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The long sixth finger illusion: The representation of the supernumerary finger is not a copy and can be felt with varying lengths

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Abstract

We can have a distorted perception of our body, instantly induced with multisensory illusions, anaesthesia or Virtual Reality, and recent studies show we can also feel extra body parts. Newport and colleagues (Newport et al., 2016) created an illusion that induces the feeling of having a sixth finger on one's hand, for a brief moment. By changing the paradigm with a double back and forth stroking, we were able to extend the duration of this illusion (Cadete & Longo, 2020), which can reflect an endured representation of a supernumerary finger. This innovation allowed us to test one specific distortion in the supernumerary finger: length. Patients with supernumerary phantom limb syndrome feel like they have an extra limb, as if one of their limbs was duplicated (Staub et al., 2006), resembling the same size and shape of the existing one. It is unclear from existing studies whether a supernumerary limb is represented as a copy of the existing limb, or if it is represented independently, with its own features. We therefore aimed to investigate whether the properties of the supernumerary sixth finger could be altered, independently of the actual little finger. Hence, we tested whether we can embody a sixth finger with double the size of the average little finger, and half its size. Participants reported feeling a long and a short sixth finger, and gave visual judgements on the felt length of the supernumerary finger, that matched the condition length. Overall, the results show that the supernumerary sixth finger is not a mere copy of the little finger but is represented independently, with distinct features from the existing finger. Moreover, the representation of the supernumerary finger is flexible, allowing the embodiment of a long or a short sixth finger.

We have a sense of owning our body, as a coherent object that we identify ourselves with. Although we experience our body as a stable object from moment-to-moment, research shows the perception of our body and its properties can be easily altered using simple multisensory manipulations. Healthy participants can be induced to experience a range of illusions of embodiment. For example, in the rubber-hand illusion (RHI) (Botvinick & Cohen, 1998) participants feel ownership of a prosthetic hand which is touched synchronously with their hidden hand. A range of similar effects using multisensory illusions and Virtual Reality (VR) have successfully induced the perception of having distorted bodily features, such as body weight (Piryankova et al., 2014; Preston & Ehrsson, 2016), the size of body parts (Kilteni et al., 2012; Lackner, 1988; Normand et al., 2011), ethnicity (Maister et al., 2013; Peck et al., 2013), age (Banakou et al., 2013), visibility (D'Angelo et al., 2017; Guterstam et al., 2013), and solidity (Senna et al., 2014). These studies show the flexibility of our body representation, allowing us to have an altered perception of our body. Through the manipulation of multisensory inputs, we can feel that a body part or the whole body has different features from the actual body.

Such results show that our immediate sensory experience can induce the perception of having a body part with altered features. Other work has demonstrated even more dramatic flexibility, including the embodiment of extra body parts, such as a third arm (Ehrsson, 2009; Newport et al., 2010; Won et al., 2015), a supernumerary 6th finger (Hoyet et al., 2016; Newport et al., 2016), and even a tail (Steptoe et al., 2013). Newport and colleagues (2016) described an effect they call the *Anne Boleyn illusion*, the feeling of having a sixth finger on one's hand, induced with conflicting multisensory signals. In this illusion, the participant's hidden hand is stroked at the same time as they see the contralateral hand being stroked through a mirror reflection, perceived as their hidden hand. The participant watches the empty space next to the little finger being stroked whilst the hidden hand is stroked on the outer side of the little finger, creating the illusion of having a sixth finger for a fleeting moment.

We recently replicated this effect and showed that by modifying the paradigm we could induce the percept of a stable sixth finger over an extended period of time (Cadete & Longo, 2020). By applying a continuous double stroking on the participant's fingers, followed by twenty double strokes on the "sixth finger" at the same time as the occluded little finger, we induced the illusion of having a sixth finger for a long duration, that is, throughout the twenty double strokes. This long-lasting experience of having a sixth finger suggests that it is not a momentary confusion due to unexpected or unusual stimuli, but an enduring representation of a supernumerary finger. It remains unclear, however, whether the supernumerary 6th finger is essentially a reduplicated copy of the little finger, or a distinct digit in its own right, which could potentially have features different from that of the little finger. To investigate whether the supernumerary finger is a copy of the actual finger, we tested whether its physical features could be manipulated independent of those of the actual finger. Specifically, we induced sixth fingers of varying lengths. If we are able to feel like we have a short and a long sixth finger, with half or double the length of our actual finger, then the sixth finger can have its own independent features, proving the supernumerary finger representation is not a copy of the existing finger.

Numerous studies have shown that the perceived length of body parts can be manipulated using a range of methods. For example, vibration of muscle tendons elicits illusory movements of the limbs which can produce perceived lengthening of body parts touching that limb (de Vignemont et al., 2005; Lackner, 1988). Research using VR has also found that congruent multisensory and sensorimotor feedback between the virtual arm and the real arm (Kilteni et al., 2012), can induce the feeling of having a very long arm. These examples demonstrate the lability of perceived size of body parts, and it has been shown that the size and shape of our bodies influence the perceived size and shape of the objects around us (Linkenauger et al., 2013). Size is one of the most studied flexible body features, which is why we chose as the manipulation feature to assess our key question on the independence of the mental body representation of the sixth finger.

There are also reasons to suspect that the supernumerary sixth finger might reflect a copy of the actual little finger. Some patients with phantoms report experiencing a supernumerary limb (Halligan et al., 1993; Hari et al., 1998; McGonigle et al., 2002; Staub et al., 2006), such as two right arms or a duplicated leg. It seems from the reported cases, that the additional phantom limb resembles the limb that is being reduplicated, in shape and size (Staub et al., 2006). It can be located in front of the copied limb, although it may as well be positioned in a less orthodox position, such as in the belly (McGonigle et al., 2002; Staub et al., 2006). The perceived similarity between the actual limb and the supernumerary phantom limb suggests that the supernumerary limb is not represented as an independent limb, with its own features, but as a copy of the existing limb (Staub et al., 2006).

It is unclear from existing studies whether the illusory sixth finger is represented as a distinct, independent body part with its own features, or merely a copy of the existing little finger. We therefore aimed to investigate whether the properties of the supernumerary sixth finger could be altered independently of the actual little finger. To do this, we tested whether participants would experience a supernumerary finger with features distinct from those of the little finger. If we can embody a sixth finger with a feature different from our actual little finger, it implies that a supernumerary finger is not a strict copy of the little finger, but is represented as a distinct digit with its own characteristics. We used the continuous version of the six-finger illusion that we recently developed (Cadete & Longo, 2020), and adapted the visual-tactile stimuli, stroking the sixth finger up to double the length of the average little finger and half of its length in another condition, to induce a long and short sixth finger, accordingly. The experimenter strokes the hidden hand's little finger at the same time as the empty space next to the hand reflected in the mirror, with the length of double the size of the average little finger or half its size. By doing this, the illusory sixth finger should be perceived as long or short, according to the induced length of the stimulus.

Methods

Participants

Twenty people ($M \pm SD$ = 32.6 ± 2.59 years; 9 females) participated after giving written informed consent. The study was performed in accordance to the Declaration of Helsinki and approved by the Department of Psychological Sciences Ethics Committee at Birkbeck. All participants were right-handed, as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971), M = 87.3, range from 62.5 to 100. In our previous study, the effect size for feeling a sixth finger with the same technique applied in this study was of d_z= 1.76. A power analysis using G*Power 3.1 (Faul et al., 2007) with a 2-tailed alpha of 0.05 and power of 0.95 indicated that 7 participants were required. Thus, our sample size of 20 should be well powered to replicate the illusion and to probe the embodiment of a six finger with varied lengths.

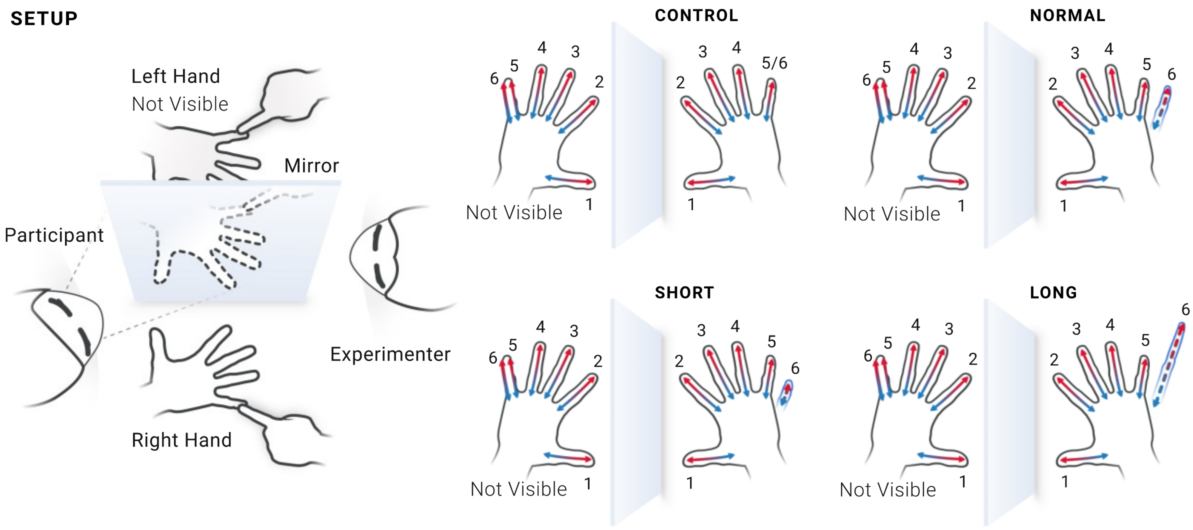


Figure 1: The experimental setup. The participant watched the reflection of their right hand in the mirror while their left hand was occluded behind the mirror. The participant saw the right hand through the reflection in the mirror, resembling the left hand due to the mirror optical reverse effect. The experimenter stroked the top of each finger twice back and forth, in both hands synchronously, from the knuckle to the tip, starting on the thumb to the ring finger. The occluded little finger was then stroked on the inside lateral at the same time as the top of the little finger on the *seen* hand, followed by twenty double strokes on the outer lateral side of the occluded little finger synchronously to touching the empty space next to the seen little finger, with the length of each condition. In the short condition, the experimenter stroked the length of half the size of the average little finger, in the long condition the strokes were double the size, and in normal condition were the average size. Participants looked in the mirror and when they saw the experimenter stroke the empty space next to their little finger at the same time as they felt a touch on their little finger (of the hidden hand), they felt like they had a sixth finger on their hand. The control condition followed the same procedure up to the little finger, stroking the *seen* little finger once again instead of the sixth finger on the last stroke. By doing the 6th stroke on the little finger, the touch should be mapped onto the little finger, therefore no illusion should occur. The arrows represent the double back and forth stroking. The stroking sequence is numbered in the figure, stroke 1 in the left hand occurs at the same time as stroke 1 in the right hand and so forth.

Design and Procedure

The participant sat at a table with a mirror (30 cm high, 40 cm wide) positioned on the table aligned with their body midline. They placed their left hand behind the mirror and their right hand in front of it. When they looked into the mirror, the reflection of their right hand thus appeared to be a direct view of their occluded left hand, as shown in Figure 1. The tip of the index finger of both hands was positioned 24 cm from the border of the table and 20 cm from the mirror, marked by two yellow dots where they were asked to place the tip of each index finger. The participant was asked to look into the mirror at the hand throughout each trial. The left hand was hidden behind the mirror and the right hand is hereafter referred as the seen hand, although it is important to note that the right hand was not seen directly, but only its reflection in the mirror, which is perceived as the left hand due to reverse optical effect of mirrors.

Each finger was stroked synchronously back and forth twice (thumb with thumb, index with index and so forth), the lateral side of the hidden finger was then touched at the same time as the seen little finger, followed by twenty strokes on the outer lateral side of the hidden little finger, at the same time as the space next to the seen little finger. The sixth finger stroking needs to be synchronous with the stroking of the actual little finger, that is hidden from sight, at a slower (long strokes) or faster (short strokes) speed so that it reaches the tip of the finger at the same time as the tip of the illusory sixth finger. The control condition consisted of twenty strokes on the little finger instead of the sixth finger. Unlike a sixth finger induced with VR (Hoyet et al., 2016), where participants can see the illusory finger, in this illusion participants feel the sixth finger while they see the empty space near their little finger being "stroked"; somatic sensations can be referred to a *discrete volume of empty space* which can be visually associated with an invisible finger, as it occurs in the invisible hand illusion (Guterstam et al., 2013).

The length of the mean little finger, 7.52 cm, was determined by averaging the little finger size of 345 participants measured during a range of studies conducted in our lab. For the short condition, the mean value was halved to a length of 3.8 cm (Figure 1). The length for the long condition was determined by doubling the little finger size: 15 cm. The control condition consisted of touching the seen little finger instead of touching the space next to the little finger, excluding the visual component of the illusion induction.

The four conditions were counterbalanced across participants according to a Latin Square design; the first participant would have an ABCD distribution, the second BDAC, the third CADB and the fourth DCBA, then the cycle is repeated. There was a total of eight trials, two trials per condition. The results for analyses were averaged across the two trials.

Participants reported the embodiment of a sixth finger using a Likert scale, in which -3 corresponded to "strongly disagree", 0 to "neither agree or disagree" and 3 to "strongly agree". The same questionnaire used in previous studies of the six-finger illusion (Cadete & Longo, 2020; Newport et al., 2016) was presented at the end of each trial:

A. It felt like I had six fingers on my left hand.
B. It felt like I had two little fingers on my left hand.
C. I felt a touch where I do not normally feel a touch.
D. I felt a touch that was not on my body.
E. It felt like I had an extra hand.

We asked participants to judge the perceived length of the little finger on all trials and asked them to judge the felt length of the sixth finger when they agreed that they had felt six fingers. Participants were also asked to indicate the felt length of the little finger and the sixth finger, using a slider apparatus similar to the one used in previous studies (Longo & Sadibolova, 2013; Mancini et al., 2011). A metal rod was attached on the top on a ruler with an orange dot at one end of the ruler. On each trial, we asked the participants to report the length of the perceived sixth finger twice. A sliding marker was placed at one end of the ruler first and at the other end of the ruler in the following report of perceived length, and vice-versa in the next trial. The values on the ruler were hidden, to be seen only by the experimenter. The participant was asked to slide the marker along the ruler rod, meaning that the length from the orange dot (the starting point of the ruler) to the location where the marker was placed would be the felt length from the knuckle to the tip of the finger. The reported length of the sixth finger, in cm, confirmed whether participants did feel a long and a short sixth finger. The measurements obtained in cm were averaged between the two reports on each trial, obtaining two values of trials of the same condition for analysis, as each condition was run twice. Those values were compared to the felt size of the little finger, demonstrated by the participant after each trial using the same method. At the end of the experiment, a photo was taken of the participant's hand with marks on the finger knuckles, positioned next to a ruler to extract the actual finger length by converting distances in pixels to cm. The actual length was obtained to compare with the felt length of both the felt little finger and felt sixth finger.

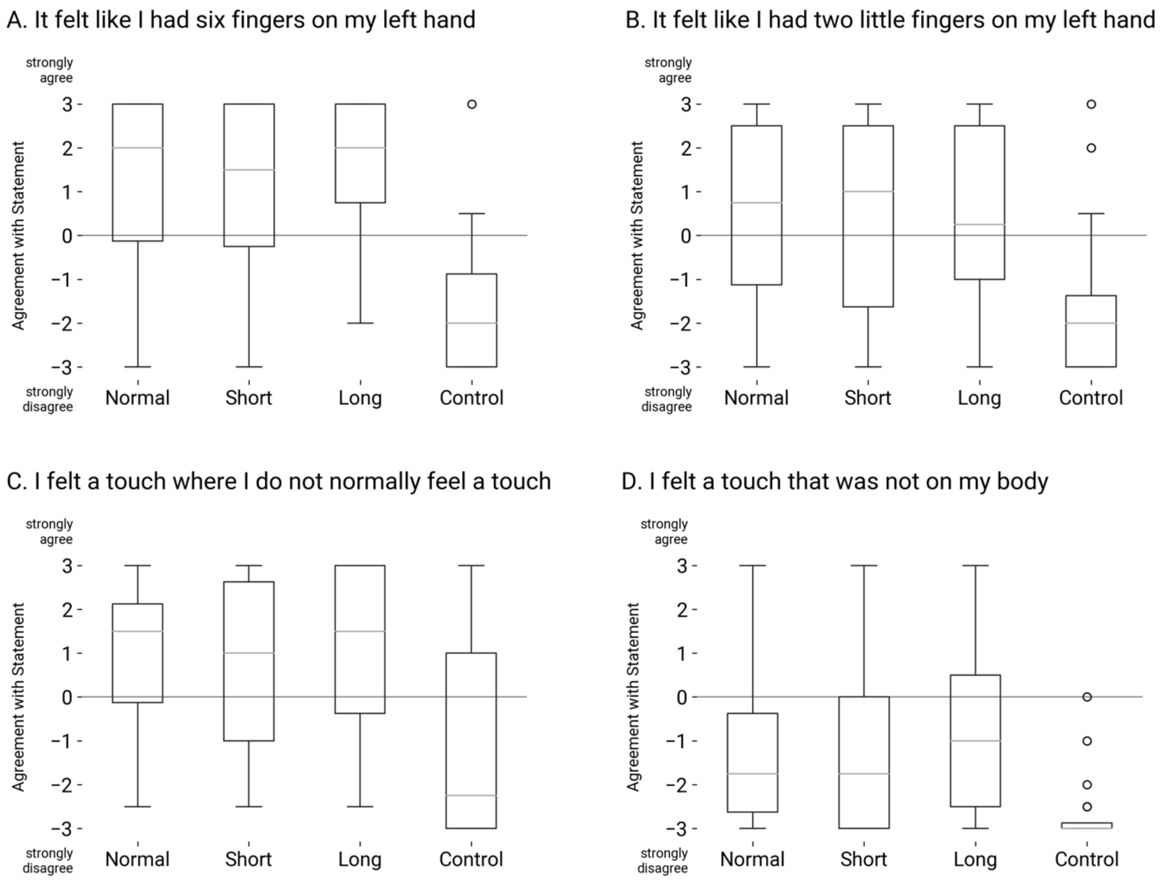
Analysis

Questionnaire

For each questionnaire item we conducted non-parametric Friedman tests of differences among repeated measures using the *Pingouin* (Vallat, 2018) and *Pandas* (McKinney, 2010) packages for Python 3. We conducted post-hoc tests, using the non-parametric Wilcoxon signed-ranks tests, with Scipy (Virtanen et al., 2020) for Python 3, to compare agreement in the long, short, and normal conditions with the control condition. Holm-Bonferroni corrections were applied. We also tested whether the means in each of the three conditions were significant against zero, the scale midpoint, using Wilcoxon tests.

Perceived finger length

When participants felt a sixth finger, we measured its perceived length. Five participants did not experience the sixth finger at one of the trials in a given condition, not producing data for every datapoint. Therefore, we analysed the difference between the length judgements for the felt sixth finger and those for the felt little finger, with a linear mixed-effects modelling (Baayen et al., 2008) using the *lme4* toolbox for R (Bates et al., 2015), as it does not require that data for each condition to be present for each participants. We also compared to the felt length of the little finger with the actual length of the little finger, with paired t-tests, to identify whether the length difference was significant in the short and long conditions and not significant in the normal condition. We applied Holm-Bonferroni corrections.



A. It felt like I had six fingers on my left hand

B. It felt like I had two little fingers on my left hand

C. I felt a touch where I do not normally feel a touch

D. I felt a touch that was not on my body

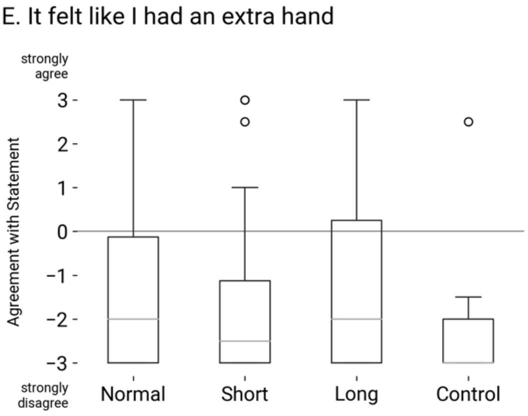


Figure 2: Boxplots for the reported experience of embodying a normal, short and long non-body part, using a 7-point Likert scale for each questionnaire item. There were two trials for each condition and the results were averaged. The sixth finger was embodied in all finger lengths, for the main items. Feeling a touch off the body and having an extra hand had negative scores. The horizontal light grey lines represent the median, the whiskers show the range of the data and the dots represent the outliers.

Results

Reported embodiment of the illusory sixth finger

Agreement with the questionnaire items for each condition is shown in Figure 2. To assess whether responses differed across the four conditions, we conducted non-parametric Friedman tests of differences. We used non-parametric Wilcoxon signed-ranks tests to compare long, normal and short condition against the control condition, all the p-values for the Wilcoxon tests are two-tailed and Holm-Bonferroni corrections were applied.

A Friedman test showed there was a significant main effect of condition for feeling a sixth finger, $Q(3) = 29.2$, $p < .001$. Compared to the control condition, the feeling of having a sixth finger on the left hand (Fig. 2a) was significantly stronger in each of the three other conditions (normal condition: $Z = 1.0$, $p < .001$, short condition: $Z = 1.5$, $p < .001$, long condition: $Z = 5.0$, $p < .001$). Compared to the scale baseline of zero, the feeling of having a sixth finger on their left hand was significantly different in each condition, (normal condition: $Z = 39.0$, $p = .02$, short condition: $Z = 39.5$, $p = .04$, long condition: $Z = 27.0$, $p = .006$).

There was a significant main effect of condition for feeling two little fingers, $Q(3) = 15.2$, $p = .001$. Compared to the control condition, the feeling of having two little fingers on the left hand (Fig. 2b) was significantly stronger in each of the three other conditions: (normal condition: $Z = 5.5$, $p = .002$, short condition: $Z = 3.0$, $p = .003$, long condition: $Z = 22.5$, $p = .003$). The scores for this item were not significantly different from zero: (normal condition: $Z = 59.5$, $p = .25$, short condition: $Z = 71.5$, $p = .21$, long condition: $Z = 49.5$, $p = .11$).

There was a significant main effect of condition for feeling a touch where it was not normally felt, $Q(3) = 22.6$, $p < 001$. Compared to the control condition, feeling a touch where it was not normally felt (Fig. 2c) was significantly stronger in each of the three other conditions (normal condition: $Z = 3.5$, $p < .001$, short condition: $Z = 16.0$, $p = .007$, long condition: $Z = 13$, $p < .001$). For this item, the scores were not significantly different from zero (normal condition: $Z = 40.0$, $p = .05$, long condition ($Z = 44.5$, $p = .02$), except in the short condition ($Z = 59.0$, $p = .14$).

There was a significant difference in the scores for feeling a touch out of the body, $Q(3) = 18.2$, $p < .001$. Compared to the control condition, feeling a touch out of the body (Fig. 2d) was significantly stronger in each of the three other conditions (normal condition: $Z = 10.5$, $p = .005$, short condition: $Z = 2.0$, $p = .006$, long condition: $Z = 3.5$, $p < 001$). The scores for this item were not significantly different from zero (normal condition: $Z = 56.0$, $p = .11$, short condition: $Z = 37.5$, $p = .10$, long condition: $Z = 59.5$, $p = .41$).

There were negative results for embodying an extra hand (Fig. 2e), as expected, and there was no significant difference between conditions for feeling an extra hand, $Q(3) = 4.79$, $p = 0.19$.

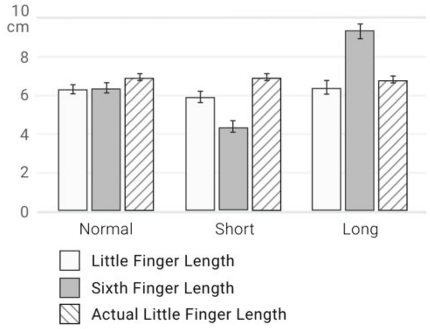


Figure 3: Participant's perceived length of their little finger and sixth finger, reported after each trial using a visual judgement task. This shows how long or short the participants felt the sixth finger was. Results show that the felt length was in accordance with the stimulus condition. The actual little finger length was measured at the end of the experiment. Error bars represent the standard error of the mean (SEM).

Felt lengths

Figure 3 shows how long or short the participants felt the sixth finger was in each condition. To assess whether participants felt a sixth finger with longer and shorter lengths, we compared the judged length of the little finger with the sixth finger for each condition, with a linear mixed-effects model. Q-Q plots showed the residuals are normally distributed in the three models, indicating the homoscedasticity of the data. In the normal condition, as expected, there was no significant difference between the felt length of the sixth finger and the little finger, $\chi^2 = 6.32$, $p = .1$. In the short condition, the felt length of the sixth finger was significantly different from the felt length of the little finger, $\chi^2 = 32.9$, $p <.001$. In the long condition, the felt length was also significantly different between the little finger and the sixth finger, $\chi^2 = 68.0$, $p <.001$.

We also tested whether participants' felt lengths of the sixth finger were significantly different from the felt little finger and the actual little finger with t-tests, for the short and long conditions, with Holm-Bonferroni correction. We compared the felt length of the sixth finger against the felt length of the little finger and not only its actual length, because judgments of finger length are known to underestimate true size (Longo & Haggard, 2012). In the normal condition, the felt sixth finger should have a similar length to the felt little finger, which was confirmed with no significant difference between them, $t(14) = -1.40$, $p = .181$, $dz = - 0.36$.

Participants felt like the sixth finger, in the short condition, was shorter than the felt little finger, $t(14) = -3.88$, $p = .001$, $dz = 1.00$. However, there was no significant difference between the felt length of the short sixth finger and the actual length of the little finger, $t(19) = -1.85$, $p = .084$, $dz = -0.41$, which was expected due to the underestimation of the length of our fingers, which is most pronounced in the little finger (Longo & Haggard, 2012). That distortion is present in the significant difference between the felt length of the little finger and its actual length, $t(19) = -2.74$, $p = .015$, $dz = -0.61$. This difference between felt and actual length of the little finger also occurred in the control condition, $t(19) = -3.46$, $p = .003$, $dz = -0.77$, but not in the long condition, $t(19) = -1.14$, $p = .288$, $dz = -0.26$.

As expected, in the long condition, participants felt a sixth finger significantly longer than the felt length of their little finger, $t(15) = -4.74$, $p = <.001$, $dz = -1.19$, confirming that participants did feel a long sixth finger, and that the felt length of the long sixth finger was indeed different from the felt length of the little finger.

Discussion

Our results provide further evidence that the experience of a supernumerary sixth finger can be induced using simple multisensory stimulation. To investigate whether the supernumerary finger is a copy of the little finger or if it has independent features, we tested whether the sixth finger with varied lengths would be embodied. If the sixth finger is a copy of the little finger, then they should be experienced as having the same features. In contrast to this prediction, our results showed that participants experienced sixth fingers both longer and shorter than they experienced their little finger. Participants agreed that they felt a sixth finger on their left hand, as well as to feeling two little fingers and a touch where they did not normally feel a touch, in the normal, short, and long conditions. Most critically, the reported length of the sixth finger differed systematically across conditions. In the long condition, participants judged the sixth finger as longer than the little finger, while in the short condition, they judged it as shorter. These results show we can embody a supernumerary finger with altered lengths, indicating that the representation of the supernumerary finger is flexible and has independent features. The sixth finger is not a copy of the little finger, or any of the fingers, as it can have distinct features.

The long and the short sixth finger scores were positive and significantly different from the control condition. The illusory somatosensory experience of an additional finger with unusual length, remaining throughout the stimulus, implies that we can experience sensations over non-body parts that do not resemble the shape of our own body parts. Research has shown we can embody non-body parts to some extent, such as in the rubber hand illusion, or an invisible hand (Guterstam et al., 2013), or even a sixth finger that we do not have (Newport et al., 2016). However, previous research has not documented differences in size or shape for embodied non-body parts. This investigation showed that tactile sensations are perceived to occur in a long or short extra finger, with a size that neither matches the estimation nor the true length of our actual fingers. This shows we can embody a supernumerary body part that is different from the existing body parts, with its own features. Participants disagreed with the item: "I felt a touch that was not on my body", although still significantly different from control condition, resembling the scores for the item "It felt like I had an extra hand". One interpretation of this result is that participants feel the touch as occurring on their own body, having embodied the sixth finger to some extent since they scored positively for feeling a sixth finger or six fingers on their left hand, but not for feeling a touch that was not on their body. Participants disagreed with feeling an out of the body touch, although they do not have a sixth finger and the sensation is localised on an empty space near the little finger, reinforcing the existing evidence that the illusory finger was embodied as part of their bodies. Our measures were explicit and perceptual. Further investigation adapting this illusion to a VR paradigm would allow the application of implicit tasks and to explore if the length variation has any effect at the sensorimotor level.

Participants also judged the lengths of the felt little finger and the felt sixth finger. As expected, in the long condition, the judged length of the sixth finger was longer than that of the little finger. Conversely, in the short condition the judged length of the sixth finger was shorter than that of the little finger. This implies that the felt length of the sixth finger corresponds to the size of the stimulus induced by the experimenter, and demonstrates that participants felt a supernumerary finger with varied lengths. The embodiment of body parts with distorted sizes is in line with studies showing the illusory embodiment of a long arm (Kilteni et al., 2012), a long nose (Lackner, 1988), a large belly (Normand et al., 2011), or a short finger (Ekroll et al., 2016). Here we showed that these length distortions can also be embodied in a supernumerary body part. This seems to indicate that the somatoperception system is using the same mechanisms both for the perception of our body and supernumerary body parts. In the same way that we can experience parts of our bodies extended, we can also feel a long or a short additional finger. Multisensory illusions have been used to explore bodily awareness and body representation flexibility (Ehrsson, 2020), investigating their underlying processes. The present study, particularly, highlights the mental process of reduplicating a limb, showing it is not creating a mere copy of a neighbour finger, but it carries the same flexibility that applies to existing body parts. The extent of this flexibility can be explored in future studies, assessing shape and other features, and whether a supernumerary finger has to resemble a finger at all.

Although both bottom-up, stimulus-driven, and top-down information from motor commands are integrated in the estimated position of the supernumerary limb, higher-level dysfunction of planning and motor intention seem to be playing a bigger part in it (Frith et al., 2000; McGonigle et al., 2002), since the felt position of the phantom extra limb mirrors the voluntary but not the passive movements of the copied limb (Hari et al., 1998; Staub et al., 2006). When patients with supernumerary phantom limbs intended to move the copied limb, it elicited the supernumerary limb, but if the movement was passive, removing the intention but maintaining the stimulus, such as someone else moving their limb, the illusion did not occur. It is unclear why there is a delayed replicated sensation from the copied limb (McGonigle et al., 2002), caused by brain damage after stroke, and why it is perceived as a supernumerary limb, rather than an extension of the existing limb or even a reminiscent sensation from a previous movement. Whereas the supernumerary phantom limb is more substantially supported by these top-down projections of planning and motor intentions, the supernumerary sixth finger induced in this study is an online, bottom-up representation that instantly emerges with multisensory manipulation. Although both bottom-up and top-down processing for body representation are eliciting a supernumerary body part, they may not share the same flexibility for its features. Further research is necessary to assess whether supernumerary phantom limbs are also independent from the existing limb or if they are a copy, unlike the online representation in the sixth finger illusion, i.e., whilst stimulation is ongoing.

Having supernumerary fingers can enhance our ability to manipulate objects, including gripping, grasping or manoeuvring. Two supernumerary robotic fingers were applied to the spared hand of an amputee, allowing the subject to operate with extended ability (Wu & Asada, 2014). These robotic fingers are longer than the normal fingers, allowing the user to grip objects that are big, heavy or odd-shaped, that would not be gripped by the normal fingers. For a review on artificial body augmentation see Eden et al. (2021). A congenital supernumerary finger also increased the neuromechanics and manipulation abilities in two individuals who were born with a sixth finger between the thumb and the index finger, having specific nerves and muscles, as well as a distinct cortical representation (Mehring et al., 2019). These individuals were tested and performed better than five-fingered subjects, and were able to perform complex tasks using the six fingers, that are not feasible without the sixth finger.

Augmentation technology, such as a robotic sixth finger, could benefit from being embodied, becoming more intuitive, adaptive, and have greater motor control (Makin et al., 2017), and one constraint to its embodiment that is discussed by the authors is the inflexibility of body ownership, evidenced by the permanence of the cortical representation of the individual fingers of a hand that was amputated decades before (Kikkert et al., 2016). However, it is possible that the embodiment of supernumerary body parts does not require dramatic cortical plasticity, since we may have a default system for the representation of a sixth finger or supernumerary body parts. The distinct cortical representation for a congenital supernumerary finger (Mehring et al., 2019) shows the flexible accommodation of supernumerary body parts, as well as flexibility in incorporating enhanced ability. However, this physical anomaly is congenital, and therefore, the nervous system of these six-fingered-individuals was shaped by it throughout their lives. Such flexibility may not transfer to embodying a supernumerary robot finger as adults. Further research is necessary to investigate which mechanisms and cortical mapping are allocated to the immediate embodiment of a supernumerary finger or body part.

A robotic sixth finger that is longer than the average finger length can enhance its functionality and augment the whole hand manipulation capacity (Wu & Asada, 2014), but little is known whether a supernumerary finger with a different length from the body configuration could compromise its embodiment. Our results, however, show that a long supernumerary finger, double the length of the average little finger, actually increased the experience of embodiment of the supernumerary finger, which might be promising to the embodiment of robotic supernumerary fingers with enhancing features.

Supplementary material

All of the raw data in this manuscript can be found on the Open Science Framework repository at:

https://osf.io/akdes/?view_only=9e489b7d495a4672886d9f8f39c78000.

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