and left side. The one stimulus that was not mirror-reversed was a cushion that was
touched centrally. Participants therefore viewed 67 videos in total. Of these videos 24 portrayed upper limbs, 20 lower limbs, 10 faces, 10 dummy limbs and 3 objects. All dummy limbs and objects viewed were shown to be poked by a finger. For the other videos the touch seen was made by either another person’s finger or an object, namely a knife, feather or flame (that approached close but did not touch). Overall 6 upper limb videos, 6 lower limb videos and 6 face videos portrayed touch by an object rather than a finger. In addition to this 4 still images were shown which pictured both a hand and a foot being injected with a needle. These images were the same as those used in the study of Avenanti et al., (2006). Different viewing perspectives were used for videos of limbs. Twenty-four of the videos were shown from an egocentric perspective so that the participant saw the limb as if watching their own limb (or phantom limb) being touched. The remaining 39 of the videos were viewed allocentrically as if watching another individual being touched. Some examples of stimuli are included in the Supplementary Online Material.

2.3. Procedure

Participants were told that they would be shown video clips and that they should note if they felt any actual (not imagined) tactile or painful experiences on their body. They were instructed to “Please answer honestly – it doesn’t matter if you say ‘no’ to all of the clips providing this is your honest answer”. A repeated measures design was employed so that all participants viewed all of the videos and the videos were randomised across participants so that each participant saw the videos in a different order. Videos were presented one at a time and appeared on the left side of the screen in a box approximately 3.5” x 4” (for a monitor size of 15”). On the right of the screen, Question 1 was displayed asking them if they “Feel anything on your body (or phantom)?” with a binary Yes/No option. All participants were additionally given the option to add any comments that they felt necessary. Each video took approximately 3 seconds to show each touch to the limb/object and were looped. If they responded ‘No’ to Question 1 then the intensity was automatically scored as 0 and the next trial started. If they responded ‘Yes’ to Question 1, participants were then asked three further questions. They were asked about the location where this sensation was felt, choosing from the following alternatives: ‘Phantom Limb’, ‘Stump’, ‘Intact Limb’, ‘Face’ or ‘Other’. They were asked to rate the intensity of the sensation on a visual analogue scale with integer units from 0 to 10 where 0 was defined as ‘No sensation’ and 10 as ‘Feeling as if you were the person in the video’. Finally, they were asked whether the sensation was painful using a binary (Yes/No) response.

As part of an additional study (conducted in a separate session), amputees completed an empathy questionnaire termed the Empathy Quotient or EQ (Baron-Cohen and Wheelwright, 2004) using the shortened 15-item version of Muncer and Ling (2006). Each item consists of a statement
(e.g. “I really enjoy caring for other people”) and responses are given on a 4 point scale ranging from ‘strongly agree’ to ‘strongly disagree’. Two points are given to a strongly empathic response, one point to a moderate empathic response and zero for both moderately non-empathic and strongly non-empathic responses. This version of the questionnaire has three sub-scales termed ‘cognitive empathy’, ‘emotional reactivity’ and ‘social skills’. The EQ was previously used by Banissy and Ward (2007) to measure empathy in mirror-touch synaesthesia.

The normal bodied control group was tested after the study with amputees was complete. This required a minor change to the wording of some questions and response options to avoid any reference to ‘phantom’ or ‘stump’. The first question was modified to “Feel anything on your body?” and they were asked to indicate the location for affirmative responses using the categories: right arm, left arm, right leg, left leg, right face, left face and other. (Note: The sidedness could be inferred for most responses given by the amputees given that the laterality of the phantom/stump was known).

3. Results

The results are summarised in Figure 1. Some of our control group (Figure 1C) occasionally reported a sensation although it tended to be weak and somatotopic (e.g. leg-to-leg, arm-to-arm). The amputees who reported sensations could be divided into two groups: a group that essentially resembles that found in controls (Figure 1B) and a second, larger, group for whom the sensations gravitated towards the phantom limb and stump (Figure 1A). This group showed a tendency to report sensations more frequently than the other amputee group and controls (see Figure 1a; $t_{(12)} = 1.698$, $p = .115$, and $t_{(15)} = 2.35$, $p = .033$, respectively), and were less likely to have a somatotopic correspondence than the sensations found in the other amputee group and controls (see Figure 1b; $t_{(12)} = .936$, $p = .368$, and $t_{(15)} = 7.46$, $p < .001$, respectively). The seemingly large difference in somatotopy between the two groups of amputees is due to only one of the five in group B (Participant 11 in Table 1) showing non-somatotopic mapping of the felt sensations. In group A, however, there were 52 trials in which synaesthetic touch was located on the phantom, 29 where they were located on the stump, but only 10 that were reported elsewhere on the body. That is, this group of nine amputees are reporting something that is both qualitatively and quantitatively distinct from other amputees and the normal bodied sample. As such, further analyses concentrate almost exclusively on this group. We will explore which stimuli tend to evoke these sensations, and we will
also consider whether this group differs from other amputees in terms of the characteristics of their amputation history, phantom limb (e.g. phantom pain), or trait empathy levels.

3.1. What Stimuli Trigger Mirror-Touch Sensations in Amputees?

Although the number of trials eliciting sensations was low overall, this may be because only certain types of visual stimuli have a strong propensity for triggering them. For this analysis, the intensity ratings for all stimuli were analysed from the group of nine responders.

A repeated-measures ANOVA indicated a significant difference between real-body, dummy and object target types in elicited sensation intensity ($F_{(2,16)} = 10.017, p = .002$). The results are shown in Figure 2. Post-hoc t-tests revealed that real-body targets elicited significantly stronger sensations than dummy targets ($t_{(8)} = 3.540, p = .008$) and object targets ($t_{(8)} = 3.353, p = .010$). There was no significant difference between dummy targets and object targets ($t_{(8)} = -0.510, p = .624$). This finding is similar to that reported for normal-bodied mirror-touch synaesthetes who tend to report synaesthetic touch only to observation of touch to a real human body (Holle et al., in press). Note that the mean intensity values tend to be low due to the inclusion of all trials, including those given an intensity rating of zero.

The video stimuli were categorised based on effector type, i.e. the specific object touching the limb in the video. Two stimulus groups were created: one of mildly painful effectors (flame, knife and injection) and another of non-painful effectors (feather and finger). A paired-samples t-test showed that elicited sensations were significantly higher if the effector was mildly painful ($M = 1.22, SE = .33$) than if it was not painful ($M = .15, SE = .06; t_{(8)} = -3.453, p = .009$). Analysed as individual effectors, a one-way repeated-measures ANOVA revealed a significant difference between the effector types ($F_{(4, 32)} = 2.711, p = .047$). This is shown in Figure 3. Post-hoc pairwise t-tests indicate that the knife elicited stronger responses than the feather and finger ($t_{(8)} = -2.682, p = .028$ and $t_{(8)} = -2.709, p = .027$, respectively), and the candle elicited a significantly stronger response than the feather ($t_{(8)} = -2.662, p = .029$). The injection did not yield a significantly different response from any of the other stimuli ($p > .05$), although Figure 2 suggests that these stimuli follow a similar pattern. No other pairwise comparisons were found to be significant ($p > .05$). Although mildly
painful stimuli were effective inducers, they did not necessarily induce painful sensations. In addition to asking about intensity, participants were asked whether the experienced sensations were painful/non-painful (a binary scale). The videos eliciting mirror-touch sensations were also counted with regards to a) whether the video showed mildly painful touch (flame, knife and injection) or non-painful touch (feather and finger), and b) whether the participant reported that the elicited sensations were either painful or non-painful. There were no significant main effects for seeing or experiencing pain ($F_{(1,12)} = 4.133, p = .065$ and $F_{(1,12)} = .146, p = .709$, respectively). There was also no interaction between these ($F_{(1,12)} = 1.83, p = .201$).

A paired-samples t-test showed no significant difference in intensity depending on whether the perspective of the videos was egocentric ($M = 0.47, SE = 0.11$) or allocentric ($M = 0.33, SE = 0.11$; $t_{(8)} = 1.453, p = .189$). It is to be noted that there is no difference in intensity between egocentric and allocentric perspectives for normal-bodied mirror-touch synaesthetes, although perspective can modulate the side of the body that it is felt on (Holle et al., in press). For this group of amputees, the side of the body that it is felt on is mainly determined by the site of amputation, as previously noted.

A mixed-model ANOVA investigated the between-subjects effect of type of amputation (upper limb or lower limb) and the within-subjects effect of body-part touched in video (upper limb, lower limb or face). There was no significant main effect of type of amputation ($F_{(1,7)} = .147, p = .713$), or of body-part touched in the video ($F_{(2,14)} = 1.149, p = .345$). The interaction between these two variables was also not found to be significant ($F_{(2,14)} = .690, p = .518$). That is, synaesthetic tactile sensations are just as likely to be reported irrespective of which body part is observed being touched. This result ought to be viewed with caution as only a small sample of upper limb amputees was tested.

In summary, synaesthetic tactile sensations in amputees are more intense when real bodies are observed to be touched (relative to dummies and objects) and when the touch is mildly painful (relative to non-painful). It is unaffected by the perspective of the observed body part (allocentric versus egocentric), and it is found for observed touch to different parts of the body. In all these respects it resembles mirror-touch synaesthesia in normal-bodied individuals (Banissy and Ward, 2007; Holle et al., in press). In one crucial respect it is different: the mapping between observed touch and felt touch is not somatotopic but is, instead, ‘captured’ by the phantom limb. This
suggests that the amputees are not merely saying what they see (a potential form of confabulation). Similarly, seeing a mildly painful stimulus was just as likely to elicit a non-painful as painful report.

3.2. What Distinguishes between Amputees Reporting ‘Mirror-Touch’ and Other Amputees?

In this section, we examine individual differences between ‘responders’ reporting mirror-touch sensations on the phantom/stump and ‘non-responders’. These analyses are based on the responses given in two questionnaires. Firstly, they had previously filled in a limb deficiency questionnaire. This asked about their amputation and phantom limb experiences. Secondly, a questionnaire asking about trait empathy (the EQ, Empathy Quotient) was given.

Participants were classified into three groups based on the frequency of their phantom limb sensations. Those who in their questionnaire reported never having experienced a phantom were coded as ‘None’, and those who had a constant feeling of a phantom limb were coded as ‘Permanent’. Anyone who had indicated that there phantom sensations come and go at various frequencies was coded as ‘Sometimes’. A 3 X 2 Chi-Squared test revealed no significant difference in the number of responders and non-responders dependent of phantom limb frequency ($\chi^2(2) = 2.22, p = .33$).

In the limb deficiency questionnaire, participants had provided a phantom pain score by drawing a line through a 100 mm visual analogue scale (VAS) yielding a score out of 100 where 0 represents no pain and 100 represents unbearable pain. An independent-samples t-test showed no significant difference in the mean phantom pain score between responders (M = 56.11, SE = 12.58) and non-responders (M= 43.29, SE = 9.85; t(21) = .807, p = .429). Moreover, a Pearson correlation showed no significant relationship between overall intensity of elicited responses and intensity of phantom limb pain ($r = .430, p = .248, n = 9$).

Cause of amputation – congenital, trauma, vascular, infection or birth defect – did not lead to a significant difference between responders and non-responders ($\chi^2(4) = 3.69, p = .450$). However, there was a significant difference in the responses of upper limb and lower limb amputees; whereas all three upper limb amputees were responders, most of the lower limb amputees (14 out of 24) were non-responders ($\chi^2(1) = 5.37, p = .021$). This finding is interesting but should be treated with caution given the small sample number of upper limb amputees tested.

Finally, the participants’ responses on the empathy quotient questionnaire was analysed in term of a total EQ score, as well as a score for three empathy subscales: a) cognitive empathy, b) emotional reactivity and c) social skills (Muncer and Ling, 2006). Figure 4 shows that responders scored significantly higher than non-responders on the emotional reactivity empathy subscale ($t(18) = -2.21, p = .04$). There was no significant difference between responders and non-responders in total
EQ score or on the other empathy subscales (p > .05). It is to be noted that this is the same subscale that was previously found to be related to the presence of mirror-touch synaesthesia in the normal-bodied population (Banissy and Ward, 2007).

4. General Discussion

This study was motivated by anecdotal reports of phantom limb sensations triggered via inter-personal observation. For example, some of the amputees in our sample had previously noted that “seeing someone get hurt causes pains in my stump” and “sometimes seeing someone else move their arms causes my phantom to imitate theirs”. It was also motivated by recent studies (e.g. Ramachandran and Brang, 2009; Fitzgibbon et al., 2010a) and reviews (e.g. Fitzgibbon et al., 2010b) concerning synaesthesia for pain and synaesthesia for touch in amputees. We showed our sample of amputees movies of people, dummies and objects being touched and asked them to report any experiences of touch (or pain) that they felt. We identified a group of 9 ‘responders’ who tended to report sensations on the phantom or stump but rarely anywhere else. The synaesthetic sensations tended to be elicited by touch to humans (but not dummies or objects) and for mildly painful stimuli relative to non-painful stimuli. In this respect, they are similar to normal-bodied mirror-touch synaesthetes (Holle et al., in press) although not necessarily quantitatively similar. That is, the normal-bodied mirror-touch synaesthetes tended to report tactile sensations on a higher proportion of trials than the amputees. However, there is one crucial difference between these groups. Normal-bodied mirror-touch synaesthetes report touch on the face when observing touch to a face, and touch to the arm when observing touch to the arm, etc. That is, somatotopy is preserved between observed touch and synaesthetic touch. This is not the case in amputees for whom the synaesthetic touch is almost always felt in the phantom/stump irrespective of the body part observed.

Although the findings are largely based on self-report data, we believe that the data cannot be explained as the amputees saying what they see (rather than what they feel), or saying what they think we want to hear (a compliance effect). Their reports often deviated from what they saw (e.g. seeing touch to an arm being reported as a sensation on the phantom leg). There was also high agreement within the group of responders suggesting that the pattern is robust. Another possible counter-argument is that the sensations are real but they are not induced; for instance, they could
reflect spontaneous changes in phantom limb sensations over time (of fluctuations in attention directed at the phantom). However, we consider this unlikely because some stimuli were more prone to elicit responses than others. We would expect the pattern to be more random if they were a result of spontaneous fluctuations. Moreover, neither the frequency nor intensity of phantom limb sensations discriminated responders from non-responders.

What causes synaesthetic sensations in amputees to gravitate towards the affected limb? There are several possibilities. One is the presence of pain in that region. Another is the loss of (veridical) sensation in that region. We could find no evidence that the intensity or frequency of phantom limb pain is related to the presence of synaesthetic experiences. However, it would be interesting to repeat the study using visual stimuli associated with higher levels of pain. For instance, Osborn and Derbyshire (2010) used images of broken limbs. Although we cannot discount the role of pain, other types of acquired synaesthesia are almost always linked to sensory loss. For example, synaesthetically induced phosphenes from sound (e.g. Afra et al., 2009) and touch (Armel and Ramachandran, 1999) have been reported in acquired blindness of peripheral origin. In patients with visual field defects, synaesthetically induced phosphenes may be localised entirely within the blind region (Jacobs et al., 1981). A recent neurological case reported synaesthetic touch in response to sounds following a thalamic lesion (Ro et al., 2007). The patient had reduced tactile sensitivity down one side of the body and the synaesthetic tactile experiences tended to be localised on this affected side. As such there is a general tendency for acquired synaesthesia to be linked to sensory loss (including localised sensory loss) and amputation may be just one example of this. One prediction is that we should find similar cases of acquired mirror-touch synaesthesia in normal-bodied people with reduced limb sensation (e.g. brachial plexus injury) but not necessarily in normal-bodied people with significant limb pain but normal sensation (e.g. extreme cases of deep vein thrombosis). It is interesting to note that the phenomenon of ‘mitempfindung’, the simultaneous sensation of touch at two different locations of the body, sometimes occurs after sensory loss (Schott, 1988), is not somatotopically consistent (Evans, 1976), and may be more common amongst synaesthetes (Burrack et al., 2006).

The mechanism that could support the emergence of acquired mirror-touch synaesthesia is cross-modal plasticity between visual (or visuo-tactile) regions and somatosensory regions. This kind of plasticity is assumed to occur in two phases: an initial unmasking (or disinhibition) of existing multi-sensory pathways followed by longer-term formation of new synaptic connections (e.g. Pascual-Leone et al., 2005). Acquired synaesthesia following sudden blindness can emerge in as little as 1-3 days (e.g. Afra et al., 2009) which is consistent with this fast acting mechanism, and it would be interesting to know when mirror-touch synaesthesia emerges following amputation.
Although the presence of mirror-touch synaesthesia in amputees was not predicted by characteristics of their phantom limb, it was predicted by one measure of empathy namely ‘emotional reactivity’. This sub-scale measures automatic emotional reactions directed towards other people (e.g. sharing their sadness) rather than the more cognitive aspects of empathy (e.g. thinking about feelings), and it was also found to be higher in normal-bodied mirror-touch synaesthetes relative to controls (e.g. Banissy and Ward, 2007). In a study that compared patients with lesions to the ventromedial prefrontal cortex, associated with cognitive perspective-taking, to patients with inferior frontal gyrus lesions, associated with emotional contagion, Shamay-Tsoori et al. (2009) found evidence to suggest that there are two dissociate pathways for these types of empathy. Differences in empathy reveal themselves in the extent to which individuals respond, physiologically, to seeing others in pain (Singer et al., 2004; Avenanti et al., 2009; Singer, 2009; Avenanti et al., 2010). Our claim is not that high empathy is a necessary condition for mirror-touch synaesthesia to occur following an amputation, but rather that these individuals have a head-start when it comes to modifying existing pathways linking observed touch to felt touch.

To conclude, we propose that like in mirror-touch synaesthesia, the somatosensory system of nearly a third of amputees reaches supra-threshold levels so that observed touch manifests as felt touch. Unlike normal-bodied mirror-touch synaesthetes the sensations are not somatotopically mapped, but usually occur in the phantom limb or stump. Such acquired synaesthesia may be the consequence of an unmasking of usually inhibitory pathways and the formation of new synaptic connections caused by the sensory loss associated with amputation. By exploring the situations leading to sensations and the characteristics of the experienced touch, the current study has enhanced our understanding of visuo-tactile interaction in amputees with phantom limb.

Acknowledgments

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References


Ramachandran VS and Brang D. Sensations evoked in patients with amputation from watching an individual whose corresponding intact limb is being touched. Archives of Neurology, 66:1281-84, 2009.


Figure Captions

Figure 1: A summary of participants who reported a tactile sensation during the observation of touch; including the average number of trials on which this occurred for these people, and whether the felt touch was reported in the same body part as the observed touch.

Figure 2: Mean intensity of elicited sensations when observing real body, dummy or objects touched (error bars show 1 S.E.M). * p<.05

Figure 3: Mean intensity of elicited sensations when observing a feather, finger, candle, knife or injection (error bars show 1 S.E.M). * p<.05.

Figure 4: Differences between responders and non-responders on the EQ questionnaire (error bars show 1 S.E.M). * p<.05.
A) AMPUTEES (N=9/28)

B) AMPUTEES (N=5/28)

C) CONTROLS (N=8/31)

a) Mean Percent Somatotopy (felt trials only)

b) Frequency of Felt Trials (N)
Intensity of Elicited Sensations (0-10)

- Feather
- Finger
- Flame
- Knife
- Injection

* Significant difference
A bar graph showing the comparison of Empathy Quotient scores between responders and non-responders. The graph includes categories for Total EQ Score, Cognitive Empathy, Emotional Reactivity, and Social Skills. The y-axis represents the Empathy Quotient Score ranging from 0 to 16. The graph indicates that responders have higher Empathy Quotient scores in most categories compared to non-responders.
<table>
<thead>
<tr>
<th>Participant Sex, Age</th>
<th>Amputation details</th>
<th>Phantom sensations</th>
<th>Mirror-touch sensations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Years since</td>
<td>Cause</td>
<td>Side and level</td>
</tr>
<tr>
<td>1. M, 45</td>
<td>24</td>
<td>Trauma</td>
<td>Right arm, above elbow</td>
</tr>
<tr>
<td>2. M, 64</td>
<td>13</td>
<td>Vascular</td>
<td>Right leg, above knee</td>
</tr>
<tr>
<td>3. M, 45</td>
<td>5</td>
<td>Trauma</td>
<td>Both leg, above &amp; below</td>
</tr>
<tr>
<td>4. M, 21</td>
<td>3</td>
<td>Trauma</td>
<td>Right leg, below knee</td>
</tr>
<tr>
<td>5. F, 70</td>
<td>3</td>
<td>Trauma</td>
<td>Left arm, above elbow</td>
</tr>
<tr>
<td>6. M, 53</td>
<td>17</td>
<td>Trauma</td>
<td>Left leg, below knee</td>
</tr>
<tr>
<td>7. M, 62</td>
<td>34</td>
<td>Trauma</td>
<td>Right leg, above knee</td>
</tr>
<tr>
<td>8. M, 64</td>
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<td>Vascular</td>
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</tr>
<tr>
<td>9. M, 63</td>
<td>N/A</td>
<td>Congenital</td>
<td>Left arm, below elbow</td>
</tr>
<tr>
<td>10. M, 49</td>
<td>5</td>
<td>Infection</td>
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</tr>
<tr>
<td>11. M, 71</td>
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<tr>
<td>12. M, 49</td>
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</tr>
<tr>
<td>13. F, 38</td>
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<td>Left leg, below knee</td>
</tr>
<tr>
<td>15. M, 54</td>
<td>5</td>
<td>Infection</td>
<td>Right leg, below knee</td>
</tr>
<tr>
<td>16. M, 66</td>
<td>48</td>
<td>Trauma</td>
<td>Right leg, below knee</td>
</tr>
<tr>
<td>17. F, 63</td>
<td>54</td>
<td>Birth defect</td>
<td>Right leg, below knee</td>
</tr>
<tr>
<td>18. M, 35</td>
<td>14</td>
<td>Trauma</td>
<td>Right leg, below knee</td>
</tr>
<tr>
<td>19. M, 41</td>
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</tr>
<tr>
<td>20. M, 53</td>
<td>23</td>
<td>Trauma</td>
<td>Right leg, through knee</td>
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<tr>
<td>21. M, 61</td>
<td>59</td>
<td>Birth defect</td>
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<tr>
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<td>23. M, 53</td>
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<td>Left leg, below knee</td>
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<tr>
<td>25. M, 50</td>
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</tr>
<tr>
<td>27. F, 61</td>
<td>18</td>
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<td>Right leg, above knee</td>
</tr>
<tr>
<td>28. M, 60</td>
<td>23</td>
<td>Trauma</td>
<td>Left leg, above knee</td>
</tr>
</tbody>
</table>

* These participants were classified as ‘responders’ as at least one video out of 67 produced a sensation of touch or pain in the phantom limb (based on classification by Osborn and Derbyshire, 2010).