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Anchoring to the hand, but not spatially distinct mappings, facilitates illusory supernumerary finger embodiment

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A B S T R A C T

To induce the Anne Boleyn illusion, an individual's hands are placed on either side of a mirror and stroked synchronously from the thumb to the empty space neighboring the reflected fifth finger, creating the perception of a supernumerary finger. The hidden fifth finger is stroked on the medial and lateral sides, which correspond to the fifth and "sixth" finger on the visible hand. The percept induced is robust enough to withstand biologically implausible manipulations that break other visuotactile illusions, making the illusion a promising avenue for exploring multisensory integration and illusory embodiment. The present study investigates three aspects of its underlying cognitive mechanisms. First, although embodiment was theorized to require tactile stimulation of two discrete fifth finger locations, we found that stroking only one location does not abolish or reduce the illusion. Second, manipulating the starting location of strokes produced differences in body part categorization of the percept, indicating the influence of top-down constraints from pre-existing body representations. Third, we aimed to identify factors underlying the illusion's robustness to enhance our understanding of illusory embodiment mechanisms. We found support for the "anchoring" hypothesis, proposing that the sixth finger's proximity to the real hand may be a critical factor.

1. Introduction

In the Anne Boleyn illusion, named after the wife of King Henry the VIII who was reputed to have a sixth finger (Bell, 1877), the participant sits at a mirror box with one hand in front of the mirror and the other hidden behind it. The participant views the reflected hand in the mirror, positioned to plausibly look like their hidden hand behind the mirror. The examiner congruently strokes the middle of the first four fingers on each hand simultaneously, and then delivers synchronous strokes on the inner side of the hidden fifth finger and the middle of the visible fifth finger. Next, the outer side of the hidden fifth finger and the empty space adjacent to the visible fifth finger are stroked simultaneously, leading to a strong percept of feeling a sixth finger. The illusion was first documented by Newport and colleagues in 2016, who reported that participants under laboratory ($n = 18$) and non-laboratory conditions ($n = 3500$) perceived a sixth finger on over 90 % of trials.

The proposed mechanisms underlying the illusion are thought to be related to the relationship between the location of tactile

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Nomenclature

Glossary

Anatomical implausibility A physical characteristic that is unlikely or impossible given the anatomy of the body (e.g., an unnatural finger shape)
Body schema The cognitive representation of one's body
Cubital fossa The area connecting the forearm and upper arm on the anterior surface of the elbow
Illusory embodiment Perceived ownership of some noncorporeal object as part of one's body
Lateral side The side farthest from the midline of the body
Medial side The side closest to the midline of the body
Metacarpophalangeal joint The joint at the base of the finger
Somatotopic mapping The process of mapping locations on the body to specific areas of the brain

stimulation on the hidden hand and illusory stroking (Newport et al., 2016). In the basic illusion, feeling strokes on two different places on the hidden fifth finger (inside, then outside of the finger) along with seeing strokes in two locations (middle of fifth finger, then empty space representing a sixth finger) creates distinct mappings in both somatotopic and viewed space. These distinct mappings are thought to facilitate the perceived distinction in location between the fifth finger and the illusory sixth finger, with the sixth finger perceived as more eccentric than the fifth finger. Since this *distinct mappings* hypothesis was initially proposed (Newport et al., 2016), all experimental research on this illusion has retained distinct stroke locations on the hidden fifth finger (Ambron & Medina, 2023; Cadete et al., 2022; Cadete & Longo, 2020, 2022; Wang et al., 2025).

Embodiment of a variety of illusory body parts can be induced by delivering visual and tactile stimulation concurrently to facilitate multisensory integration. The rubber hand illusion (RHI) involves stroking the participant's obscured hand at the same time as a lifelike rubber hand, which can be perceived as the participant's own hand (Botvinick & Cohen, 1998) or, with slight modifications, an extra arm (Guterstam et al., 2011. This method has been extended to produce illusory feet (Crea et al., 2015; Lenggenhager et al., 2015), and a variant using virtual reality technology elicits embodiment of a virtual arm (virtual arm illusion; Slater et al., 2008). Employing a similar procedure of congruent visual and tactile stimulation, stroking in empty space can induce embodiment of an invisible hand (the invisible hand illusion; Guterstam et al., 2013) or face (invisible enfacement illusion; D'Angelo et al., 2021).

Theoretical accounts of these phenomena draw on investigations of constraints on embodiment. A necessary condition is stroking congruence between the body and the object (Armel & Ramachandran, 2003; Botvinick & Cohen, 1998). This suggests that bottom-up processes such as temporal and spatial synchrony between visual and tactile stimuli (Stein & Meredith, 1990) facilitate multisensory integration, leading the participant to believe the seen and felt touch are experienced on the same location in external space. However, evidence indicates that the strength of embodiment of noncorporeal objects is modulated by certain cues that substantiate the plausibility of the object belonging to the body, demonstrating that stroking congruence is necessary but not sufficient. These cues include visual similarity to the felt body part (Haans et al., 2008), postural congruence between the body and the object (Costantini & Haggard, 2007), and proximity to the body (Kalckert & Ehrsson, 2014; Lloyd, 2007). A purely bottom-up account of embodiment could not account for these constraints, which suggest that perceived conflict between the object and pre-existing body representations hinders or prevents multisensory integration. Accordingly, Tsakiris' (2010) neurocognitive model of body ownership proposes that the RHI elicits embodiment through a combination of bottom-up and top-down processes that require congruent stimulation and are constrained by visual, anatomical, and structural properties of a pre-existing body model. A complementary perspective approaches this combination within a Bayesian framework, emphasizing the participant's probabilistic inference of body ownership based on available sensory evidence (de Vignemont, 2010).

Compared to the RHI, the Anne Boleyn illusion is particularly robust. By manipulating the shape and length of the stroke in empty space, experimenters have successfully induced embodiment of impossibly long (Cadete & Longo, 2022) and curved (Cadete et al., 2022) sixth fingers. The illusion is not abolished by a variety of anatomical implausibilities, including unnatural finger shape, unnatural orientation, incongruent hand posture, and spatial distance (Ambron & Medina, 2023). These results contrast previous findings about the constraints of other body illusions. Recall that asynchronous stroking (Kalckert & Ehrsson, 2012), postural incongruence (Costantini & Haggard, 2007), excessive distance (Kalckert & Ehrsson, 2014), and attempted embodiment of a non-hand-like object (Haans et al., 2008) have significantly reduced the RHI. Although it is a fairly strong illusion, the Anne Boleyn illusion is weakened when the hand is oriented implausibly or when stroking is fairly distant from the body (Ambron & Medina, 2023), a limitation also observed in the rubber hand illusion (Ehrsson et al., 2004; Lloyd, 2007). Differences in flexibility across body part illusions, and the methodological differences to which they can be attributed, can be used to investigate the malleability of the body schema.

Existing theoretical accounts cannot specifically explain the minimal constraints associated with the Anne Boleyn illusion. There are several possible reasons for this flexibility. First, the illusion creates an extra finger rather than replacing an existing one. Supernumerary body parts may be less constrained by pre-existing body representations due to the fact that they are additive rather than incorporated into the body plan (de Preester & Tsakiris, 2009). When body parts are added as extensions rather than replacements, there is no stored body part representation onto which the new body part can be mapped, which may eliminate body-part-specific visual, anatomical, and motor constraints. However, empirical evidence comparing the RHI and the supernumerary limb illusion, which are nearly identical methodologically but differ in whether the illusory percept is incorporated or added to the body plan, appears to contradict this claim. Guterstam and colleagues (2011) collected agreement ratings for statements characterizing the qualia of the illusion (e.g., subjective sense of disownership of the real hand) and found neither a main effect of illusion type nor an interaction between illusion type and statement type, indicating no evidence for quantitative or qualitative differences in embodiment between the two procedures.

Second, as we have previously discussed (Ambron & Medina, 2023), the Anne Boleyn illusion differs from other instances of supernumerary embodiment in that it creates a percept of an extra finger rather than an arm or hand (Fan et al., 2021; Guterstam et al., 2011). Postaxial polydactyly (having an additional finger adjacent to the fifth finger) is rare, with frequency estimates ranging from 1/100 to 1/3300 (Kyriazis et al., 2023). However, polymelia (having an additional arm) is extremely rare and has only been documented a few times (Mennen et al., 1997; O'Rahilly, 1951). A percept of an extra finger is thus more biologically plausible and might represent a less extreme violation of the body plan.

Third, the *anchoring* hypothesis proposes that the illusory finger's proximity to the participant's real hand provides visual evidence that facilitates the spontaneous inclusion of the empty space in the body schema. In other words, the "anchoring" of the sixth finger to an existing body part facilitates the robustness of the illusion. This aspect is a critical distinction between sixth finger embodiment and more constrained visuotactile illusions such as the rubber hand illusion, the strength of which is modulated by various top-down inhibitory constraints (e.g., violations of the typical body plan; Tsakiris & Haggard, 2005) that appear to be negligibly impactful in the Anne Boleyn illusion due perhaps to the presence of facilitatory top-down influences such as anchoring. Several factors point to the theoretical and empirical feasibility of the *anchoring* hypothesis relative to those described above. First, anchoring of the percept to the existing body increases biological plausibility, a top-down factor which robust evidence suggests increases embodiment strength in both the Anne Boleyn illusion (Ambron & Medina, 2023) and other visuotactile illusions (Tsakiris, 2010). Second, it is consistent with well-established principles of multisensory integration. The spatial rule posits that spatial proximity between the stimuli renders multisensory integration stronger or more likely (Holmes & Spence, 2005). Thus, when the participant's hidden fifth finger is stroked, it should be more likely to elicit multisensory integration, or produce stronger embodiment, when the viewed strokes are closer to the viewed hand. Third, proximity of the empty space strokes to the visible hand can easily be systematically manipulated in an experimental setting.

The current study investigates three aspects of the illusion: whether distinct mappings between somatotopic and external space are necessary, whether increasing the stroke length alters the illusion, and the effect of distance from the body on the illusion.

First, we implemented the first experimental test of the *distinct mappings* hypothesis. Despite its importance to the hypothesized cognitive processes responsible for the illusion, it has not yet been empirically examined whether stroking in two distinct locations on the hidden hand is necessary or even increases embodiment. Simply having concurrent touch anywhere on the hidden fifth finger and external space next to the visible hand may be sufficient to create an illusory sixth finger. To address this question, we developed three novel conditions in which the hidden fifth finger is stroked only on the medial side, middle, or lateral side—not moving from the medial to the lateral side of the finger as in the traditional illusion. The *distinct mappings* hypothesis predicts that stroking only one location on the hidden fifth finger will decrease the strength of embodiment, indicating that distinct stroke locations facilitate the remapping of touch onto the empty space. However, if the single-location conditions did not decrease embodiment strength, this would suggest that distinct mappings are not necessary and that the illusion is attributable to other mechanisms.

Second, in most existing versions of the Anne Boleyn illusion (including those examining unnaturally long sixth fingers; Cadete & Longo, 2022), individuals are stroked from the metacarpophalangeal joint (i.e., the base knuckle of the finger) to the tip of the finger. One possibility is that increasing the spatial extent of synchronous stroking increases the amount of congruent visuotactile information, leading to differences in the strength and quality of embodiment. To examine this, the next set of experimental conditions modified the basic illusion by systematically varying the starting and departing locations of the strokes, an aspect of the illusion that has not previously been manipulated. We predicted that conditions with an increased amount of synchronous stimulation (e.g., a stroke going from the wrist to the fingertip) would be associated with stronger embodiment. We also anticipated that starting location on the arm would impact the categorization of the illusory body part.

Finally, while numerous modifications of the Anne Boleyn illusion demonstrate the ways in which it is less constrained than other body illusions, the reason for its resilience remains unclear. Therefore, we devised new conditions to provide a novel test of the *anchoring* hypothesis. In Ambron & Medina (2023), we found inconsistent evidence for a spatial proximity effect. In the first experiment, we reported no difference in the strength of embodiment regardless of whether the viewed stroke was "anchored" to the visible hand (i.e., starting at the metacarpophalangeal joint of the fifth finger) or started in empty space (three inches away from the hand). However, displacing the sixth finger by six inches resulted in significantly lower embodiment ratings compared with the basic illusion. Our final set of conditions varied both the starting location of the visible induction strokes ("anchored" to the metacarpophalangeal joint or three inches away) and violations of a natural body shape (curved finger inward, curved finger outward, embodied pen). We anticipated that the combination of both spatial and body shape violations would reduce the effectiveness of the illusion, since the presence of multiple violations may be inconsistent enough with existing body representations to hinder embodiment. The *anchoring* hypothesis predicts that, for these biologically implausible variants, anchored conditions would elicit stronger embodiment than unanchored conditions, indicating that spatial proximity to the visible hand facilitates the illusion's flexibility to body shape violations. Similarity between anchored and unanchored conditions would suggest that the effect of spatial proximity is negligible or small at best.

The Anne Boleyn illusion offers a unique opportunity to investigate how the brain integrates conflicting multisensory inputs to produce a coherent sense of embodiment of a supernumerary, and therefore additive, body part. The present experiment's exploration of the *distinct mappings* hypothesis, the effect of elongated strokes, and the *anchoring* hypothesis yields insights into the mechanisms that generate the illusion, modulate embodiment strength, and facilitate its unique robustness. Testing the *distinct mappings* hypothesis will determine whether the illusion requires touch in two distinct locations, informing the importance of spatial differentiation in the remapping of touch in external space more broadly. Examining the effect of elongated strokes enables us to assess whether the spatial extent of tactile stimulation contributes to multisensory integration. Investigating anchoring as a possible explanation for the illusion's relatively minimal constraints will advance our understanding of which methodological aspects are critical to the illusion's robustness, elucidating how the body plan extends to include biologically implausible appendages.

2. Methods

2.1. Participants

Thirty-five individuals participated in the study, approved by the University of Delaware Institutional Review Board (IRB) ($M_{\text{age}} = 27.1 \pm 13.6$ years, $Mdn_{\text{age}} = 21.0$; 24 women, 7 men, 2 non-binary/gender non-conforming individuals, 1 self-described queer individual, and 1 individual identifying as a woman and non-binary/gender non-conforming individual). Participants were recruited via fliers on the University of Delaware, Newark campus and word of mouth. They provided verbal informed consent before the session began and were compensated $10 for their participation. Previous work suggests that the basic illusion is very strong, with effect sizes as large as $d_z = 4.125$ (Newport et al., 2016) and $d_z = 1.75$ (Cadete & Longo, 2020). However, as we were testing conditions estimated to be less powerful than the original illusion, we assumed a medium effect size. A power analysis using G*Power 3.1 revealed that 25 participants were needed ($d_z = 0.6$, $\alpha = 0.05$, power $= 0.8$; Faul et al., 2007).

2.2. Apparatus

The mirror box in Ambron & Medina (2023) and Liu & Medina (2017) was used in this experiment. The apparatus was painted black (except for the mirror) and comprised a wooden platform measuring 91.4 cm by 40.6 cm and a right-facing acrylic mirror (30.5 cm high and 40.6 cm wide) rising from the center. Black paper covered the top of the left half of the mirror box such that the hidden left hand was not visible to the participant.

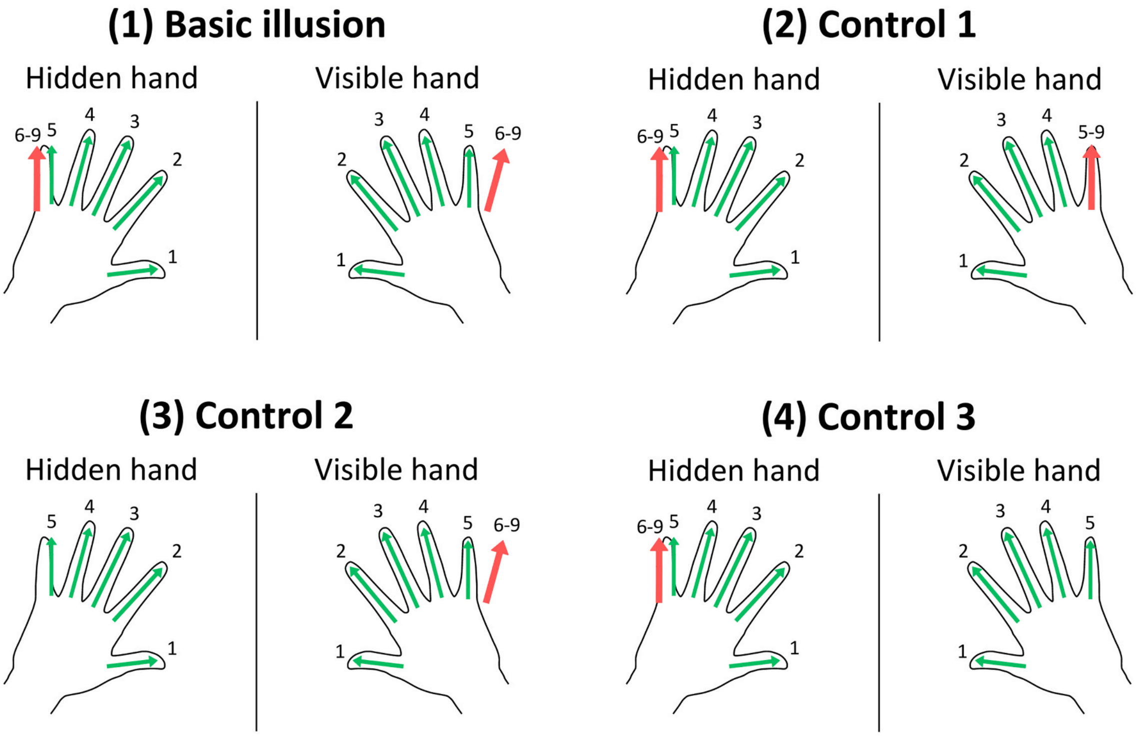

Fig. 1. *Basic and Control Conditions. Note.* The vertical line between each pair of hands represents the mirror. The numbers and arrows indicate stroke order and direction, respectively. Note that all strokes across all 22 conditions were administered along the middle of the finger unless otherwise specified in the figure notes. Conditions 1–4 had the following exceptions: the fifth stroke was administered to the medial side of the hidden fifth finger across all conditions, and strokes 6–9 were administered to the lateral side of the hidden fifth finger in the basic illusion, the fifth finger stroking control condition (Control 1), and the tactile-only control condition (Control 3). Figures are meant to be an approximation, and are not necessarily drawn to scale.

2.3. Procedure

Participants were asked to remove hand accessories (e.g., rings, jewelry, and watches) and roll up sleeves to above the inner elbow. Participants' hands were placed palm-down on either side of the mirror box approximately 9 cm from the mirror and centered depth-wise, positioned so that the fifth fingers and arms were roughly parallel to the mirror. The left hand was concealed, while the right hand was visible and reflected in the mirror. Participants were asked to remain still and keep their gaze only on their reflected hand throughout the session.

In keeping with prior work on the Anne Boleyn illusion (Ambron & Medina, 2023; Newport et al., 2016), the examiner stroked the participants hands and arms with their own fingers. The examiner first completed an "establishing count" in which they stroked the hidden hand and the visible hand synchronously from the thumb to the fifth finger while counting aloud from one to five. They asked the participant to count with them, and administered the five congruent strokes a second time. Unless otherwise noted, participants' fingers during the establishing count and the subsequent experimental conditions were stroked from the top of the metacarpophalangeal joint to the tip of the finger at a rate slightly higher than one stroke per second.

Next, the examiner carried out the 22 conditions in randomized order, performing one trial of each condition. All conditions consisted of two phases: a simple touch phase in which we stroked the fingers on both hands simultaneously (strokes 1–5), and then an induction phase (strokes 6–9) which included the experimental manipulation. We placed these 22 experimental conditions in four categories: basic illusion and control conditions, hidden fifth finger stroke location conditions, length and location of stroke conditions, and anchoring conditions. We describe the induction phase of these conditions in the following sections (for a complete list, see Appendix A).

2.3.1. Basic and control conditions (Conditions 1–4)

Conditions 1–4 (see Fig. 1) were the (1) basic illusion from Newport et al. (2016) and the three control conditions used in Ambron & Medina (2023). The basic illusion followed the approach first reported by Newport et al. (2016), with one stroke for each of the first five fingers (the fifth finger comprising a stroke along the middle of the visible fifth finger and the medial side of the hidden fifth finger) and four strokes delivered synchronously to the lateral side of the hidden fifth finger and the empty space adjacent to the visible fifth finger. The three control conditions were identical to those used in Ambron & Medina (2023). The fifth finger stroking control condition (Control 1), originally developed by Newport et al. (2016), was a modification of the basic illusion in which the final five visible hand strokes were administered along the middle of the fifth finger. In the visual-only control condition (Control 2), the strokes on the hidden hand stopped after the fifth stroke while the basic illusion procedure continued on the visible hand. The tactile-only control condition (Control 3) followed the basic illusion for the hidden hand, but had no sixth finger strokes on the visible hand. Thus, while Control 2 (visual-only) removed only the tactile component of the illusory sixth finger, Control 3 (tactile-only) removed only the visual component.

2.3.2. Hidden fifth finger stroke location (Conditions 5–7)

Conditions 5–7 retained the basic illusion procedure on the visible hand. Typically in the illusion, the fifth stroke is on the medial side of the hidden fifth finger, with the induction strokes (6–9) on the lateral side of the finger. In these conditions, the stroke location on the hidden hand remained in the same location for strokes 5–9 (see Fig. 2). For each condition, we varied whether the hidden hand stroke was on the medial side (condition 5), middle (condition 6), or lateral side (condition 7) of the hidden hand.

2.3.3. Systematic variance of starting and departing locations (conditions 8–16)

Conditions 8–16 systematically varied the starting location and the location where the viewed "sixth finger" stroke left the body in a

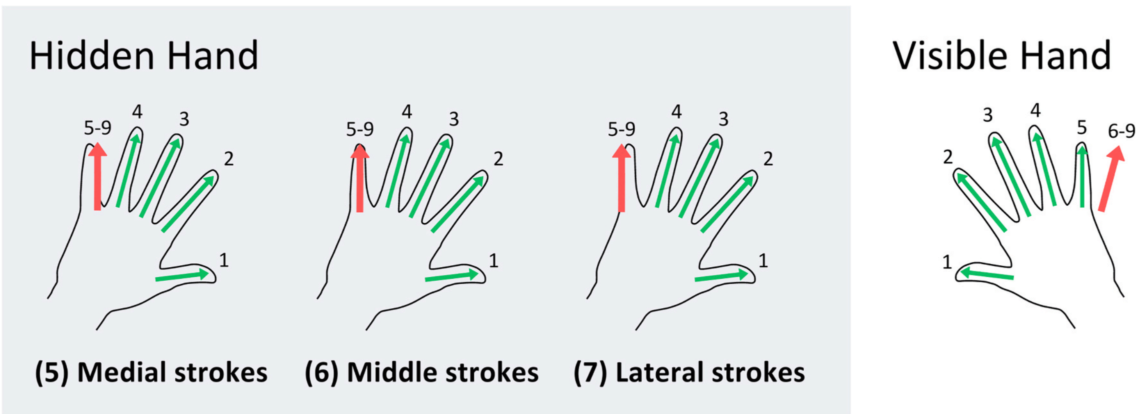

Fig. 2. *Conditions with Strokes in One Location on the Hidden Fifth Finger. Note.* Only the location of strokes 5–9 on the hidden hand varied across these three conditions. Strokes 5–9 were administered to the medial side of the hidden fifth finger in the medial strokes condition (5), and to the lateral side of the hidden fifth finger in the lateral strokes condition (7).

3 × 3 manner (for visual depictions, see Fig. 3). The starting location for both the hidden and viewed hand strokes was the wrist (conditions 8–10), the distal-proximal midpoint of the forearm (conditions 11–13) or the midpoint of the cubital fossa (i.e., the elbow crease; conditions 14–16). In two of the conditions within each group, the strokes were administered starting at the midpoint along the mediolateral axis of the starting location. These conditions departed from the body at either the metacarpophalangeal joint of the fifth finger (conditions 8, 11, and 14) or the side of the hand or arm (conditions 9, 12, and 15). A third group of "disconnected" conditions involved stroking the empty space adjacent to the body (conditions 10, 13, and 16). Note that in the "disconnected" conditions, unlike the others, the visible strokes intended to induce illusory embodiment never touched the body. Given that the strokes were longer, they

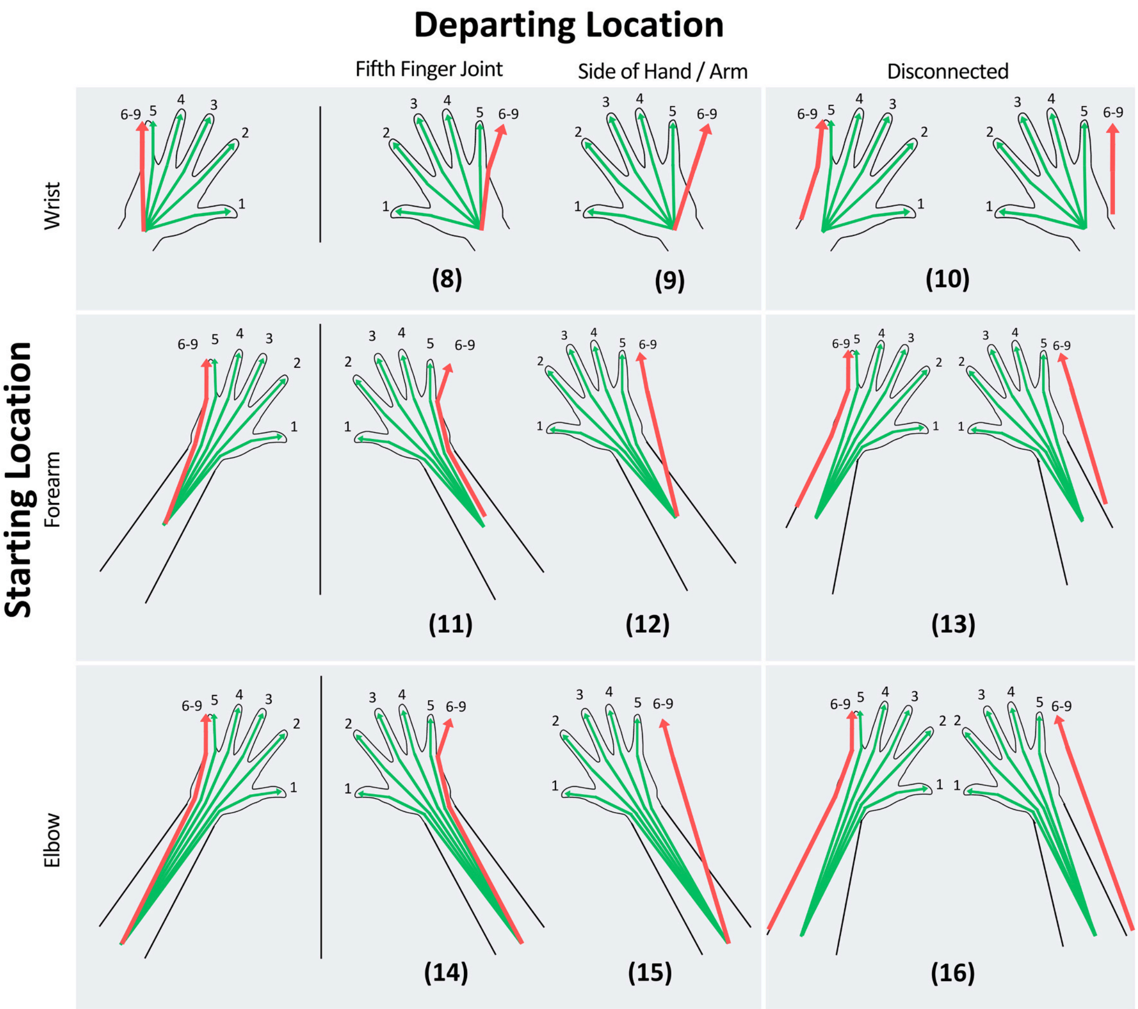

Fig. 3. *Conditions with Varied Starting and Departing Locations. Note.* The leftmost column depicts the hidden hand strokes which correspond with the visible hand strokes on both of the following two hands/arms. The rightmost column presents both hands/arms to highlight that the sixth finger strokes started from the side, rather than the middle, of the hand/arm in those conditions. The fifth stroke was administered to the medial side of the hidden fifth finger across all conditions, and strokes 6–9 were administered to the lateral side of the hidden fifth finger across all conditions. Strokes 1–5 on the visible hand and strokes 1–4 on the hidden hand began at the midpoint along the mediolateral axis of the wrist (conditions 8–10), the distal-proximal midpoint of the forearm (conditions 11–13) or the cubital fossa (i.e., the elbow crease; conditions 14–16), continued in a direct route to the metacarpophalangeal joint, and finished along the middle of the finger. Stroke 5 on the hidden hand followed the same procedure up to the metacarpophalangeal joint, but then continued along the medial side in all conditions. Strokes 6–9 varied most notably across conditions. In the metacarpophalangeal-joint-departing conditions (conditions 8, 11, and 14), the visible strokes departed at the metacarpophalangeal joint into the empty space adjacent to the fifth finger, and the hidden strokes followed the same procedure as the corresponding fifth strokes up to the metacarpophalangeal joint but then continued along the lateral side of the fifth finger. The side-departing conditions (conditions 9, 12, and 15) retained this procedure for the hidden strokes, but the visible strokes followed a straight line from the starting location to a point about an inch from the tip of the fifth finger (the plausible location of a sixth finger), departing from the body along the side of the arm or hand. In the "disconnected" conditions (conditions 10, 13, and 16), the visible strokes began in the empty space immediately adjacent to the lateral side of the body and continued in a straight line to a point about an inch from the tip of the fifth finger, and the hidden strokes were administered to the lateral side of the body, starting at the side of the arm or wrist and continuing to the lateral side of the fifth finger. The spacing of figures, especially those in the "Disconnected" column, are approximations and not to scale.

were delivered at a rate of about one stroke per second.

2.3.4. Anchoring (Conditions 17–22)

Conditions 17–22 were a 2 × 3 design with proximity to the hand and type of anatomical implausibility as factors (see Fig. 4). The sixth finger stroke was either adjacent to the fifth finger (these will be referred to as "anchored"; conditions 17–19) or three inches away from the fifth finger ("unanchored"; conditions 20–22). Three anatomically implausible conditions were used: curved outside (conditions 17 and 20), curved inside (conditions 19 and 22), and embodied pen (conditions 18 and 21).

These anatomically implausible conditions were adapted from Ambron & Medina (2023) and were selected because, of the conditions that could feasibly be performed anchored and unanchored and for which anchored and unanchored variants had not already been tested, they had the highest embodiment ratings. Therefore, we thought that they would be least likely to exhibit a floor effect.

2.4. Measures

2.4.1. Embodiment questionnaire

After each condition, participants were told to rate their level of agreement with the forthcoming statements on a scale of –3 (strongly disagree) to 3 (strongly agree). A printout of the 7-point Likert scale was hung on the wall behind the examiner and shown to the participant. The statements were adapted from questionnaires used in previous work using the illusion (Ambron & Medina, 2022; Cadete & Longo, 2020; Newport et al., 2016) and supplemented with additional statements specific to some of the novel conditions. Participants were asked to rate their agreement with 8–12 of the 14 total statements, depending on which condition had just been administered. Statements 1–6 were presented for all conditions, while the latter statements pertain only to some of the conditions, as noted in Table 1. The statements were presented in the order indicated below for each trial.

When participants asked clarifying questions, they were advised to generate the most accurate response they could to their literal

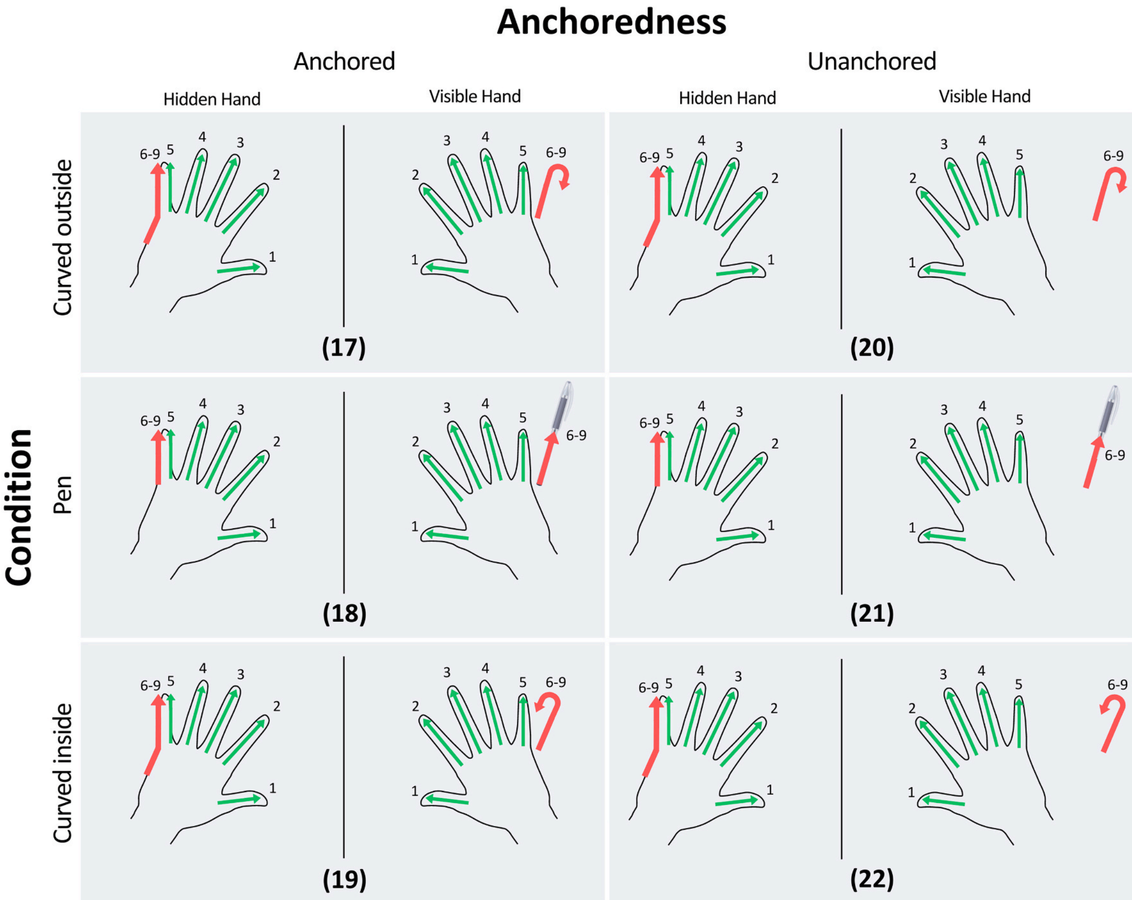

Fig. 4. *Anchoring Hypothesis Conditions. Note.* The pen was fixed to the base of the mirror box using an adhesive to prevent unexpected movement. The fifth stroke was administered to the medial side of the hidden fifth finger across all conditions, and strokes 6–9 were administered to the lateral side of the hidden fifth finger across all conditions. As depicted, the hidden "sixth finger" strokes in the curved conditions (conditions 17, 19, 20, and 22) started midway between the metacarpophalangeal joint and the wrist, while the pen conditions (conditions 18 and 19) followed the basic illusion procedure on the hidden hand.

Table 1
Embodiment questionnaire agreement statements and aspects examined.

Statement	Associated conditions	Aspect examined
1. It felt like I had six fingers on my left hand	All conditions	Perception of sixth finger (Primary Statement)
2. It felt like I had two pinkies on my left hand	All conditions	Perception of additional fifth finger
3. I felt a touch where I do not normally feel a touch	All conditions	Localization of the tactile sensation
4. I felt a touch that was not on my body	All conditions	Embodiment of the touch
5. I felt like I had an extra hand	All conditions	Control statement: Perception of an extra hand
6. I felt a sixth finger that was part of my body	All conditions	Embodiment of the sixth finger
7. It seemed that the empty space was part of my body	Conditions 1–17, 19–20, 22 (all except for pen embodiment conditions)	Embodiment of the empty space
8. The touch in the empty space did not feel like part of my body	Conditions 1–17, 19–20, 22 (all except for pen embodiment conditions)	Localization and embodiment of the tactile sensation
9. I felt touch where the examiner was stroking in the empty space	Conditions 1–17, 19–20, 22 (all except for pen embodiment conditions)	Localization of the tactile sensation
10. I felt a body part coming out of my wrist / forearm / elbow	"Wrist": Conditions 9–10 "Forearm": Conditions 12–13 "Elbow": Conditions 15–16	Embodiment of an extra body part extending from the starting location
11. I felt a finger coming out of my wrist / forearm / elbow	"Wrist": Conditions 9–10 "Forearm": Conditions 12–13 "Elbow": Conditions 15–16	Embodiment of an extra finger extending from the starting location
12. I felt an arm coming out of my wrist / forearm / elbow	"Wrist": Conditions 9–10 "Forearm": Conditions 12–13 "Elbow": Conditions 15–16	Embodiment of an extra arm extending from the starting location
13. I felt a touch on the pen	Conditions 18, 21 (pen embodiment conditions)	Embodiment of the touch on the pen
14. It felt like the pen was part of my body	Conditions 18, 21 (pen embodiment conditions)	Embodiment of the pen

Note. Statement 5 functioned as a control statement, as the illusion is not expected to induce the feeling of a supernumerary hand. Statements 7–9 were not presented in Conditions 18 and 21, the pen embodiment conditions, because they refer to the embodiment of "empty space" which was not the intention of the illusion in these conditions.

interpretation of the statement. On occasion, participants gave decimal numbers and were asked to choose a whole number.

2.4.2. Qualitative interviews

At the conclusion of the session, participants were asked the following open-ended questions:

1. What did that feel like?
2. What did it feel like was happening?
3. How did you feel about it?
4. Was anything particularly unexpected?

Participants were sometimes asked followup questions to draw out more complete answers, as well as specific questions about unusual responses or reactions the participant exhibited during the trials at the discretion of the examiner. Responses were documented by the examiner, and direct quotes were noted where appropriate.

3. Results

Two participants with tattoos on their hands or arms were removed from the final dataset, as was one participant who exhibited signs of inattentiveness and one participant who misunderstood the agreement scale. Of the remaining participants, 22 (71.0 %) reported an agreement score of > 0 for Statement 1 ("It felt like I had six fingers on my left hand") after the basic illusion. Participants who did not report feeling a sixth finger with the basic illusion were excluded to prevent a floor effect, as has been done in previous research testing modifications of the illusion (Ambron & Medina, 2023).

Wilcoxon signed-rank tests were used for pairwise comparisons and one-sample Wilcoxon tests were used to test differences from 0. All analyses were planned except the bimodal coefficients, which are not a measure of statistical significance. Still, to minimize risk of type I error, we applied Bonferroni corrections to account for multiple comparisons. Due to varying numbers of comparisons across different research questions, we report only Bonferroni corrected p values. Two-way repeated measures ANOVAs were used for analyses with two factors and Friedman rank sum tests, which are non-parametric repeated measures tests, were used for one-factor comparisons of multiple groups. For some cases where differences were not significant, Bayesian paired samples t-tests were used to investigate statistical evidence for similarity. We calculated Bayes factors (BF_{01}) assessing the likelihood of the null hypothesis (no between-condition differences) being supported. Bayes factors of 3–10 denote "substantial" or "positive" evidence for similarity and factors of 1–3 denote "anecdotal" or "weak" evidence (Jarosz & Wiley, 2014; Jeffreys, 1961; Raftery, 1995).

This section focuses on the primary statement (feeling six fingers), Statement 11 (feeling an extra finger), and Statement 12 (feeling an extra arm). For analyses of the other statements, see the online supplementary materials.

3.1. Basic and control conditions

Agreement scores for Statement 1 (feeling a sixth finger) for all experimental conditions were significantly higher than the fifth finger stroking and visual-only control conditions (see Fig. 5 and supplementary materials). However, none of the 19 experimental conditions produced greater illusory embodiment than the tactile-only control (Control 3). The fifth finger stroking and the visual-only control conditions were not significantly different from each other, $V = 22$, $p = 0.56$, $r = 0.28$. However, the tactile-only control ($M = 0.50 \pm 2.37$) was significantly different from the fifth finger stroking ($M = -2.57 \pm 0.60$; $V = 136$, $p = 0.001$, $r = 0.75$) and visual-only ($M = -2.14 \pm 1.32$; $V = 161$, $p = 0.003$, $r = 0.70$) control conditions.

3.2. Hidden fifth finger stroke location

For Statement 1, each of the single-location conditions produced agreement scores significantly greater than 0 (medial: $V = 236$, $p < 0.001$, $r = 0.77$; middle: $V = 227.5$, $p = 0.001$, $r = 0.71$; lateral: $V = 234$, $p < 0.001$, $r = 0.75$). As noted above, the three conditions (medial: $M = 2 \pm 1.38$; middle: $M = 1.86 \pm 1.73$; lateral: $M = 1.77 \pm 1.31$) were also significantly different from the fifth finger stroking ($M = -2.57 \pm 0.60$) and visual-only ($M = -2.14 \pm 1.32$) control conditions. The basic illusion, in which the hidden fifth finger was stroked on both the medial and lateral sides, did not differ significantly from the medial ($V = 29$, $p = 1.00$, $r = 0.02$), middle ($V = 29$, $p = 1.00$, $r = 0.02$), or lateral ($V = 39$, $p = 1.00$, $r = 0.09$) stroke conditions. Bayesian analyses showed substantial evidence for similarity between the basic and the medial ($BF_{01} = 4.42$), middle ($BF_{01} = 4.10$), and lateral ($BF_{01} = 3.34$) conditions. There were no significant differences between the three single-location conditions, $\chi^2(2) = 1.88$, $p = 0.39$. Accordingly, Bayesian analyses showed substantial evidence for similarity between the medial and middle ($BF_{01} = 4.30$), medial and lateral ($BF_{01} = 3.70$), and middle and lateral ($BF_{01} = 4.40$) conditions. Overall, these results provide evidence that stroking different locations on the fifth finger of the hidden hand is not necessary to induce the illusion.

3.3. Starting and departing location effects

A two-way repeated measures ANOVA with starting location (wrist, middle of forearm, elbow crease) and departing location (base of fifth finger, side of hand, disconnected) as factors revealed only a significant main effect of starting location on agreement with Statement 1 ("It felt like I had six fingers on my left hand"), $F(2, 42) = 11.63$, $p < 0.001$, $\eta^2G = 0.08$. There was no main effect of departing location ($F(1.53, 32.17) = 1.90$, $p = 0.17$, $\eta^2G = 0.02$) or interaction ($F(4, 84) = 0.35$, $p = 0.84$, $\eta^2G = 0.005$). Two Friedman tests found significant effects of both starting location ($\chi^2(2) = 17.48$, $p < 0.001$) and departing location ($\chi^2(2) = 6.08$, $p = 0.048$), but Wilcoxon signed-rank tests did not find significant differences between any of the three departing locations ($ps = 0.28$–$.55$). Bayes factors indicate substantial evidence for similarity between the metacarpophalangeal-joint-departing and side-departing conditions ($BF_{01} = 3.02$) and the side-departing and disconnected conditions ($BF_{01} = 4.97$), but not between the metacarpophalangeal-joint-departing and disconnected conditions ($BF_{01} = 1.24$). Of the starting locations, wrist-starting conditions ($M = 2.14 \pm 1.15$)

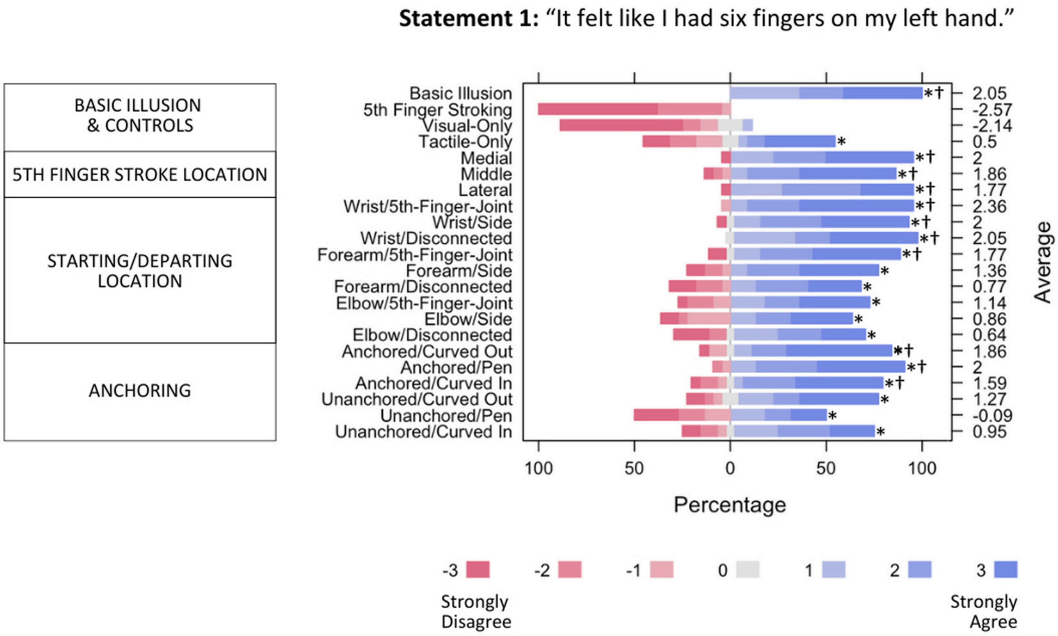

Fig. 5. *Response Distributions and Score Averages: Statement 1 (Perception of Sixth Finger). Note.* * = significantly different from the fifth finger stroking control condition (Control 1). † = significantly greater than 0.

produced higher embodiment than forearm-starting ($M = 1.30 \pm 2.07$; $V = 168$, $p = 0.01$, $r = 0.62$) and elbow-starting ($M = 0.88 \pm 2.10$; $V = 199$, $p = 0.001$, $r = 0.74$) conditions, but the latter two were not different ($V = 105$, $p = 0.55$, $r = 0.28$) and a Bayes factor test suggested weak evidence for their similarity ($BF_{01} = 2.48$).

We anticipated that starting location would affect participants' subjective perceptions of the illusory body part. Statements 10, 11 and 12 measure participants' perceptions of supernumerary body parts (unspecified), fingers, and arms respectively. They were not presented following metacarpophalangeal-joint-departing conditions (conditions 8, 11, and 14); thus, the analysis of these statements excludes these conditions. For each starting location, averaged composite scores of the side-departing and disconnected conditions were calculated (i.e., wrist-starting/side-departing and wrist-starting/disconnected; forearm-starting/side-departing and forearm-starting/disconnected; and elbow-starting/side-departing and elbow-starting/disconnected). Consult Table 2 for descriptive statistics of each of the compared groups.

A Friedman test found that for Statement 10 ("I felt a body part coming out of my wrist / forearm / elbow"), starting location did not have a significant effect on embodiment, $\chi^2(2) = 2.34$, $p < 0.31$. Bayes factors suggest substantial evidence for similarity between the elbow-starting conditions and the wrist-starting ($BF_{01} = 3.76$) and forearm-starting ($BF_{01} = 4.63$) conditions, but not between the wrist- and forearm-starting conditions ($BF_{01} = 0.86$).

A Friedman test revealed a significant effect of starting location for Statement 11 ("I felt a finger coming out of my wrist / forearm / elbow"), $\chi^2(2) = 6.5$, $p = 0.04$. For this statement, forearm-starting conditions were significantly higher than elbow-starting conditions, $V = 160$, $p = 0.03$, $r = 0.56$. Wilcoxon signed-rank tests did not find significant differences between the wrist-starting and forearm-starting conditions ($V = 102$, $p = 1.00$, $r = 0.15$) or elbow-starting conditions ($V = 135.5$, $p = 0.09$, $r = 0.46$). Bayesian analyses found substantial evidence for similarity between wrist-starting and forearm-starting conditions ($BF_{01} = 4.29$), but not between wrist-starting and elbow-starting conditions ($BF_{01} = 0.18$), likely because this comparison was significantly different before Bonferroni correction.

Starting location had a significant effect on agreement with Statement 12 ("I felt an arm coming out of my wrist / forearm / elbow"), $\chi^2(2) = 17.94$, $p < 0.001$. Agreement ratings for an extra arm (Statement 12) were significantly higher for the forearm-starting ($V = 120$, $p = 0.002$, $r = 0.72$) and elbow-starting ($V = 146.5$, $p < 0.003$, $r = 0.70$) conditions than the wrist-starting conditions, but arm embodiment was not found to be significantly different between the forearm- and elbow-starting conditions ($V = 63.5$, $p = 1.00$, $r = 0.04$) and substantial evidence suggested the two composite scores were similar ($BF_{01} = 6.00$). See Fig. 6 for response distributions of Statements 11 and 12.

A two-way repeated measures ANOVA with starting location (wrist vs. forearm vs. elbow) and embodiment type (Statement 10/"I felt a body part coming out of my wrist / forearm / elbow" vs. Statement 11/"I felt a finger coming out of my wrist / forearm / elbow" vs. Statement 12/"I felt an arm coming out of my wrist / forearm / elbow") as factors revealed a significant interaction ($F(1.49, 31.32) = 13.18$, $p < 0.001$, $\eta^2G = 0.09$) and a significant main effect of embodiment type ($F(1, 21) = 14.96$, $p < 0.001$, $\eta^2G = 0.14$). The main effect of starting location was not significant, $F(1, 42) = 2.78$, $p = 0.07$, $\eta^2G = 0.02$.

Follow-up Wilcoxon signed-rank tests are reported in Table 3. Bayes factors providing evidence for similarity between groups were calculated for comparisons in which Wilcoxon tests did not find significant differences.

3.4. Anchoring

Analysis of anchoring effects examined differences in agreement ratings for Statement 1 ("It felt like I had six fingers on my left hand"; see Fig. 7 for response distributions). A two-way repeated measures ANOVA was conducted with condition (curved outside, pen embodiment, or curved inside) and anchoring (anchored or unanchored) as factors. The test found significant effects of anchoring ($F(1, 21) = 10.08$, $p = 0.005$, $\eta^2G = 0.08$) and the interaction between condition and anchoring ($F(2, 42) = 3.74$, $p = 0.03$, $\eta^2G = 0.03$). A Wilcoxon test found, accordingly, that anchored conditions ($M = 1.82 \pm 1.65$) produced higher embodiment ratings than unanchored conditions ($M = 0.71 \pm 2.15$; $V = 171.5$, $p = 0.002$, $r = 0.65$). The main effect of condition was not significant, $F(2, 42) = 2.26$, $p = 0.12$, $\eta^2G = 0.02$. The anchored and unanchored curved outside conditions were not significantly different from one another ($V = 36$, $p = 0.36$, $r = 0.33$) and the curved inside conditions were also not significantly different ($V = 82.5$, $p = 0.62$, $r = 0.27$). However, the anchored ($M = 2.00 \pm 1.35$) and unanchored ($M = -0.09 \pm 2.31$) pen embodiment conditions were significantly different, $V = 168.5$, $p = 0.009$, $r = 0.63$. Bayesian analyses revealed weak evidence for similarity between the curved outside ($BF_{01} = 1.18$) and curved inside ($BF_{01} = 2.43$) conditions.

Table 2
Means scores by starting location and embodiment type.

Starting location	Embodiment type		
	Unspecified Body Part[a]	Finger[b]	Arm[c]
Wrist (Conditions 9, 10)	0.45 ± 2.30	0.84 ± 2.15	–1.84 ± 1.60
Forearm (Conditions 12, 13)	1.18 ± 2.23	0.70 ± 2.17	–0.55 ± 2.26
Elbow (Conditions 15, 16)	0.86 ± 2.25	–0.39 ± 2.24	–0.45 ± 2.28
Overall	0.83 ± 2.26	0.39 ± 2.24	–0.95 ± 2.15

Note. For graphical depictions of these conditions, see Fig. 3. For a list of statements presented, see Table 1. [a] Statement 10: "I felt a body part coming out of my wrist / forearm / elbow." [b] Statement 11: "I felt a finger coming out of my wrist / forearm / elbow." [c] Statement 12: "I felt an arm coming out of my wrist / forearm / elbow.".

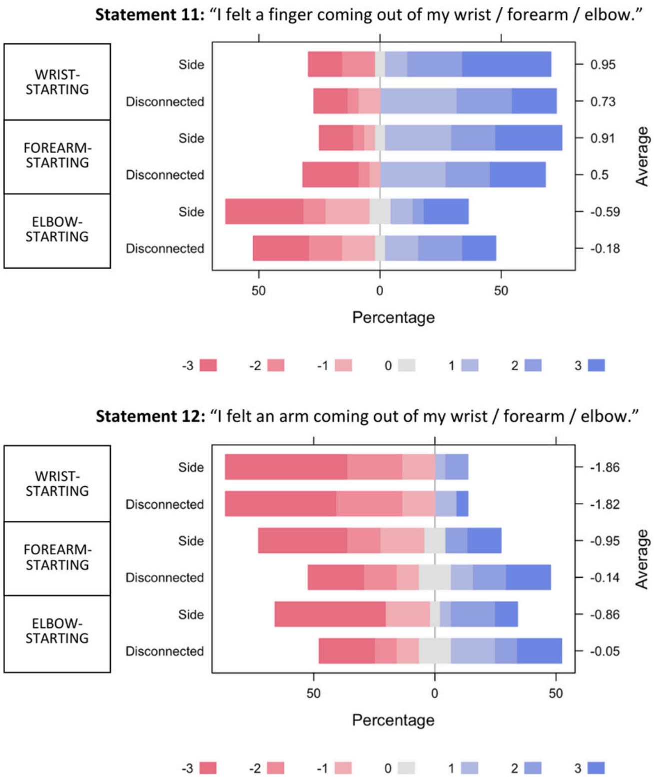

Fig. 6. *Response Distributions and Score Averages: Statements 11 (Extra Finger) and 12 (Extra Arm). Note.* Statements 11 and 12 were not presented after any of the control conditions, rendering comparisons to a control condition impossible. None of the conditions were significantly higher than 0 after Bonferroni correction.

Table 3
Wilcoxon signed-rank test results for effects of embodiment type by starting location.

Starting location	Embodiment type		
	Unspecified[a] vs. Finger[b]	Finger vs. Arm[c]	Unspecified vs. Arm
Wrist	$V = 18, p = 0.93, r = 0.35$; $BF_{01} = 1.33$	$V = 528, p < 0.001, r = 1.05$***	$V = 465, p < 0.001, r = 1.02$***
Forearm	$V = 71, p = 0.70, r = 0.38$; $BF_{01} = 1.71$	$V = 359.5, p = 0.08, r = 0.56$; $BF_{01} = 0.15$	$V = 347.5, p < 0.001, r = 0.93$***
Elbow	$V = 219, p = 0.003, r = 0.77$**	$V = 176, p = 1.00, r = 0.08$; $BF_{01} = 6.04$	$V = 289, p < 0.001, r = 0.85$***
Overall (Simple Effects)	$V = 796, p = 0.02, r = 0.60$*	$V = 3070, p < 0.001, r = 1.05$***	$V = 3202.5, p < 0.001, r = 1.63$***

Note. [a] Statement 10: "I felt a body part coming out of my wrist / forearm / elbow." [b] Statement 11: "I felt a finger coming out of my wrist / forearm / elbow." [c] Statement 12: "I felt an arm coming out of my wrist / forearm / elbow.".
*$p < 0.05$ **$p < 0.01$ ***$p < 0.001$.

3.5. Order effects

The effect of trial order was explored using linear mixed-effects models carried out using the package "lme4" in R. All models included subjects as a random intercept. Adding trial order as a fixed factor significantly improved the model, $\chi^2(1) = 4.83, p = 0.03$. Participants were slightly more likely to experience the illusion over time, with embodiment increasing by 0.03 points per trial on average. Adding a condition–order interaction parameter did not significantly improve model fit, $\chi^2(1) = 2.46, p = 0.12$.

3.6. Bimodality

Exploratory analyses used bimodal coefficients (BC) to examine bimodality in the data (Pfister et al., 2013). Analyses included participants who did not report a score of > 0 for Statement 1 following the basic illusion, as concern over a floor effect was not relevant for this question. BCs greater than 0.55 indicate bimodality. Aggregated across subjects, the data seem to be bimodal, BC = 0.76. To ensure that aggregating the data across subjects did not mask the true distribution of responses, bimodal coefficients were also calculated for each subject, with a mean BC of 0.70. The most frequent scores were 3 and –3, which together accounted for 52.4 % of scores.

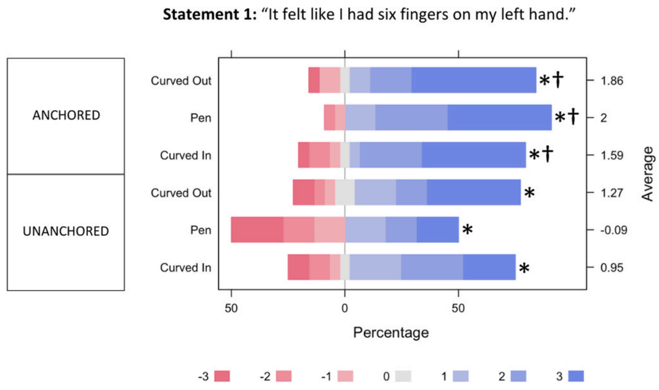

Fig. 7. *Response Distributions and Score Averages for Anchored and Unanchored Conditions: Statement 1 (Perception of Sixth Finger). Note.* * = significantly different from the fifth finger stroking control condition (Control 1). † = significantly higher than 0.

3.7. Qualitative data

Reactions throughout the session included gasps, laughs, and comments such as "This is so weird." In response to the open-ended questions, most participants (21) characterized the illusion as feeling "weird" or a similar adjective ("strange," "trippy," "crazy," or "bonkers"). The vast majority enjoyed the experience, describing it as "cool" (six participants), "interesting" (three participants), "entertaining" (one participant), "neat" (one participant), and "excellent" (one participant). However, two participants expressed negative emotions, saying they felt "stress" or "slight discomfort" at feeling "something that I knew wasn't there." Seven participants noted that they experienced feelings of confusion or disorientation. Several participants indicated that the tactile-only control condition (Control 3) was uniquely surprising.

Some of the participants' qualitative experiences were not captured in the presented Likert questions. One participant felt like "an invisible finger was stroking my hand," rather than them owning an invisible finger. That same participant also experienced several different types of embodiment for the conditions that started at the forearm or elbow and departed at the side of the arm or were disconnected. These included embodying an appendage that "felt like tentacle," "half a hand," "some sort of weird stick," and half of a duplication of their arm. To them, the curved fingers felt like a "spiral or vine." The conditions in which strokes started higher than the wrist elicited embodiment of an extra hand in a few participants. Some participants felt like the examiner was "touching me through something" like a "pillow" (one participant), that "the empty space was touching me" (one participant), or that a "ghost" was touching them (two participants). One participant likened the "sense of looking at something and feeling like it shouldn't be there" to gender dysphoria. Three participants noted that they knew that the two sides of the left fifth finger were being stroked but still experienced the illusion. On the curved finger conditions, some participants felt a curved tactile sensation despite the hidden fifth finger strokes being straight. While most participants embodied the supernumerary body part, some dissociated from it, and one even described feeling "that my pinky wasn't part of my body anymore." Attending to the tactile component rather than the visual seemed to break the illusion for at least one participant, who said they focused "more on the sensation in my left hand than what I was seeing" and, as a result, were not "distracted" enough by the misleading visual stimulus to "feel like I grew any extra body parts.".

Some participants reported unexpected illusory postural changes, motor activity, or tactile sensation. One participant said "it felt like my pinky had somehow moved without me knowing it, and that I couldn't see it anymore." Another "felt like I was writing with my left hand," or that the hand or finger "was moving." A few participants reported tactile sensation in non-stimulated locations, including the feeling of "someone touching my hair" (one participant) and "tingly" sensations on the right fifth finger (one participant) or right leg (one participant).

4. Discussion

We examined how manipulations of the Anne Boleyn illusion modulate embodiment strength, yielding several insights about the cognitive mechanisms underlying the illusion. First, all experimental conditions produced higher embodiment ratings than the fifth finger stroking and visual-only control conditions, further substantiating the robustness of the illusion previously reported by Ambron & Medina (2023). This emphasizes that, despite the variety of violations of stored body representations, bottom-up concurrent visuotactile inputs were sufficient to produce the illusion. Second, stroking in two distinct locations on the hidden fifth finger is not necessary to produce the illusion and does not even seem to strengthen it, as previously proposed (Newport et al., 2016). This evidence undermines the current theoretical account, which posits that spatially discrete mappings of the fifth and illusory sixth finger contribute to the illusion by facilitating remapping. We propose instead that spatial coherence between the viewed and felt touch enables embodiment of the empty space. Third, when the strokes start and depart at or above the wrist, starting location affects the categorization of the illusory body part. Agreement ratings indicate that illusory body parts extending from the wrist were more likely to be perceived as fingers than arms, and strokes from the elbow prompted perception of an unspecified "body part" more than illusory fingers or arms. This suggests that the illusory percept is easier to categorize when it extends from the wrist, a more biologically plausible location, than the elbow. Fourth, proximity to the hand increased embodiment for one of the three conditions violating a natural body shape, providing some evidence for an "anchoring" effect in which proximity to the individual's visible hand contributes to the robustness of the illusion.

4.1. Robustness of the illusion

The present study replicates and extends past work evaluating the extent of the illusion's robustness to violations of typical body constraints. All 19 experimental conditions elicited stronger illusory embodiment than the fifth finger stroking and visual-only control conditions, demonstrating that the illusion withstands a diverse range of body shape violations. As previously reported (Ambron & Medina, 2023), participants embodied illusory curved fingers and pens. Furthermore, relative to the control conditions, participants embodied supernumerary fingers starting as high as the elbow, curved fingers 3 in. away, and noncorporeal objects (pens) 3 in. away from the hand.

These variants of the illusion deliver visual and tactile stimulation synchronously and in the same approximate location, facilitating multisensory integration (Holmes & Spence, 2005). Concurrent visuotactile inputs typically originate from the same source (i.e., when an individual both sees and feels moving touch on their hand, those sensory experiences are usually from one object). This may explain why, in the Anne Boleyn illusion, the viewed touch of the empty space adjacent to the reflected hand is integrated with the felt touch on the hidden fifth finger, creating a percept of an invisible supernumerary finger. Notably, this illusion is more robust than other visuotactile illusions proposed to arise from the same bottom-up processes (e.g., the rubber hand illusion; Ambron & Medina, 2023). This may be explained by the spatial proximity of the illusory body part to the individual's real hand (the *anchoring* hypothesis, which is discussed further below).

4.2. Spatially distinct mappings are unnecessary

According to the original procedure (Newport et al., 2016), referred to here as the "basic illusion," the hidden fifth finger is stroked first on the medial side, corresponding with strokes along the middle of the visible fifth finger. For participants who experience the illusion, the viewed touch in the mirror is integrated with the synchronously felt touch on the hidden hand. Next, the hidden fifth finger is stroked on the lateral side at the same time as the empty space adjacent to the reflected fifth finger is stroked. The authors hypothesized that, since touch localization relies on somatotopic mapping of the body, the empty space is embodied because the visual and tactile inputs associated with the illusory finger are both more eccentric than those associated with the fifth finger. Therefore, the spontaneous remapping of the touch onto the empty space was initially attributed to the administration of strokes to two distinct locations on the hidden fifth finger. The present study, however, presents strong evidence against the *distinct mappings* hypothesis.

We tested the necessity of stroking in two discrete locations on the hidden fifth finger using three single-location conditions with strokes administered solely to the medial side, middle, or lateral side of the finger. Recall that in the basic illusion, the hidden fifth finger is stroked on its medial and lateral sides for the remapped fifth and sixth finger. We found that stroking in one location did not break the illusion, as participants' embodiment ratings remained significantly above zero, the fifth finger stroking control condition (Control 1), and the visual-only control condition (Control 2). Moreover, stroking in only one location did not significantly reduce the effect of the illusion on embodiment, and we even found substantial evidence for similarity between the basic and single-location conditions.

Originally, it was assumed that illusory embodiment required two somatotopically distinct tactile inputs on the hidden hand to map onto the two locations on the mirrored visible hand (the fifth finger and the empty space). The present findings indicate that, contrary to this assumption, stroking in two locations is not necessary for spontaneous remapping onto a sixth finger. We did not find evidence that stroking in only one location on the hidden fifth finger even undermined the illusion, as single-location conditions did not decrease embodiment ratings relative to the basic condition. This evidence sheds light on the relative weighting of different factors contributing to the illusion. Spatially and temporally congruent multisensory inputs are more likely to be integrated (Holmes & Spence, 2005; Stein & Meredith, 1990). Although the basic illusion involves temporal synchrony and visual coherence between the viewed and felt touch, delivering the strokes at inconsistent speeds or directions does not significantly decrease the illusion's effectiveness (Ambron & Medina, 2023), indicating that small spatial and temporal inconsistencies do not abolish the illusion. Taken together, this evidence supports the notion that precise mappings between visual and tactile inputs are not essential, and that, instead, the relationship between the tactile stimulation on the hidden hand and the viewed location of the visible hand in the mirror most strongly contributes to the illusory embodiment. Location has been identified as a key component of embodiment (Longo et al., 2008), and categorical processing may contribute to imprecise touch localization. Badde and colleagues (2019) demonstrate that touch can be mislocalized onto a different limb when occupying the typical location of that limb, suggesting that touch localization mechanisms may rely on categorical representations denoting side of the body and limb type. As Cadete & Longo (2020) discuss, the visual stimulation in the Anne Boleyn illusion is located within a plausible location of a finger on the left hand. As a result, the viewed and felt strokes do not need to precisely mimic one another, and the tactile stimulation associated with the fifth and sixth fingers need not be distinct, for touch to be misattributed to the empty space.

4.3. Starting and departing location effects

4.3.1. Effect of increased amount of congruent visuotactile information on illusion strength

We hypothesized that increasing the amount of congruent visuotactile information by increasing stroke length would strengthen embodiment, reflecting higher embodiment ratings. To address this question, we systematically manipulated the starting location of the strokes so that they began at the wrist, the distal-proximal midpoint of the forearm, or the midpoint of the cubital fossa (i.e., the elbow crease). Interestingly, starting the strokes at the elbow or forearm produced lower embodiment ratings. Touching distal to the wrist seems to have weakened the illusion. Skin is more sensitive to tactile stimulation on the hand than on the elbow (Tirrell et al., 2025), likely due to increased innervation density (Pardo et al., 2022), which may facilitate the integration of visual and tactile cues and strengthen embodiment.

Exploratory analysis revealed a bimodal distribution in the embodiment ratings, with the majority of trials eliciting responses at either the highest or lowest points on the scale. Therefore, the data may indicate that embodiment of the empty space is more binary than continuous—that is, participants either embody the sixth finger or did not—and that the congruent strokes at their original length are sufficient to induce the illusion, rendering the additional visuotactile stimulation from the longer strokes unimpactful.

An alternative explanation is that the present findings indicate not a decrease in embodiment strength overall, but a decrease in categorization of the percept as a finger specifically. Therefore, we also explored the effects of starting location on perceived body part type.

4.3.2. Starting location effects on perceived body part type

We anticipated that, for conditions in which the sixth strokes depart immediately or are disconnected from the body, starting location would modulate participants' categorization of the illusory appendage. Two conditions each had strokes that started at the wrist, forearm, or elbow: one that departed at the side of the hand/arm and one that was disconnected from the body (starting in the empty space adjacent to the starting location). Participants indicated their agreement level with statements measuring embodiment of an unspecific "body part," a "finger," and an "arm" extending from the starting location. The first statement does not specify a particular body part and serves as a baseline for overall strength of the illusion, since the primary statement refers to a "sixth finger" and therefore may not be sensitive to embodiment of appendages perceived to be non-finger-like.

Starting location affected embodiment ratings for a finger and an arm but not of an unspecified body part, indicating that starting location did not impact illusion strength but did affect how the percept was categorized. Stroking from the wrist produced lower embodiment of an arm than a finger, while stroking from the elbow produced similar embodiment scores for both a finger and an arm, both of which were lower than scores for the unspecified body part. Embodiment of a finger was lower in the elbow-starting conditions than the forearm-starting conditions, and we found substantial evidence for similarity between the forearm- and wrist-starting conditions. Conversely, embodiment of an arm was lowest in the wrist-starting conditions, and the forearm- and wrist-starting conditions were similar.

This evidence suggests that an illusory body part extending from the wrist or forearm is likely to be perceived as a finger, while illusory body parts extending from the elbow produce similar levels of embodiment but do not fit neatly into either category. These findings are in line with biological plausibilities and stored body representations. The wrist and forearm are closer to the hand, from which fingers extend, than the elbow is, and supernumerary appendages extending from the elbow have no anatomically plausible stored body part representation to map onto. Furthermore, while past research has demonstrated that body part location is a central component of embodiment, this study demonstrates that location of embodied empty space specifically affects how participants perceive and categorize illusory appendages.

Interestingly, the forearm-starting location seems to be a somewhat flexible starting point. For finger embodiment, forearm-starting conditions were similar to wrist-starting conditions and higher than elbow-starting conditions. However, for arm embodiment, they were similar to elbow-starting conditions and higher than wrist-starting conditions. This suggests that certain anatomical landmarks, such as joints, constrain categorization of illusory body parts. It is unclear whether the flexibility of the forearm starting location is due to its positioning halfway between the wrist and elbow, or whether anatomical landmarks such as joints have radiuses of proximity within which specific body parts are biologically feasible. If the former is correct, systematically varying the starting location between the wrist and elbow (e.g., dividing the forearm into quarters) should reveal a continuous gradient between the two joints. If the latter is correct, the gradient may accelerate as the starting location nears the critical marker.

These results emphasize constraints informed by location-dependent top-down influences from stored body representations on perceived body part type. While constraints from stored body representations do not seem to prevent the integration of the visual and tactile stimuli, as demonstrated by the illusion's robustness to biologically implausible manipulations such as the curved sixth finger, they do seem to constrain how the illusory percept is categorized. The present findings also demonstrate the existence of qualitative constraints on the illusion. Agreement ratings for a perceived extra finger were higher than they were for an arm, suggesting that the body schema is more susceptible to the addition of certain body parts than others. This parallels the difference in likelihood of polydactyly (1 out of 100–3300; Kyriazis et al., 2023) and polymelia (of which only a few cases have been reported; Mennen et al., 1997; O'Rahilly, 1951), suggesting that constraints on body schema manipulations may have evolved to be differentially accommodating of more common abnormalities. As polydactyly can be inherited, the evolution of body schema manipulation constraints to address external body abnormalities may partly explain individual differences in illusory embodiment, though this is speculative.

4.4. Spatial proximity ("anchoring") effects on robustness to body shape violations

To test whether proximity to the participant's visible real hand facilitated the illusion, we included three conditions depicting unnatural sixth fingers for which embodiment was shown to be relatively strong (Ambron & Medina, 2023). These included the curved outside sixth finger, the pen, and the curved inside sixth finger. These were compared to three conditions that were identical but started 3 in. from the metacarpophalangeal joint of the fifth finger. If proximity to the participant's real hand, or "anchoring," played a significant role in the persistence of the illusion during unnatural manipulations, we would expect a main effect of anchoring. We found higher illusion ratings for anchored compared to unanchored conditions. There was also a significant interaction between anchoring and condition, with follow up tests showing that the pen embodiment condition was the only condition in which embodiment was significantly reduced in the unanchored condition. Therefore, this constitutes some support for the *anchoring* hypothesis, but not conclusive evidence.

The *anchoring* hypothesis posits that the viewed proximity of the sixth finger to the participant's real hand facilitates the illusion's ability to accommodate diverse body plan violations. Anchoring involves two components: spatial proximity to the hand, which facilitates multisensory integration via spatial congruence (a bottom-up mechanism; Stein & Meredith, 1990) and biological plausibility (a top-down mechanism), and the visual similarity of the participant's viewed hand to their stored representation of that body part (a top-down mechanism; Tsakiris, 2010). The present experiment manipulates anchoring, yielding theoretical implications for how body ownership extends to include biologically implausible illusory body parts. It may be easier to extend the body plan to include "unnatural" body parts when the sixth finger appears to originate from the fifth finger metacarpophalangeal joint, an anatomical feature of the hand of which a mental representation already exists. This is consistent with theories (e.g., Tsakiris, 2010) emphasizing the importance of biological plausibility as an indicator of similarity between the present stimuli and pre-existing body representations. Interestingly, anchoring appears to interact with the perceived plausibility of the object, as only the pen embodiment condition exhibited an anchoring effect. This may imply that anchoring is especially facilitatory when the visual stimulus is a physical object (rather than empty space) or deviates substantially from the typical body part. In cases of stronger body plan violation, proximity to the body may be compensatory, allowing multisensory integration to occur despite these constraints. This points to a flexible perceptual system in which likelihood of embodiment is predicted by differently-weighted sources of evidence, similar to the Bayesian approach described by de Vignemont (2010).

A combination of factors may explain why we failed to find anchoring effects in all three illusion variants. The illusion may be flexible enough to simultaneously accommodate an unnatural shape or object that is also three inches away. That is, a distance of three inches may be insufficient to detect anchoring effects. Ambron & Medina (2023) found that, manipulating the basic illusion, displacing the sixth finger by three inches did not reduce embodiment but displacing it by six inches did. We anticipated that unnatural conditions would not necessitate a six inch displacement, but further research is needed to determine whether our approach was adequate. Also, as mentioned above, we only manipulated proximity, which is just one component at play in anchoring. The fact that the participant views the embodied space in the same visual frame as their real hand may account for the majority or entirety of an anchoring effect. Future work may test the relative importance of these two components of anchoring—proximity and real-handedness—and their interaction by systematically manipulating both. If proximity does independently play a significant role, our study may not be well-powered enough to detect it given our sample is designed for medium effect sizes.

As previously discussed, this study extends previous knowledge about the extent of the illusion's robustness. Earlier work has shown that the illusion can withstand manipulating the distance from the metacarpophalangeal joint as well as the type of object embodied and shape of the sixth finger, but not two of these anatomical implausibilities concurrently. Interestingly, we found no effect of anchoring on two of the three pertinent embodiments and, as noted above, all experimental conditions produced significantly higher embodiment than the fifth finger stroking and visual-only control conditions (Controls 1 and 2). This supports Ambron & Medina's (2023) previously noted suggestion that stored body representations may constrict novel body parts less than existing ones, and that spatial and temporal coincidence is a key facilitator of the Anne Boleyn illusion.

4.5. Conclusion

The present study explores the perceptual and cognitive mechanisms underlying the Anne Boleyn illusion. We show that the illusion is robust and flexible, withstanding a variety of biological implausibilities. Notably, tactile stimulation in two spatially distinct locations on the fifth finger is not a requisite for the illusion as previously proposed, and we suggest instead that the spatial and temporal alignment of visual and tactile inputs is the key factor driving multisensory integration. Manipulating the starting location of the strokes produced differences in the qualia of embodiment, substantiating the existence of top-down constraints from existing body representations on categorization of the illusory body part. We demonstrate that proximity to the individual's hand facilitates embodiment, providing preliminary evidence for the *anchoring* hypothesis. Future investigation of this hypothesis should examine how spatial proximity of the embodied space and realism of the viewed hand produce the illusion, independently or interactively.

CRediT authorship contribution statement

Isabel T. Folger: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Jared Medina:** Writing – review & editing, Supervision, Resources, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A1
Complete list of conditions.

Category	Associated conditions
Basic and Control Conditions	1. Basic illusion
	2. Fifth finger stroking control condition (Control 1)
	3. Visual-only control condition (Control 2)
	4. Tactile-only control condition (Control 3)
Hidden Fifth Finger Stroke Location	5. Medial strokes
	6. Middle strokes
	7. Lateral strokes
Systemic Variance of Starting and Departing Locations	8. Wrist-starting/metacarpophalangeal-joint-departing
	9. Wrist-starting/side-departing
	10. Wrist-starting/disconnected
	11. Forearm-starting/metacarpophalangeal-joint-departing
	12. Forearm-starting/side-departing
	13. Forearm-starting/disconnected
	14. Elbow-starting/metacarpophalangeal-joint-departing
	15. Elbow-starting/side-departing
	16. Elbow-starting/disconnected
Anchoring	17. Anchored/curved outside
	18. Anchored/pen
	19. Anchored/curved inside
	20. Unanchored/curved outside
	21. Unanchored/pen
	22. Unanchored/curved inside

Appendix B. Supplementary material

Supplementary data analysis to this article can be found online at https://doi.org/10.1016/j.concog.2025.103892. The raw data, protocol handout, and R script can be found at https://osf.io/jnxz6/.

References

Ambron, E., & Medina, J. (2023). Examining constraints on embodiment using the Anne Boleyn illusion. *Journal of Experimental Psychology: Human Perception and Performance, 49*(6), 877–892. https://doi.org/10.1037/xhp0001125

Armel, K. C., & Ramachandran, V. S. (2003). Projecting sensations to external objects: Evidence from skin conductance response. *Proceedings of the Royal Society of London. Series B: Biological Sciences, 270*(1523), 1499–1506.

Badde, S., Roeder, B., & Heed, T. (2019). Feeling a touch to the hand on the foot. *Current Biology, 29*(9), 1491–1497. https://doi.org/10.1016/j.cub.2019.02.060

Bell, D. C. (1877). *Notices of the historic persons buried in the chapel of St. Peter ad Vincula: In the tower of London. With an account of the discovery of the supposed remains of Queen Anne Boleyn*. J. Murray.

Botvinick, M., & Cohen, J. (1998). Rubber hands "feel" touch that eyes see. *Nature (London), 391*(6669), 756. https://doi.org/10.1038/35784

Cadete, D., Alsmith, J. T., & Longo, M. R. (2022). Curved sixth fingers: Flexible representation of the shape of supernumerary body parts. *Consciousness and Cognition, 105*. https://doi.org/10.1016/j.concog.2022.103413

Cadete, D., & Longo, M. R. (2020). A continuous illusion of having a sixth finger. *Perception, 49*(8), 807–821. https://doi.org/10.1177/0301006620939457

Cadete, D., & Longo, M. R. (2022). The long sixth finger illusion: The representation of the supernumerary finger is not a copy and can be felt with varying lengths. *Cognition, 218*. https://doi.org/10.1016/j.cognition.2021.104948

Costantini, M., & Haggard, P. (2007). The rubber hand illusion: Sensitivity and reference frame for body ownership. *Consciousness and Cognition, 16*(2), 229–240. https://doi.org/10.1016/j.concog.2007.01.001

Crea, S., D'Alonzo, M., Vitiello, N., & Cipriani, C. (2015). The rubber foot illusion. *Journal of Neuroengineering and Rehabilitation, 12*, 1–6.

D'Angelo, M., Maister, L., Tucciarelli, R., Frassinetti, F., & Longo, M. (2021). Embodying an invisible face shrinks the cone of gaze. *Journal of Experimental Psychology: General, 150*(6), 1132–1146. https://doi.org/10.1037/xge0000953

De Preester, H., & Tsakiris, M. (2009). Body-extension versus body-incorporation: Is there a need for a body-model? *Phenomenology and the Cognitive Sciences, 8*, 307–319.

de Vignemont, F. (2010). Body schema and body image—Pros and cons. *Neuropsychologia, 48*(3), 669–680. https://doi.org/10.1016/j.neuropsychologia.2009.09.022

Ehrsson, H. H., Spence, C., & Passingham, R. E. (2004). That's my hand! Activity in premotor cortex reflects feeling of ownership of a limb. *Science, 305*(5685), 875–877. https://doi.org/10.1126/science.1097011

Fan, C., Coppi, S., & Ehrsson, H. H. (2021). The supernumerary rubber hand illusion revisited: Perceived duplication of limbs and visuotactile events. *Journal of Experimental Psychology: Human Perception and Performance, 47*(6), 810–829. https://doi.org/10.1037/xhp0000904

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175–191. https://doi.org/10.3758/BF03193146

Guterstam, A., Gentile, G., & Ehrsson, H. H. (2013). The invisible hand illusion: Multisensory integration leads to the embodiment of a discrete volume of empty space. *Journal of Cognitive Neuroscience, 25*(7), 1078–1099. https://doi-org.ezproxy.carleton.edu/10.1162/jocn_a_00393.

Guterstam, A., Petkova, V. I., & Ehrsson, H. H. (2011). The illusion of owning a third arm. *PLoS One, 6*(2). https://doi.org/10.1371/journal.pone.0017208

Haans, A., IJsselsteijn, W. A., & de Kort, Y. A. (2008). The effect of similarities in skin texture and hand shape on perceived ownership of a fake limb. *Body Image, 5*(4), 389–394. Doi: 10.1016/j.bodyim.2008.04.003.

Holmes, N. P., & Spence, C. (2005). Multisensory integration: Space, time and superadditivity. *Current Biology, 15*(18). https://doi.org/10.1016/j.cub.2005.08.058

Jarosz, A. F., & Wiley, J. (2014). What are the odds? A practical guide to computing and reporting Bayes factors. *The Journal of Problem Solving, 7*(1), 2. https://doi.org/10.7771/1932-6246.1167

Jeffreys, H. (1961). *Theory of probability* (3rd ed.). Oxford University Press.

Kalckert, A., & Ehrsson, H. H. (2012). Moving a rubber hand that feels like your own: A dissociation of ownership and agency. *Frontiers in Human Neuroscience, 6*(40). https://doi.org/10.3389/fnhum.2012.00040

Kalckert, A., & Ehrsson, H. H. (2014). The spatial distance rule in the moving and classical rubber hand illusions. *Consciousness and Cognition, 30*, 118–132.

Kyriazis, Z., Kollia, P., Grivea, I., Stefanou, N., Sotiriou, S., & Dailiana, Z. H. (2023). Polydactyly: Clinical and molecular manifestations. *World Journal of Orthopedics, 14*(1), 13.

Lenggenhager, B., Hilti, L., & Brugger, P. (2015). Disturbed body integrity and the "rubber foot illusion". *Neuropsychology, 29*(2), 205.

Liu, Y., & Medina, J. (2017). Influence of the body schema on multisensory integration: Evidence from the mirror box illusion. *Scientific Reports, 7*(1), 1–11. https://doi.org/10.1038/s41598-017-04797-0

Lloyd, D. M. (2007). Spatial limits on referred touch to an alien limb may reflect boundaries of visuo-tactile peripersonal space surrounding the hand. *Brain and Cognition, 64*(1), 104–109. https://doi.org/10.1016/j.bandc.2006.09.013

Longo, M. R., Schüür, F., Kammers, M. P., Tsakiris, M., & Haggard, P. (2008). What is embodiment? A psychometric approach. *Cognition, 107*(3), 978–998. https://doi.org/10.1016/j.cognition.2007.12.004

Mennen, U., Deleare, O., & Matime, A. (1997). Upper limb triplication with radial dimelia. *Journal of Hand Surgery, 22*(1), 80–83. https://doi.org/10.1016/S0266-7681(97)80025-3

Newport, R., Wong, D. Y., Howard, E. M., & Silver, E. (2016). The Anne Boleyn Illusion is a six-fingered salute to sensory remapping. *i-Perception, 7*(5), Doi: 10.1177/2041669516669732.

O'Rahilly, R. (1951). Morphological patterns in limb deficiencies and duplications. *American Journal of Anatomy, 89*(2), 135–193. https://doi.org/10.1002/aja.1000890202

Pardo, L. A., Jr, Markovic, M., Schilling, A. F., Wilke, M. A., & Ernst, J. (2022). Vibrotactile mapping of the upper extremity: Absolute perceived intensity is location-dependent; perception of relative changes is not. *Frontiers in Neuroscience, 16*, Article 958415. https://doi.org/10.3389/fnins.2022.958415

Pfister, R., Schwarz, K. A., Janczyk, M., Dale, R., & Freeman, J. B. (2013). Good things peak in pairs: A note on the bimodality coefficient. *Frontiers in Psychology, 4*, 700. https://doi.org/10.3389/fpsyg.2013.00700

Raftery, A. E. (1995). Bayesian model selection in social Research. *Sociological Methodology, 25*, 111–163. https://doi.org/10.2307/271063

Slater, M., Perez-Marcos, D., Ehrsson, H. H., & Sanchez-Vives, M. V. (2008). Towards a digital body: The virtual arm illusion. *Frontiers in Human Neuroscience, 2*(6). https://doi.org/10.3389/neuro.09.006.2008

Stein, B. E., & Meredith, M. A. (1990). Multisensory integration: Neural and behavioral solutions for dealing with stimuli from different sensory modalities. *Annals of the New York Academy of Sciences, 608*(1), 51–70. https://doi.org/10.1111/j.1749-6632.1990.tb48891.x

Tirrell, E. M., Kalantaryardebily, N., Feldbush, A. C., Sydnor, L., Grubb, C., Parcetich, K., & Gurari, N. (2025). Considerations for tactile perceptual assessments: Impact of arm dominance, nerve, location, and sex in young and older adults. *Experimental Brain Research, 243*(4), 92. https://doi.org/10.1007/s00221-025-07044-5

Tsakiris, M. (2010). My body in the brain: A neurocognitive model of body-ownership. *Neuropsychologia, 48*(3), 703–712. https://doi.org/10.1016/j.neuropsychologia.2009.09.034

Tsakiris, M., & Haggard, P. (2005). The rubber hand illusion revisited: Visuotactile integration and self-attribution. *Journal of Experimental Psychology: Human Perception and Performance, 31*(1), 80.

Wang, G., Wang, W., Wang, Z., Huang, S., Liu, Y., & Ming, D. (2025). The sixth finger illusion induced by palm outside stroking shows stable ownership and independence. *Scientific Reports, 15*(1), 11447.