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Curved sixth fingers: Flexible representation of the shape of supernumerary body parts

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Abstract

A recent perceptual illusion induces the feeling of having a sixth finger on one's hand. It is unclear whether the representation of supernumerary fingers is flexible for shape. To test whether we can embody a sixth finger with a different shape from our own fingers, we induced a sixth finger which curved laterally though 180°. Participants reported feeling both curved and straight sixth fingers, depending on the stimulation pattern. Visual comparative judgements of the felt curvature of the supernumerary finger, showed means of 182° in the curved condition, and 35° in the straight condition. Our results show we can feel a supernumerary finger with different shape from our actual fingers, indicating that shape is represented flexibly in the perception of our hands. This study also adds evidence to the independence of the supernumerary finger from the actual fingers, showing we can represent the sixth finger with its own shape.

The flexibility of bodily experience has been documented with studies showing we can embody body parts and full bodies with altered bodily properties, such as age (Banakou, Groten, & Slater, 2013; Tajadura-Jiménez, Banakou, Bianchi-Berthouze, et al., 2017), size (Ehrsson, Kito, Sadato, et al., 2005; Kilteni, Normand, Sanchez-Vives, et al., 2012; Piryankova, Wong, Linkenauger, et al., 2014; Preston & Ehrsson, 2016), or visibility (D'Angelo, di Pellegrino, & Frassinetti, 2017; D'Angelo, Maister, Tucciarelli, et al., 2021; Guterstam, Abdulkarim, & Ehrsson, 2015). These alterations to the perception of our body can be easily induced with Virtual Reality (VR) and multisensory illusions, such as the Rubber Hand Illusion (RHI, Botvinick & Cohen, 1998), in which we embody an artificial rubber hand as our own. Changes to bodily perception are not limited to body configuration, or to embodying artificial limbs such as in the RHI that, nevertheless, resemble the shape of our body parts. Recent studies show we can embody extra body parts: instead of having an altered perception of our body parts, these studies show we can also experience having supernumerary body parts. For example, Guterstam, Petkova and Ehrsson (2011) induced the somatosensory experience of having a third arm; Newport and colleagues (2010) created the illusion of having two left hands, and more recently developed the illusion of having a supernumerary finger on one's hand (Newport, Wong, Howard, et al., 2016). The embodiment of four hands was also induced (Chen, Huang, Lee, et al., 2018) in a paradigm that includes the participant's two actual hands and two supernumerary fake hands facing the participant. Not only can we embody extra body parts that resemble our own, such as a duplicated arm, but also extra body parts that greatly differ from ours, such as a tail (Steptoe, Steed, & Slater, 2013).

Newport and colleagues (2016) created an illusion that induces the feeling of having a sixth finger on one's hand. The experimenter strokes both hands synchronously, while the participant sees the reflection of one hand in the mirror, resembling the hand that is hidden behind the mirror. When the hidden little finger is stroked at the same time as empty space next to the reflected hand, the participant feels a sixth finger for a fleeting moment.

We recently showed that by changing the pattern of stimuli of Newport et al.'s six finger illusion (Newport, Wong, Howard, et al., 2016) to a double back and forth stroking along the participant's fingers, followed by twenty strokes on the sixth finger location simultaneously to the hidden hand's little finger, we were able to maintain the illusion of having a sixth finger for an extended period of time (Cadete & Longo, 2020). This suggests an enduring representation of the supernumerary finger.

Having the sixth finger illusion lasting longer in time allowed us to manipulate the perceived physical properties of the supernumerary finger. One possibility is that supernumerary body parts are represented as a copy of an existing body part, of whether they can have different features. When one feels an illusory supernumerary finger, it may be perceived as identical to one of their fingers, or it may feel different, such as longer or wider. It remains unclear from these results whether we can embody a supernumerary body part that has its own features, distinct from the features of the actual body part. Some evidence comes from patients that have supernumerary phantom limb syndrome (Halligan, Marshall, & Wade, 1993; Halligan & Marshall, 1995; McGonigle, Hänninen, Salenius, et al., 2002; Staub, Bogousslavsky, Maeder, et al., 2006), a condition in which patients feel a duplicated limb, such as two left arms or three hands. In these patients, the extra limb seems to resemble the same size and shape of the existing limb, which suggests that it may be a duplication of the existing limb, rather than a distinct body part, with independent features.

To investigate whether supernumerary body parts can have independent features or are represented as a copy of the existing limbs, we tested if we can embody an illusory supernumerary sixth finger with varied lengths. We used the continuous sixth finger illusion, changing the visual-tactile stimuli to induce a sixth finger with altered lengths (Cadete & Longo, 2022). When stroking of the space where the sixth finger was perceived was made longer or shorter than actual finger size, participants reported feeling a long and a short sixth finger, respectively, and judged its length with half or double the size of the average little finger. Critically, however, the perceived length of the actual little finger did not change in these conditions, which indicates that the sixth finger is not a copy of the little finger, but a distinct body part which can have features unlike those of any of the actual five fingers.

The data available at present suggest two contrasting hypotheses. One hypothesis is that body size representation is especially flexible when compared to representation of other properties of the body, such as its shape. A clear motivation for this hypothesis is that, as our bodies grow throughout childhood to adulthood, a body representation that is flexible for body size, and, particularly, the length of our limbs, would assist a set of functional abilities (Gottwald, Bird, Keenaghan, et al., 2020). It would support us to move, sense and perceive the body more accurately as it grows, as well as making accurate measurements of the surrounding world based on the size of our body parts (Linkenauger, Leyrer, Bülthoff, et al., 2013). Unlike size, shape is fairly constant throughout development. We retain the overall humanoid form we develop in gestation – we do not, for instance, gain an extra limb during our postnatal development. Moreover, drastic changes in body shape are typically restricted to specific interventions, such as cosmetic or reconstructive surgery, amputation or oedema.

An alternative hypothesis is that representation of body shape is as flexible as representation of body shape. This hypothesis would be compatible with the more general flexibility demonstrated in individuals representing their bodies as, e.g., older than they are, or invisible, or having more parts than they actually have. Indeed, although drastic changes to body shape do not naturally occur, the existence of supernumerary phantom body parts shows that this does not preclude individuals from representing themselves as having a non-humanoid form. However, there is clearly a dearth of directly relevant evidence here, as there have been no attempts to systematically test the flexibility of body size and shape using the same paradigm and procedure.

In the present study we investigated whether we can embody a finger with a different shape than our actual fingers. To this end, we tested and compared two conditions in which the stroking of the sixth finger is either straight and curved. The straight condition is similar to the condition which produced clear experiences of an enduring sixth finger in our previous experiments (Cadete & Longo, 2020, 2022). In contrast, in the curved condition we changed the visual-tactile stimuli, stroking the empty space next to the reflected hand (i.e, the *sixth* finger location) in a curved shape, subtending 180º of arc (see Figure 1). After each trial, participants reported the embodiment of a straight and a curved sixth finger, using a Likert scale to agree or disagree with a set of questionnaire items about their experience of the sixth finger and its perceived shape. We also asked participants to report the felt shape of the sixth finger and their actual little finger, using a panel with a range of images displaying a straight finger in the first figure and progressively more curved fingers up to the seventh finger, with an angle of 270º. This method for reporting a felt bodily property with visual judgements is adapted from a study on the invisible hand illusion (Guterstam, Abdulkarim, & Ehrsson, 2015).

We predicted that participants would embody a curved sixth finger in the curved condition, but a straight sixth finger in the straight condition. These results would show that we have a flexible body representation of hand shape and that we can embody a supernumerary body part with a different shape from our actual body parts. All procedures, including design, sample size, methods, materials, hypotheses and analysis plans were pre-registered on the Open Science Framework (OSF, osf.io/wdvr6).

Methods

All methods were in line with our pre-registered plans.

Participants

Twenty people ($M \pm SD$ = 32.7 ± 2.1 years; 14 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 but one, were right-handed, as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971), M = 80, range from 20 to 100. All participants underwent the illusion with the same hand.

In our previous study (Cadete & Longo, 2022), for the main questionnaire item "It felt like I had six fingers on my left hand", there was an effect size of d_z= 1.26 in the analysis comparing the condition for normal sixth finger length with the control condition, which consisted in stroking the seen little finger instead of the empty space near the reflected hand, and does not induce the illusion.

As we are comparing the felt shape of the sixth finger with the actual little finger, we want to have a sample size that is well powered for this analysis. In our previous study we tested whether the felt length of the sixth finger was significantly different from the felt size of the actual little finger. In a condition that induced a long sixth finger, the effect size of that contrast was of d_z= 1.19.

A power analysis using G*Power 3.1 (Faul, Erdfelder, Lang, et al., 2007) , with a 2-tailed alpha of 0.05 and power of 0.95 indicated that 11 participants were required, when considering the effect size of d_z= 1.26 and 12 participants when considering an effect size of d_z= 1.19. Thus, our sample size of 20 should be well powered to replicate the illusion (straight condition) and to probe the embodiment of a curved six finger, both in questionnaire data and visual judgements data.

Design and Procedure

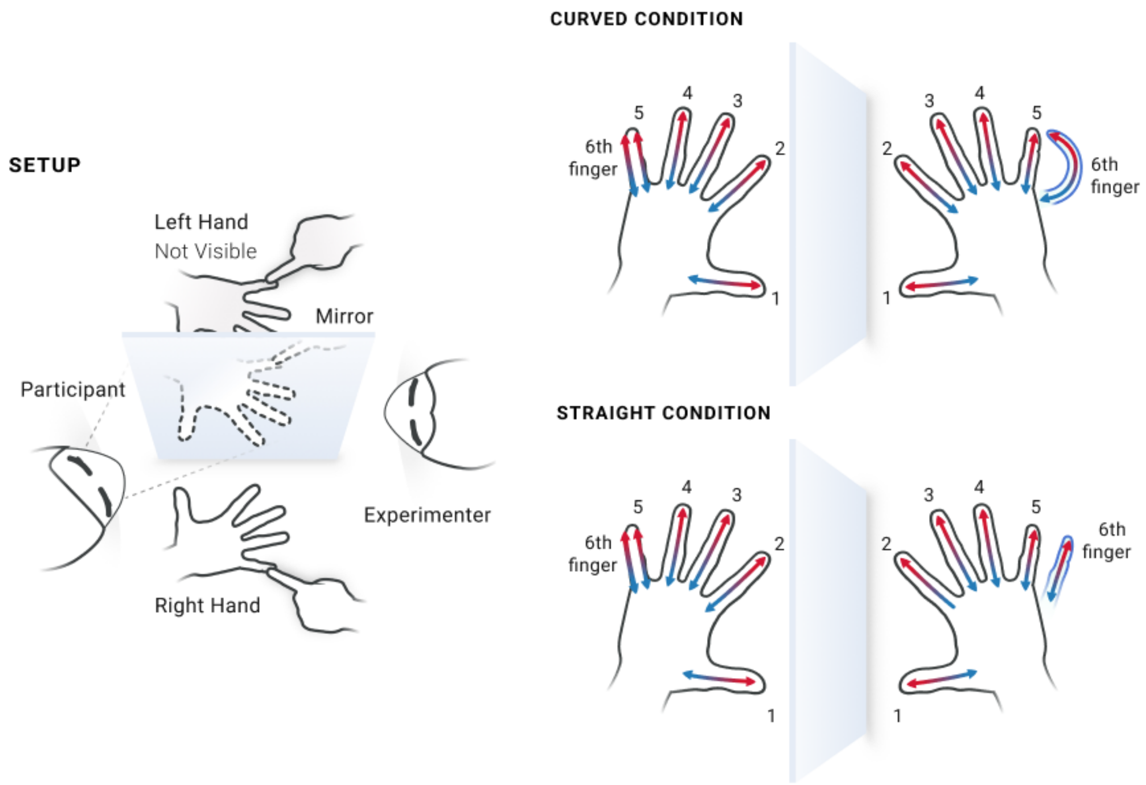


Fig. 1: Setup and procedure for inducing a sixth finger (Cadete & Longo, 2020; Newport, Wong, Howard, et al., 2016). The participant sat midline to the mirror and placed a hand to each side of the mirror. We asked the participant to look in the mirror throughout the trials, where they saw their right hand

reflected, resembling their left hand. We stroked each finger synchronously, thumb with thumb and so forth. We then stroked the inner lateral side of the hidden little finger at the same time as the top of the seen little finger followed by twenty strokes on the outer lateral side of the hidden little finger, at the same time as the empty space next to the seen little finger. In the curved condition, these twenty strokes on the sixth finger had a curved shape, with an angle of 180º, in a semi-circle shape. In the straight condition, these 20 strokes were straight instead of curved, inducing a straight sixth finger, with the same shape of the actual little finger. This condition controlled for shape.

We followed the same experimental procedure and paradigm of Newport and colleagues' (2016) sixth finger illusion, using the pattern of stimulation version we developed in our previous study, that allowed the illusion to be felt for a long duration (Cadete & Longo, 2020). Similar to Newport and colleagues' 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. The mirror's 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 17 cm from the mirror, marked by two yellow dots where they were asked to place the tip of each index finger. The participant was also asked to look at the hand reflected in the mirror throughout each trial.

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 reflected little finger, i.e., the perceived location of the sixth finger. The double stroking in each finger lasts between 1.6 s and 2.2 s, and the last twenty strokes last for 16 s and 22 s. These twenty strokes had a curved shape, covering 180º of arc, similar to a semi-circle shape (Figure 1). The speed of stroking is spatially and not temporally locked, meaning the speed of the little finger stroking is slower than the stroking in the curved empty space, so that the end of the stroking of the curved *sixth* finger matches the fingertip of the hidden little finger. In the straight condition, the twenty strokes had a straight shape instead of curved, using the same pattern of stimuli of the normal condition in our previous studies (Cadete & Longo, 2020, 2022). The length of the stroking was matched to the length of the participant's actual little finger, from the knuckle to the tip of the finger, in the straight condition. In the curved condition, the radius of the arc also had the same length as the participant's actual little finger. We chose a stroking length that is similar to the participant's actual little finger, so that the main distinctive feature was the one we are manipulating, shape/curvature.

Randomisation

The two conditions were counterbalanced in an ABBA sequence. There was a total of four trials, two trials per condition. The results for analyses were averaged across the two trials. The conditions were also counterbalanced across participants, with the second participant having a BAAB sequence, and the third again with an ABBA sequence, and so forth.

Questionnaire

We applied the same reporting method for agreement with the questionnaire items used in Newport and colleagues' study and our studies using the sixth finger paradigm (Cadete & Longo, 2020, 2022; Newport, Wong, Howard, et al., 2016). At the end of each trial, participants reported the embodiment of a sixth finger and its properties using a

Likert scale, in which -3 corresponds to "strongly disagree", 0 to "neither agree or disagree" and 3 to "strongly agree". The first questionnaire item assessed the embodiment of the illusory sixth finger, similar to the first questionnaire item used in this paradigm's studies cited above:

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

As the first questionnaire item in Newport's study has shown to be the one that most captures the embodiment experience felt by the participants, in their study and in our two studies using this illusion (Cadete & Longo, 2020, 2022; Newport, Wong, Howard, et al., 2016), we only used this question. We have not used the other four questionnaire items as our aim was to assess the embodiment of a bodily property of the sixth finger and not focusing on the overall embodiment of the sixth finger, which was already validated in the mentioned studies.

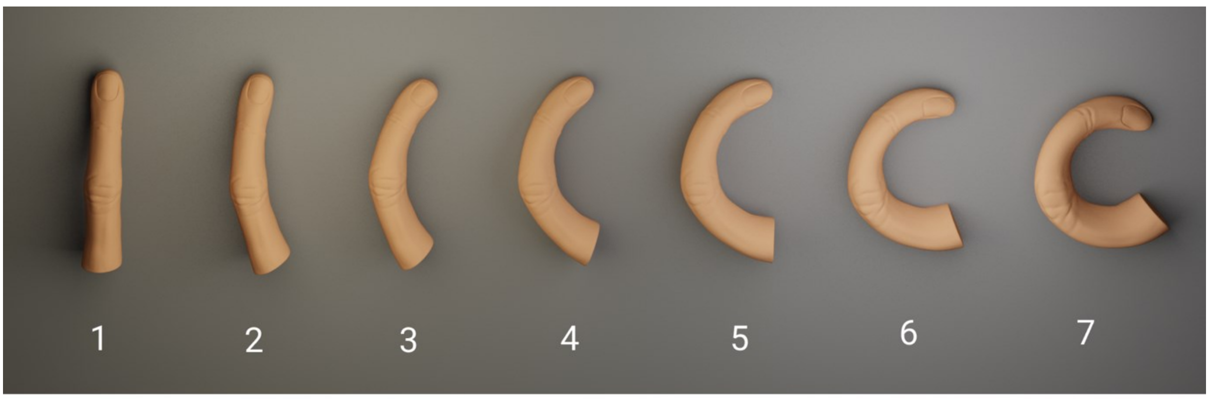
When the participant gave a positive rating in the previous questionnaire item (from 1 to 3 in the Likert Scale), agreeing to feeling a sixth finger, we followed-up with 3 more questionnaire items:

2. It felt like I had a curved sixth finger.
3. It felt like I had a straight sixth finger.
4. It felt like I had a finger with a shape that is different from my actual fingers.

Visual judgements

In order to assess the perceived shape of the sixth finger, we used a visual judgement task, analogous to that used in the invisible body illusion to capture the experience of having a transluscent body (Guterstam, Abdulkarim, & Ehrsson, 2015).

Guterstam and colleagues used a range of schematic drawings with 7 figures of bodies ranging from a normal visible body to increasingly transparent bodies. After the trial, participants used the drawings with body-figures with different degrees of visibility to report which of the seven bodies better resembled their experience during the experiment. We used a similar question and a similar visual stimulus (Fig. 2) adapted to the bodily property we were testing, to measure the participants' experience of embodying a body part with a different shape. We presented an image (24 x 10.5 cm) with seven fingers with different degrees of curvature, from straight to curved in a ratio-scaled measure with varying degrees of arc subtended, on a screen, at a distance of 50 cm from the participant. The fingers were modelled using the 3D software Blender (Blender Foundation, Amsterdam, Netherlands), and each 3D finger was shaped to have a specific curvature degree, using an empty object linked to the bend modifier applied to the finger mesh. Each bend modifier was attributed a numeric curvature degree, specified below Fig.2. We asked participants: ‘‘How did you experience your **little/sixth** finger? On the screen there are seven schematic figures of your finger during the experiment. Please select the finger on the screen which best corresponds to your experience.’’



0°   45°   90°   135°   180°   225°   270°

Fig. 2: The visual stimulus for participants to judge the felt shape of the sixth finger and their little finger. The stimulus consisted of a panel with 7 fingers with different shapes. Finger 1 is straight, finger 5 has a 180º angle, in a semi-circle shape, and finger 7 has an angle of 270º. The angle number of each finger was not displayed to participants. We used left fingers because that is the finger that is experienced in the mirror, and the hand to which the felt sixth finger will be mapped onto, and not a right finger which is where the curved shape is traced out by the experimenter.

When the participant answered positively to feeling a sixth finger, we asked the participant to judge the shape of the sixth finger with a visual judgement task, using a range of 7 images of a human finger (Fig. 2) with a straight finger to a progressively rounder/curved finger, up to an extremely curved finger with an angle of 270º. The finger shape that is coded as number 5 is a full round shape with 180º, matching the visual-tactile stimulus induced in curved condition. The angle of each finger displayed in the panel is presented in Figure 2. This information on the angle degrees was not available to the participants.

The panel with the range of images was used by participants to indicate which image in the scale from straight to curved it felt like the sixth finger was, in both conditions. Using the same panel, the participants also reported the felt shape of their actual little finger. The results of the visual judgments for the actual finger were compared with the results for the sixth finger. The visual judgement results of the curved finger condition were compared with the results of the straight condition to assess whether the manipulation induced a curved-shaped finger for the control condition.

Analysis

Analyses were in line with our pre-registered analysis plans, with the exception of the visual judgments of perceived finger curvature, as described below.

Questionnaire

The first questionnaire item was only used to assess if the participant was eligible for the follow-up questions, and was not statistically analysed beyond its descriptive statistics. When participants felt a sixth finger, we conducted the follow-up questions. Six participants did not report experiencing a sixth finger, in both conditions, not producing data beyond the first questionnaire item, according to our design. Therefore, we analysed the difference between the curved and the straight conditions in the follow-up questions with a linear mixed-effects model (Baayen, Davidson, & Bates, 2008) using the lme4 toolbox for R (Bates, Mächler, Bolker, et al., 2015), as it does not require that data for each condition be present for each participant. We conducted a similar analysis for the follow-up questions in our previous studies (Cadete & Longo, 2020, 2022). We modelled condition and participants as random effects, fitting in the model variability brought by condition, with random intercepts and slopes to allow for a different effect of each condition in the embodiment scores. We then compared a simple model without random effects with the mixed-effects model, to assess which model had a better maximum likelihood estimation, which inform us if the variability in scores is better explained by the effect of condition (Barr, Levy, Scheepers, et al., 2013). If the random-effects model explains more variance than the simple model, we can assume there is a significant difference between the straight and curved conditions. We used R with RStudio to conduct these analyses, using the lme4 toolbox for R (Bates, Mächler, Bolker, et al., 2015).

Perceived finger curvature

In our pre-registration document, we wrote that we would analyse the visual comparison judgments of finger curvature using a t-test to compare the curved and straight conditions. Unfortunately, however, this analysis plan did not take account of the fact that judgments were obtained in each of these conditions for both the sixth finger and for the actual little finger. We therefore conducted a 2x2 repeated-measures analysis of variance (ANOVA) with condition (curved, straight) and finger (sixth finger, little finger) as within-subjects factors.

To compare the visual judgements for the felt sixth finger and those for the felt little finger in each condition, we conducted linear mixed-effects models, as well, to assess whether there was a significant difference between the judgements for each finger in the two conditions: straight and curved. We also used linear mixed-effects models to test if there was a significant difference between the same finger in both conditions, specifically between the little finger in curved and straight conditions and the sixth finger between the same two conditions. The visual judgement task is a measure of perceived shape of the finger in terms of arc subtended, from 0º up to 270º (finger number 7), if participants feel the finger with an 180º arc (finger number 5), it means they felt the finger curved, and 0º means they felt the finger straight. The analysis plan is similar to our previous study, where we used linear mixed-models to compare the felt lengths of the sixth finger and little finger in four conditions (Cadete & Longo, 2022). Additionally, we converted these results to ratios to measure gain. In this experiment, gain is quantified as the difference in shape from the actual little finger, measured by the increase of arc degrees.

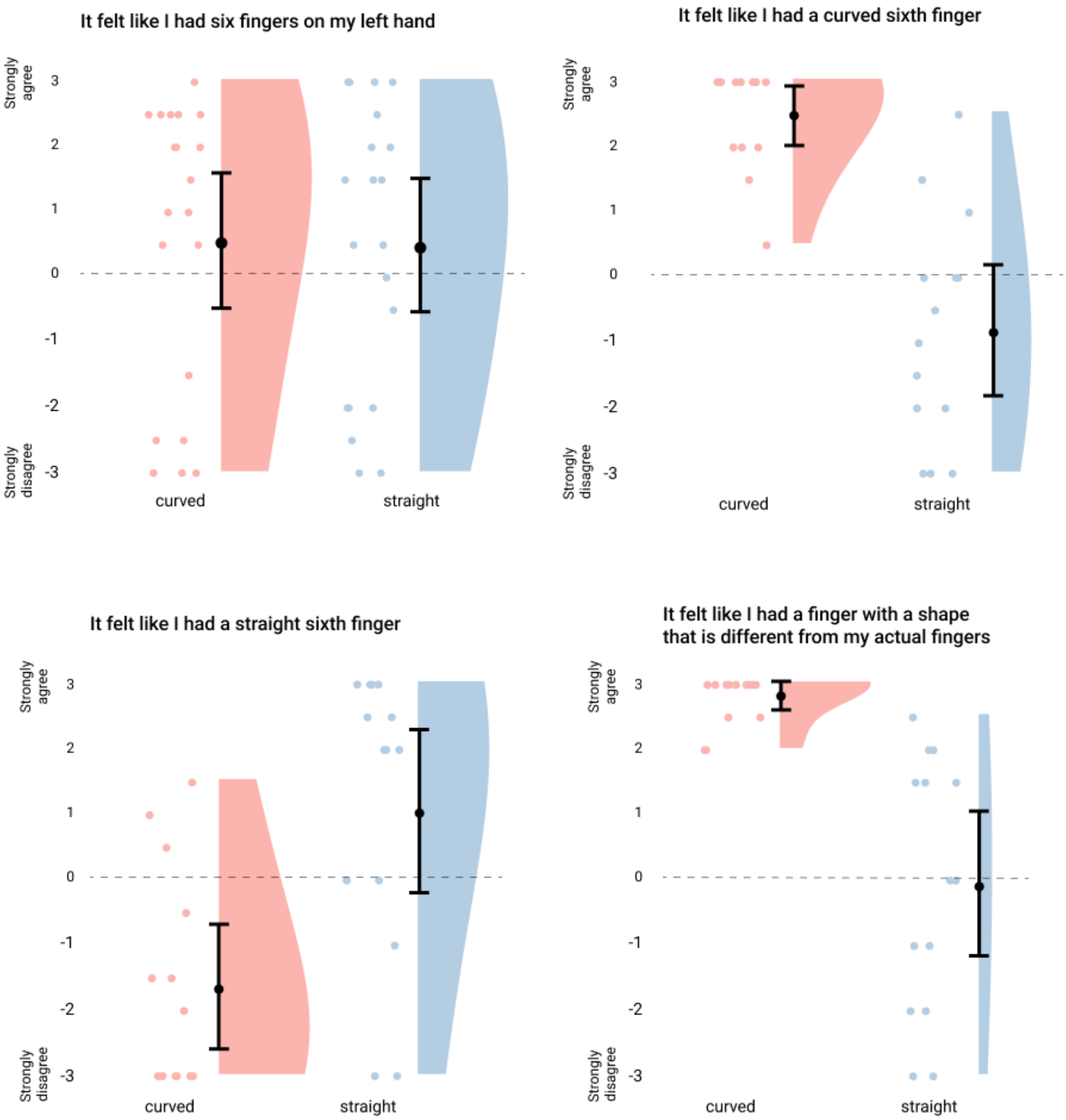


Fig. 3: Mean scores for the reported experience of embodying a sixth finger that is curved, straight and with a different shape, using a 7-point Likert-type scale for each questionnaire item. There were two trials for each condition and the results were averaged. Participants embodied a curved finger in the curved condition and not in the straight condition. In the straight condition, participants embodied a straight finger and not curved. Participants also reported feeling a finger with a different shape from their actual fingers, in the curved condition. The raincloud plots show the distribution of the data (Allen,

Poggiali, Whitaker, et al., 2021), with dots represent individual data scores and the clouds show the probability density of responses in each condition. The bars represent the confidence intervals and the central dot marks each condition mean.

Results

Reported embodiment of a curved and straight sixth finger

Agreement with the questionnaire items for each condition is shown in Figure 3. To assess whether the curved condition was significantly different from the straight condition in the follow-up questions, we conducted mixed-effects models. Q-Q plots showed the residuals are normally distributed in the three models, indicating the homoscedasticity of the data. Feeling a curved sixth finger (M = 2.50, SE = 0.21) scored significantly higher than feeling a straight finger (M = -0.79, SE = 0.47) in the curved condition,$\chi^2(1) = 26.7$, p <.001. Feeling a curved sixth finger (M = -1.68, SE = 0.44) scored significantly lower than feeling a straight finger (M = 1.14, SE = 0.58) in the straight condition, $\chi^2(1)= 15.5$, p <.001. Feeling a finger with a different shape from the actual fingers scored significantly higher in the curved condition (M = 2.79, SE = 0.10), than in the straight condition (M = -0.07, SE = 0.52), $\chi^2(1) = 21.2$, p <.001. These results confirm our prediction, showing that participants felt a curved sixth finger in curved condition, but not in the straight condition. In contrast, participants felt a straight finger in the straight condition and not in the curved condition. Participants also felt like they had a finger with a shape that was different from the other fingers, when we induced the curved sixth finger, significantly more than when we induced a straight sixth finger.

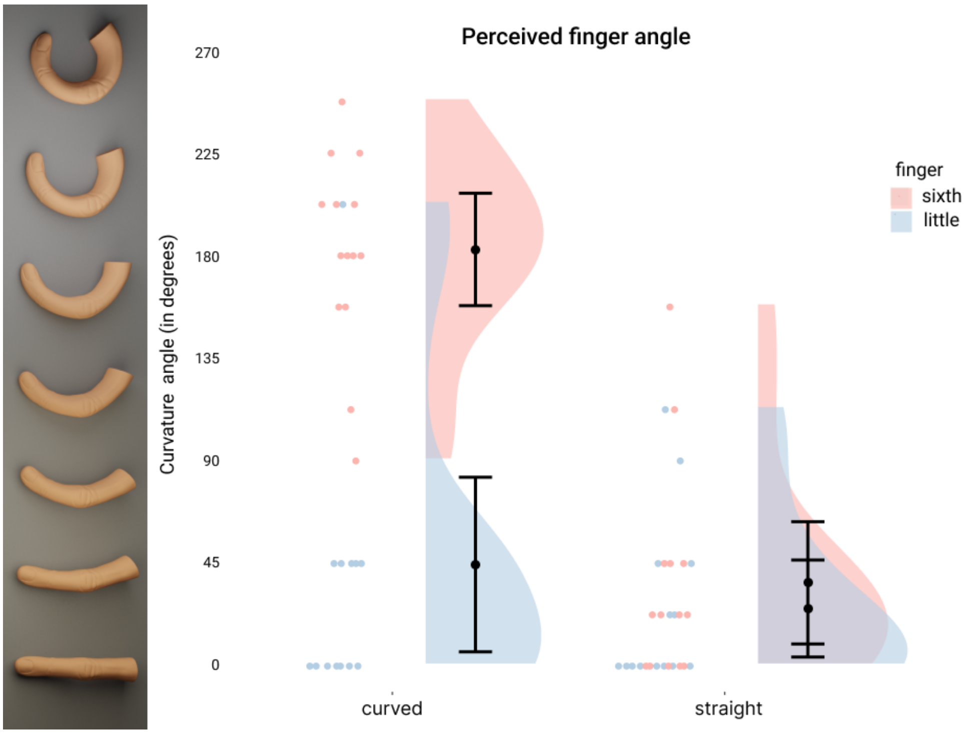


Figure 4: Participant's perceived curvature of their little finger and sixth finger, reported after each trial using a visual judgement task. This shows how curved the participants felt the sixth finger and little finger were, in angle degrees. Results show that the felt curvature was in accordance with the stimulus condition. Participants felt a sixth finger with a mean of 182° in the curved condition, opposed to 35° in the straight condition. The felt curvature of the little finger and the sixth finger in normal condition are similar, in contrast with the curved condition, with participants feeling a curved sixth finger while experiencing their little finger straight. Dots represent individual data scores and the clouds show the probability density of responses in each condition. The bars represent the confidence intervals and the central dot marks each condition mean.

Felt curvature

Figure 4 shows how curved or straight the participants felt the sixth finger and the little finger were in each condition. We conducted a 2x2 repeated-measures ANOVA with condition (curved/straight) and finger (little/sixth) as factors, to assess the difference in the felt curvature across conditions. There was a significant effect of condition, $F(1,13) = 65.1$, $p < .001$, $\eta_p^2 = .834$, and finger $F(1,13) = 38.8$, $p < .001$, $\eta_p^2 = .749$ in the finger felt curvature. There was also a significant interaction between condition and finger, $F(1,13) = 48.6$, $p < .001$, $\eta_p^2 = .789$, since the sixth finger is perceived significantly more curved than the straight finger in the curved condition but not in the straight condition.

We then compared the pairs of means for how curved or straight a finger felt, between the little and sixth finger in each condition, with a mixed-effects model, modelling finger as a condition. In other words, we assessed whether the curvature of the sixth finger was significantly higher than the little finger, in both conditions. The sixth finger was felt significantly more curved (M = 182°, SE = 11.4) than the little finger in the curved condition (M = 43.4°, SE = 17.7), $\chi^2(1) = 28.1$, $p < .001$. In contrast, in the straight condition there was no significant difference $\chi^2(1) = 1.13$, $p = .29$ between the felt curvature of the little finger (M = 24.1°, SE = 9.86) and the sixth finger (M = 35.4°, SE = 12.4).

We also compared directly the felt curvature of the 6th fingers in the straight and curved conditions, to verify if the curved condition significantly increased how curved the 6th finger felt. The sixth finger felt curvature in the curved condition was significantly higher (M = 182°, SE = 11.4) than in the straight condition (M = 35.4°, SE = 12.4), $\chi^2(1) = 38.9$, $p < .001$. To assess whether the curved finger illusion modulated the experience of one's actual finger, we also compared the felt curvature of the little fingers in both conditions. We did not identify a significant difference for the little finger's curvature $\chi^2(1) = 2.3$, $p = .13$, between the curved (M = 43.4°, SE = 17.7) and the straight condition (M = 24.1°, SE = 9.9).

To measure the gain of the perceived bodily experience of the curved sixth finger induced in this illusion, we calculated its ratio. If zero degrees is the baseline and 180° is the maximum of curvature induced, and participants reported feeling a sixth finger with a mean of 182° in the curved condition, this is an overall gain of 1.01, or in percentages 101%.

Discussion

To investigate whether shape is a flexible bodily property, we tested whether a curved sixth finger could be embodied. If we can feel a sixth finger with a different shape than our own fingers, it means the hand's mental representation is flexible for shape. Our results show we can embody a curved sixth finger when the visual stimulus is induced in a curved shape, with participants reporting feeling a curved sixth finger in the curved condition and not in the straight condition. Participants also reported the felt curvature of the supernumerary illusory finger with visual judgements. When presented with a set of seven finger images with different angles of curvature from 0° to 270°, participants reported which finger better corresponded to their experience during the trial. Critically, our result of a felt curvature mean of 182°, matched the prediction of participants embodying a 180° degrees sixth finger in the curved condition. This shows we can feel a curved sixth finger, with a different shape from the little finger. Participants also agreed to feeling a finger with a different shape from their actual fingers when we induced a curved sixth finger.

We are able to place our fingers in a somewhat curved position by curling our fingers. However, the shape of the felt curved sixth finger is curved laterally to the actual straight fingers and straight hand, placed on the table, inducing a finger that would be naturally curved, without bending the finger articulations. Our results show that not only can we feel like we have a curved finger, but also that this finger can have biomechanical violations, and altered physical structures, such as different muscles, bones and tendons. This is also evidenced by the visual judgements using the 3D set of fingers, which were modelled with a lateral curvature with a range of increasing angles, with participants identifying feeling a finger with a mean of 182° curvature. Feeling a sixth finger that violates the biomechanical constraints of our fingers, points to clues on the processes and resources the bodily perception of a supernumerary finger is recruiting. We simulate the rotation of our hands to match seen rotated hands (Parsons, 1987), and we peak in error rates and reaction times at 180° rotation from the position of our hands (Cooper & Shepard, 1975), *i.e.*, when we see hands that are in opposite direction of our own. This is due to biomechanical constraints, and it shows that we use our body template with proprioceptive information of its position, for motor imagery, that is, imagining we are performing a movement with our body. Spinal cord injury patients do not show this biomechanical constraint disadvantage; it seems they are not rotating their body representation to match the rotated seen hands (Fiori, Sedda, Ferrè, et al., 2014), showing that sensory and motor signals, which are partially or totally absent in these patients, influence motor imagery. Body image, on the other hand, seems to be maintained after sensory and motor loss, with patients with varied levels of spinal cord injury sharing the same bodily distortions (Fuentes, Pazzaglia, Longo, et al., 2013). It is unknown whether motor imagery is involved in the curved sixth finger. If it is, biomechanical constraints could impact the strength of the illusion or even prevent it, which did not occur in this study. However, it may be that rotation of the hands is more implausible or strenuous for motor imagery than a curved finger, especially the inward curvature we used in the stimulus, since little fingers naturally curve inwards to different degrees in healthy participants (Flatt, 2005).

In our previous study we demonstrated that we can embody a long and a short sixth finger (Cadete & Longo, 2022), simultaneously to feeling our actual little finger with a normal size, which suggests the supernumerary finger is not represented as a copy of the actual finger, but independently, with its own features. This study provides further evidence to this claim, as our results show we can feel a curved sixth finger, with a shape that is different from the shape of our fingers. If the sixth finger was represented as a copy of the actual finger, the illusion would either fade when presented with a curved visual stimulus, or participants would feel a straight finger, in the same position and shape as the other fingers. Our results, however, show participants felt a 182° curved sixth finger on their left hand.

In support of how different from the actual fingers the sixth finger can be, as evidence of its independence from the representation of our own fingers, we measured its gain ratio, showing that participants felt the sixth finger was 101% more curved when compared to a straight finger with zero degrees of curvature. Also, participants felt a straight little finger at the same time as they felt a curved sixth finger, when we induced the curved sixth finger illusion, showing that the actual and the supernumerary fingers can have different shapes simultaneously. Moreover, feeling a curved extra finger did not modulate how participants experienced their actual finger. Although they felt their actual little finger as being more curved in the curved condition, compared to the straight condition, this difference was not significant.

Feeling that an artificial object is part of one's body, as occurs in the rubber hand illusion, does not seem to occur when the viewed object does not resemble the human hand (Tsakiris, 2010). In the RHI, the embodiment of the rubber hand seems constrained by its shape, with participants experiencing the illusion over a realistic prosthetic hand, but not over a wooden stick (Tsakiris & Haggard, 2005), a flat sheet of realistic skin (Haans, IJsselsteijn, & de Kort, 2008), or a block of wood (Tsakiris, Carpenter, James, et al., 2010). Even when the artificial hand does not have skin-like texture, the hand is embodied if it is hand-shaped (Haans, IJsselsteijn, & de Kort, 2008). This shows that shape is relevant for feeling that an artificial hand is part of one's body, specifically the hand-shape is important to embody an object as one's own hand. However, shape does not seem sufficient to induce the RHI, since a wooden hand did not elicit the illusion (Tsakiris, Carpenter, James, et al., 2010), even though its shape resembled a human hand. In the present study we show that in the sixth finger illusion, the shape of the induced finger does not need to resemble the shape of one's own fingers, with participants feeling a curved finger with different shape and different physical structures. There are fundamental differences between the two illusions, the RHI presents a visual representation of the hand (a rubber hand) be embodied, whereas the 6th finger uses the experimenter’s trace of the 6th finger with a stroke. In the RHI, the stroking is not applied to the whole hand at the same time, whereas in the 6th finger, the stroking is applied to the whole extra finger’s invisible surface. Further investigation is needed to assess what is enabling the shape flexibility of this illusion. A way of doing this would be to apply some elements of the curved sixth finger illusion to an RHI setup, such as reproducing the stimulation pattern and even attempting degrees of visibility.

Using a tool with the shape of a hand induces changes to the representation of one's own hand, but not when it has the shape of an arm (Miller, Longo, & Saygin, 2014). Similarity between the shape of the tool and the shape of the hand using the tool is relevant to its embodiment. These constrains do not seem to apply to illusory supernumerary fingers. Even though the embodiment of tools greatly differs from the embodiment of body parts, briefly addressing shape flexibility in both types of embodiment is useful to build future paradigms. It may be that we have higher degrees of flexibility for the representation of extra body parts, or it may be that, as long as there is not an object in the viewed component of the multisensory illusion, we can experience a wide range of variations to the bodily properties. An object onto which a synchronous touch is mapped may limit the perceptual experience by providing key information about that object, that reduces the likelihood of that object being one's own body part, if it does not resemble a human hand. However, without an object or a visual shape such as a 2D or 3D model, to constrain that experience, it may be that our mental representation allows for a higher degree of flexibility.

Perceptual augmentation through the illusory embodiment of an additional limb provides cues about how flexible our mental body representation is and how it may accommodate the embodiment and control of augmentation technology. Supernumerary fingers can be felt for a long duration (Cadete & Longo, 2020), have different sizes (Cadete & Longo, 2022), and in the present study we show it can have a different shape from our actual fingers. However, it remains unknown whether supernumerary fingers can have the same functionality and movement degrees of freedom as our actual fingers, and whether they can have augmented movement abilities (Eden, Bräcklein, Ibáñez, et al., 2022). Further research is necessary to investigate whether we can embody supernumerary body parts with extended movement ability.

One interesting distinction is between approaches based on 'hard' embodiment, which reproduce the existing form of the body template, and 'soft' embodiment, in which the sensorimotor apparatus is co-opted for a function different from that of the original body (Makin, de Vignemont, & Micera, 2020). The six finger illusion is in some sense intermediate between these approaches. It is 'soft' in the sense that it induces the experience of a bodily form different from the participant's own hand. But it is also 'hard' in the sense that the extra body part induced is serially-homologous with the existing fingers, and hence is the same *type* of body part which already exists. Engineering artificial limbs to fit a purpose, instead of copying a body part template means redefining the design and the mechanics, as well as the neural processes or computation of an embodied technology. Designing for the purpose of a task means designing novel shapes, that will differ from our body structure, not only from the limb being replaced, but possibly also from any body part that we have experienced throughout our lives. Instantly feeling a curved finger means feeling a finger in a shape that we have not experienced before and computing what does having a body part with such shape infers about its structure, position, movement or utility, even before the interpretation of that novel feeling.

Human movement augmentation has its own set of challenges, as it implies a repurposing of resources, of the neural system and body structures, combining with an existing functional body, as well as a need to make room for a new device and related skill. An open question under debate is if this extended ability would limit natural movement of the existing body (Eden, Bräcklein, Ibáñez, et al., 2022), with some promising leads by the study of individuals born with six fingers on their hands, that have extended abilities compared to five-fingered individuals (Mehring, Akselrod, Bashford, et al., 2019).

In line with this, it is also unclear whether we can feel supernumerary body parts without decreased perception of our actual body parts. A range of multisensory illusions elicit the embodiment of an artificial hand or virtual body part by *replacing* the participant's actual body part with the artificial or virtual one (Botvinick & Cohen, 1998; Guterstam, Petkova, & Ehrsson, 2011; Hoyet, Argelaguet, Nicole, et al., 2016). Sensory stimulation applied to the actual body part is mapped onto the illusory body part that is embodied. That is not the case in the sixth finger illusion, where both hands are available in one sensory modality, the participant receives tactile inputs from both hands, and this is also valid for the fingers. We do not need to resource to a confusion between the actual and fake finger to induce the illusion. There is no replacement, where one actual finger being touched needs to be disembodied to elicit the illusion, all fingers can be perceptually available, at least with tactile stimulation, and still feel a sixth finger. This seems to indicate we can indeed feel a supernumerary finger, without detriment to feeling our actual hands and fingers. This supernumerary finger can be felt with a curved shape, while feeling our actual finger straight. This adds evidence to our ability to feel supernumerary body parts with different features while maintaining a reliable perception of our actual body parts.

Manipulating the shape of the sixth finger induced some variations to the perceptual experience during the illusion. During the debriefing of the experiment, participants shared their experience with this body illusion. Some participants who disagreed with feeling a curved sixth finger, felt instead that their little finger was curved, and that they had a wider little finger, with the width of two little fingers. These participants had the same experience with the straight sixth finger, feeling a wider straight finger. One participant felt that the experimenter had an invisible finger that was stroking their seen little finger and another participant felt the touch was out of their body. In the original illusion (Newport, Wong, Howard, et al., 2016), a subset of participants reported actually seeing a sixth finger that promptly disappeared, and on the other end, other participants felt no touch at all when they did not see the contact with the skin, despite the experimenter’s stroke along their hidden fifth finger. The authors attribute these to different weighting of somatosensation versus vision. No participants reported a distorted little finger, such as the large little finger here anecdotally reported. It is uncertain whether this effect is due to the different shape of the sixth illusory finger. These variations to the perceptual experience of this shape illusion also occurred in Lackner's study (1988), where muscle vibrations were applied to parts of the participant's body, while they were blindfolded. Muscle vibrations are known to elicit illusory movement of the body or body parts in various directions (Lackner & Levine, 1979). Vibrations applied to the biceps brachii in the upper arm, while participants grabbed their own nose, elicited a set of variations to the illusion, with 5 participants feeling their nose elongating, 3 feeling their fingers elongating instead, and 2 experiencing both the nose and fingers elongating. Other participants felt no movement or movement without displacement and tilting the head backwards. This shows the variety of interpretations elicited by body illusions manipulating shape and position, with alterations perceived in the body parts that are involved in an experimental manipulation. Asking the participants about a sixth finger may limit the spectrum of bodily experiences that the illusion can generate. Participants felt a straight finger and a curved finger, however it is possible that the sixth finger was felt sequentially, which could specify the experience into a sixth finger; or simultaneously, which could generate the large little finger experience in a small subset of participants. This temporal spectrum could explain the split in the bodily experiences during this illusion and could be tested by manipulating the pattern of stimulation into stroking the five fingers simultaneously to the 6th finger, and adding conditions with sequential versus simultaneous temporal stimuli.

In this study, most participants experience the illusion as a sixth finger, however a smaller group of participants experience alterations to the little finger instead. Not only is the body representation for shape flexible, allowing for impossible physical configurations of the body, but there is also another type of flexibility, that allows for a variety of experienced perceptual phenomena under the same stimulation. As our brain tries to make sense of conflicting sensory information related to the same body parts, a set of possible interpretations arise to solve that conflict in a plausible perceptual experience, even if our somatosensory system has to elicit extreme alterations to the perception of our body parts.

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