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Examining Constraints on Embodiment Using the Anne Boleyn Illusion

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Using a mirror box, the concurrent stroking of the lateral side of the fifth finger behind the mirror along with stroking the empty space next to the mirror-reflected hand's fifth finger results in a strong sense of having a sixth finger—the Anne Boleyn illusion. We used this illusion to understand what constraints illusory embodiment. In Experiment 1, we manipulated the anatomical constraints, posture, and stroking of the sixth finger, along with other variants. Given evidence from other body illusions, we predicted no illusory embodiment in conditions in which the sixth finger was created in a manner incompatible with a typical hand, when the mirror and viewed hands were in different posture, and when stroking differed. Surprisingly, the illusion was persistent in most variants, including those with curved fingers, elongated fingers, and even with mismatches between the posture of the viewed and hidden hand. In Experiment 2, we manipulated the orientation, shape, and length of the illusory sixth finger, presenting more extreme versions of the illusion. The illusion was significantly diminished only when the sixth finger was far from the hand, or in a very implausible posture. This evidence suggests that body representations are extremely flexible and allow for embodiment of empty space in conditions not seen in other body illusions. We suggest that bottom-up information from concurrent visuotactile input, combined with reduced constraints provided by the "blank canvas" of empty space, results in a particularly robust illusion.

Public Significance Statement
This study demonstrates that the illusory perception of a sixth finger in the empty space has little constraints and provides strong evidence regarding the flexibility of the body representation.

Keywords: Anne Boleyn illusion, rubber hand illusion, multisensory integration, touch, vision, mirror box

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Various studies using the rubber hand illusion (Botvinick & Cohen, 1998; Golaszewski et al., 2021), mirror box illusion (Liu & Medina, 2017; Medina et al., 2015), invisible enfacement illusion (D'Angelo et al., 2021), and virtual reality (Ambron et al., 2020) have shown that it is possible to perceive ownership of a visual object that looks like, but is not, one's own body. Interestingly, individuals can also embody *empty space* with concurrent visuotactile stimulation, either as an invisible body (Guterstam et al., 2015), hand (Guterstam et al., 2013), or by creating the percept of a sixth finger. To do this, Newport et al. (2016) placed participants' hands in a mirror box, viewing a reflection of their left hand in the location of their right hand (what we will call the "mirror hand"), with their actual right hand (the hidden hand) located behind the mirror in the same location as the visual image of the left hand. Each trial began with synchronous stroking of both hands simultaneously, with one stroke for each finger (first to fourth). For the fifth stroke, the experimenter stroked the *medial* side of the fifth finger of the right hand behind the mirror (the hidden hand), while simultaneously stroking the middle of the fifth finger of the mirror hand. On the critical sixth stroke, the experimenter stroked the *lateral* side of the hidden fifth finger while on the mirror hand, simultaneously stroking from the metacarpophalangeal joint of the fifth finger out into empty space. Participants reported a strong sense of embodying a sixth finger, which was not observed in a control condition with asynchronous stroking (see also Cadete & Longo, 2020). This illusion was named the "Anne Boleyn" after the second wife of Henry the VIII of England (Bell, 1877) who was portrayed as having a sixth finger on her right hand.

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This illusion demonstrates that the concurrent visuotactile stimulation of a viewed and hidden hand can lead to the illusory perception of an invisible sixth finger. Interestingly, the illusion does not need to be subject to the physical constraints of an object or of the hand like in other illusions (e.g., rubber hand), as stroking the illusory finger occurs in empty space. The stroking that leads to a perceived invisible sixth finger in the original Anne Boleyn illusion can be "remixed" in several ways, for example, location, shape, length, etc.; all of which may influence the effectiveness and experience of the illusion.

Furthermore, an examination of what does (and does not) lead to illusory embodiment can provide evidence regarding potential constraints on embodiment. Prior studies on embodiment typically involve the participant's real hand and a second, embodiable object (e.g., a rubber hand, mirror image of the opposite hand, a virtual-reality avatar of their hand or body). In these studies, there are three major factors that influence embodiment: whether the embodiable object has a similar visual form as the participant's own body, whether stroking is congruent between the participant's body and the embodiable object, and whether there is postural congruency between the participant's body and the embodiable object. These findings have informed general models of embodiment and body ownership and posit that embodiment will not occur when these constraints are violated (see Tsakiris, 2010 for an example). However, these models are informed primarily by experiments in which the participant needs to embody a distinct object that is disconnected from their own body, for example, a rubber hand. In those types of experiments, participants will report embodiment of their own hand (if the illusion fails), the rubber hand (if the illusion succeeds), but not both. In these examples, there is no alteration of the typical body plan of the individual.

Supernumerary embodiment involves the illusory augmentation and/or alteration of one's own body plan. Previous studies on supernumerary embodiment have found that individuals can embody multiple hands, in paradigms that involve both single (Guterstam et al., 2011) or double (Fan et al., 2021) rubber hands. Examining the limits of embodying supernumerary hands, Guterstam et al. (2011) found that ownership of a supernumerary hand dramatically decreases if there is no correspondence between real and rubber hands in terms of hand laterality, anatomical congruency (i.e., the rubber hand rotated 180°), visuotactile congruency (i.e., synchronous vs. asynchronous touch; see also Fan et al., 2021), or effector congruency (i.e., a rubber foot instead of rubber hand). Supernumerary limb embodiment has also been examined in an "invisible hand illusion" in which participants embody empty space. Similar to the Anne Boleyn illusion, Guterstam et al. (2013) stroked the participant's hidden hand while making similar strokes in viewed, empty space. Participants reported embodiment of the invisible hand. However, this illusion also broke down during asynchronous stroking (Experiment 1), incongruence between the stroking direction and hand location (Experiment 2), when the invisible hand was placed outside the peripersonal space (Experiment 3), and when viewed stroking happened over a block of wood rather than the empty space (Experiment 4). These experiments all provide evidence consistent with nonsupernumerary rubber hand studies: That visual form, posture, the location of touch, and temporal congruency between viewed and felt touch are all necessary for illusory ownership to occur.

However, there are major differences between previous supernumerary rubber hand studies and the Anne Boleyn illusion. Although adding a supernumerary finger and limb are both violations of the typical body plan, ulnar or postaxial polydactyly (having an additional finger ulnar to the fifth finger) occurs in about one in five hundred individuals (McCarroll, 2000), whereas polymelia (having additional limbs) is extremely rare with only a few cases in the literature (e.g., Mennen et al., 1997; O'Rahilly, 1951). Furthermore, the Anne Boleyn illusion typically involves illusory strokes that are directly connected to one's own body, whereas this is not the case in the rubber hand illusion (either the supernumerary or traditional version). Although previous models of embodiment (e.g., Tsakiris, 2010) have been presented generally in a way that applies to all findings, one possibility is that supernumerary finger embodiment in the Anne Boleyn illusion does not operate based on the same constraints as embodiment as measured using the rubber hand paradigm. In this paper, we examined three potential constraints that have been considered essential for embodiment in the rubber hand illusion literature: anatomical plausibility, spatiotemporal congruence, and postural congruence.

One potential constraint on supernumerary embodiment is whether the additional finger conforms to an anatomically plausible body plan. In the original paper reporting the illusion (Newport et al., 2016), the illusory sixth finger was fairly typical: located in an anatomically plausible location consistent with the most common forms of polydactyly in humans (sixth finger on the ulnar side of the hand) and the same length as a usual fifth finger. An open question is whether altering the plausibility of the sixth finger influences illusory supernumerary embodiment. Given that the illusory strokes occur in empty space, this illusion can be altered in ways to "create" fingers that do not conform to typical body representations. For example, the sixth finger could be positioned in a manner that would be anatomically unlikely based on a typical body plan (e.g., disconnected from the hand, perpendicular to the other fingers, or extended upwards beyond the limits of typical finger movement). Changes in perceived body size have been examined with the Pinocchio illusion (De Vignemont et al., 2005; Lackner, 1988) and other body illusions (Byrne & Preston, 2019). Recently, Cadete and Longo (2022) found that the Anne Boleyn illusion could change the perceived length of the illusory sixth finger, making it feel shorter or longer than a fifth finger. In a separate study, Cadete et al. (2022) also found that participant can embody and perceive a curved sixth finger curved laterally toward the fifth finger at 180°. In the present study, we modified the Anne Boleyn illusion to examine whether changes in size and shape of the illusory sixth finger, specifically curvature or bends in the finger (laterally toward and away from the fifth finger), would influence embodiment of the illusory sixth finger. For conditions in which the orientation or shape of the illusory sixth finger was altered, we predicted that perception of an illusory sixth finger would decrease in conditions that would be impossible for a real finger, under the assumption that this illusory finger operated with the same constraints as a typical finger. Therefore, "impossible" positions for a typical finger should result in less illusory embodiment. We also predicted a similar decrease in illusion strength for changes in finger size or length.

Second, the temporal and spatial rules of multisensory integration state that events in temporal and spatial proximity are likely to be perceived as coming from the same source (Holmes & Spence, 2005). These rules apply to ownership of the rubber hand such that the illusion is dramatically reduced when touch is presented asynchronously to the two hands (Botvinick & Cohen, 1998). Costantini and Haggard (2007) showed that the rubber hand illusion is maintained if the stroking direction is congruent with hand position, while the illusion decreases in conditions in which stroking is incongruent between hands or both stroking and hand position are incongruent. To examine temporal and spatial factors in the Anne Boleyn illusion, we altered the congruency between the strokes to the invisible sixth finger and the actual finger in three ways: changing stroke direction (knuckle to tip on illusory sixth finger, tip to knuckle on actual fifth finger), speed of stroking (four quick strokes on the hidden fifth finger for every stroke on the illusory sixth finger), and by stroking different fingers (stroking the thumb on the hidden hand and the illusory sixth finger of the viewed hand). Given the importance of temporal and spatial congruence in past literature, we predicted that these incongruent stroke conditions would decrease the strength of the illusion.

Third, postural congruence between the actual and viewed hand may also affect embodiment. Costantini and Haggard (2007) also manipulated the relative posture of the rubber and actual hands in the rubber hand illusion, finding that a mismatch between the position of the rubber and real hands diminished the strength of the illusion as measured via proprioceptive drift. Liu and Medina (2017) instructed individuals to make bimanual movements in a mirror box, in which the postural mismatch between the hidden hand and the mirror-reflected hand varied anywhere from 0° to 270° of angular rotation (e.g., both hands palms down vs. hidden left hand facing outward, mirror-reflected hand positioned palm up). They found that the amount of postural incongruence influenced the strength of the illusion, with more perceived illusory rotation of the hand (toward the viewed position) with less postural incongruence. Both results suggest that postural congruence is important for multisensory integration and embodiment. To examine this in the Anne Boleyn illusion, we positioned the hidden hand palm up, opposite the posture of the viewed hand. Given the mismatch between the posture of the viewed and felt hand, we predicted a significant decrease in the illusion in these conditions.

In addition to the effects of these three main factors, the Anne Boleyn illusion offers an opportunity to test other aspects of embodiment. Using a variant of the rubber hand illusion, Armel and Ramachandran (2003) reported evidence that suggested embodiment of noncorporeal objects is possible. We examined whether people would report feeling a pen as a sixth finger using this illusion. Furthermore, given that the original Anne Boleyn illusion could create additional fingers, and those other illusions using tendon vibration (Craske, 1977) or rubber hands (Ehrsson, 2009; Newport et al., 2010) have resulted in perceiving additional arms, we attempted to use the Anne Boleyn illusion to create the sensation of an additional arm.

Experiment 1 tested which conditions influenced the Anne Boleyn Illusion, manipulating the anatomical constraints of the hand, the effect of stroking procedure, hand posture, and other factors. One hypothesis is that the constraints observed in rubber hand illusion studies are generalizable to all body illusions and would be the same for supernumerary finger embodiment. If so, then one would predict that incongruence along these dimensions (body form, stroking congruency, and postural congruency) would result in diminished supernumerary finger embodiment. However, differences between the Anne Boleyn and rubber hand illusion may result in differences such that previously identified constraints on embodiment may not apply to the Anne Boleyn illusion.

Surprisingly, we found that the illusion was fairly robust to incongruencies, as ratings of perceiving an illusory finger were significantly higher in most experimental conditions, including those with incongruence along these dimensions, compared to a control condition. In Experiment 2, we tested the results of Experiment 1 further parametrically manipulating the orientation, location, and shape of the six fingers. As the results of Experiment 1 showed a reduction of the illusion when the sixth finger was placed at an unusual orientation (120°) concerning the basic illusion, we tested whether an additional reduction of the illusion occurred when the sixth finger was presented at a more extreme orientation (180°). If on one hand the location and shape of the sixth finger did not seem to have a primary effect on the illusion in Experiment 1, on the other hand, it was possible that the manipulations of Experiment 1 might not have been too extreme to influence the illusion. In Experiment 2, we parametrically varied these factors and included conditions that were more extreme than in Experiment 1 (e.g., finger angled at 135° or placed 6 in. away from the body). The illusion of the sixth finger was consistent in most of the conditions and diminished only in conditions that were quite distinct from a typical body.

Material and Method

Apparatus

The same apparatus was used in all experiments. We used a mirror box apparatus (used in Liu & Medina, 2017), consisting of an acrylic mirror facing rightward (16″ [40.6 cm] Depth × 12″ [30.5 cm] Height) located at the center of the mirror box perpendicular to a wooden base (36″ [91.4 cm] Wide × 16″ [40.6 cm] Deep). Participants comfortably sat with their trunk midline aligned with the mirror, hands palm down, with the medial edge of each hand positioned 9.5 cm from the mirror midline. The right hand was reflected in the mirror and will be called the visible hand, while the left hand was located behind the mirror and will be called the hidden hand. Note that by viewing the mirror, the reflection of their right hand looked like their left hand was in the same space as their actual, hidden left hand. Participants were asked to remove any jewelry, so that both hands looked similar. No participants with tattoos on their hands were tested. Participants were instructed to look at the mirror hand during the entire experiment.

Experiment 1

Participants

Thirty-four undergraduate students (24 women; $M_{age} = 19.27$, $SD_{age} = 1.20$) took part in the present study. Participants were recruited from the General Psychology subject pool of the University of Delaware and this study was approved by the University of Delaware Institutional Review Board (IRB). All participants provided verbal consent prior to starting the testing session and received course credit for their participation. All participants were naïve to the purpose of the study, and no participants had been in any other body illusion experiments. A previous study using the Anne Boleyn illusion showed a large effect size for the primary illusion ($d = 1.76$; Cadete & Longo, 2022). Given that we were examining variants of the illusion which may be less likely to occur, we aimed for a sample size of $n = 33$ to detect a medium effect size ($d = 0.6$, alpha level 0.05; power 0.9) (G*Power 3.1; Faul et al., 2007). Data of this experiment was collected during 2020–2021.

General Procedure

Participants were presented with a series of conditions that were variants of the Anne Boleyn illusion (what we call the basic illusion in this paper) as described by Newport et al. (2016). Each condition entailed two phases: a simple touch phase where we stroked the fingers on both hands simultaneously, and an induction phase immediately afterward in which we attempted to create an illusory finger. After the induction phase, participants were provided with a short questionnaire. The simple touch phase and the questionnaire were similar across trials, while the induction phase changed for each trial. Each condition was presented once to each subject (one trial for each condition), and condition order was randomized across participants. This study was not preregistered.

Simple Touch Phase. The examiner used their own fingers to stroke (from the knuckle to the tip of the finger) each finger of both the hidden and visible hands at the same time, starting from the thumb to the fifth finger (approximately for each stroke). The examiner counted the first five strokes aloud and urged the participant to do the same (see Newport et al., 2016).

Induction Phase. The induction phase of our experimental manipulations varied from the original illusion. The examiner stroked both hands of the participant at the same time with his/her index fingers without counting. The stroking proceeded from the thumb to the fifth finger (about a second for each stroke), starting from the metacarpophalangeal joint (knuckle) to the tip of the finger and proceeded from the thumb to the fifth finger. On the fifth stroke of the induction phase, the experimenter simultaneously stroked the *medial* side of the fifth finger of the hidden hand and the center of the fifth finger dorsum of the visible hand (see Figure 1, Basic Illusion). In our version of the basic illusion, for the next four induction strokes (sixth–ninth), the examiner stroked the *lateral* side of the fifth finger of the hidden hand at the same time as stroking the empty space of the visible hand. These strokes in empty space began at the metacarpophalangeal joint of the fifth finger and extended out as if creating an additional finger.

We included two control conditions, which removed either the stroking of empty space or the tactile input (stroking the fifth finger of the hidden hand). Our first control condition was similar to the control condition in Newport et al. (2016). The first four induction strokes were the same as in the basic illusion, while for Induction Strokes 5–9, the experimenter stroked the hidden hand in the same manner (fifth induction stroke—medial side of the fifth finger; sixth–ninth induction stroke—lateral side of the fifth finger). For the mirror hand on Induction Strokes 5–9, instead of stroking empty space, the experimenter stroked the dorsum of the fifth finger (see Figure 1, Control 1). In the second control condition, we matched the basic illusion for visual input while removing tactile input (see Figure 1, Control 2). The examiner simultaneously stroked the inner portion of the fifth finger of the hidden hand and the dorsum of the fifth finger on the visible hand (fifth induction stroke). For Induction Strokes 6–9, only empty space was stroked with no touch presented to the actual unseen hand (Figure 1).

For most of our experimental conditions, the primary difference from the basic illusion was due to the strokes in the induction phase (6–9) that "created" the sixth finger. Figure 2 provides a graphical summary of these manipulations, and Table 1 provides a brief summary of these manipulations. Please see Handout 1 (in the online supplemental material) for the detailed experimenter instructions.

Questionnaire. Our questionnaires were based on previous research on this illusion (Cadete & Longo, 2020; Newport et al., 2016). Seven statements were presented in a fixed order after each induction phase, and participants were asked to rate their level of agreement with each statement using a 7-point Likert scale from −3 (*strongly disagree*) to 3 (*strongly agree*). In addition to these general statements regarding different aspects of the illusion, we also asked specific statements tailored to certain experimental conditions (see Table 2).

Data Analysis. Likert scale responses violated the normality assumption (tested with Shapiro–Wilk Test) and were analyzed using two series of Wilcoxon signed-rank tests. We first examined illusion effectiveness by comparing responses in illusion conditions with the first control condition (Control 1) in which there was no stroking of empty space, and no illusory finger perception should occur. If the illusion was effective at changing body perception, we hypothesized a significant increase in Likert scale ratings to questions related to perceiving additional fingers.

Second, we examined whether the strength of the illusion in our experimental manipulations was reduced in conditions that violated the anatomical constraints or the spatiotemporal congruency of tactile and visual inputs. To do this, we compared Likert scale ratings in the basic illusion condition to ratings in one of our novel illusion variants. To avoid floor effects in which decreases could not be observed in those who do not experience the illusion, we only selected a subset of individuals—those who perceived a sixth finger in the basic illusion condition (ratings from +1 to +3 on the question "it felt like I had six fingers on my left hand," 24 out of 34 participants). We then computed the difference score from basic illusion with each novel experimental condition and tested whether this score differed from zero using one-sample Wilcoxon signed-rank tests. These data were also analyzed using Bayesian statistics, implemented in R using the BayesFactor package, to test whether each variant of the illusion elicited the same sensation of the sixth finger as the basic illusion.

Effect sizes for Wilcoxon signed-rank tests were estimated using "rcompanion" package in R. We used a Bonferroni-corrected α of $p = .05$ (uncorrected, $p = .0025$). Values are reported uncorrected in the results section, and only value $<.0025$ described as significant. In the main text, we report results from Statements 1 ("It felt like I had six fingers on my left hand"), 4 ("I felt a touch that was not on my body"), and 5 ("I felt like I had an extra hand"). Responses for other statements are presented in the online supplemental material.

Transparency and Openness. For both experiments, raw data, scripts, and handouts necessary to replicate this study are available on Open Science Framework at the following link https://osf.io/kt8nw/.

Results

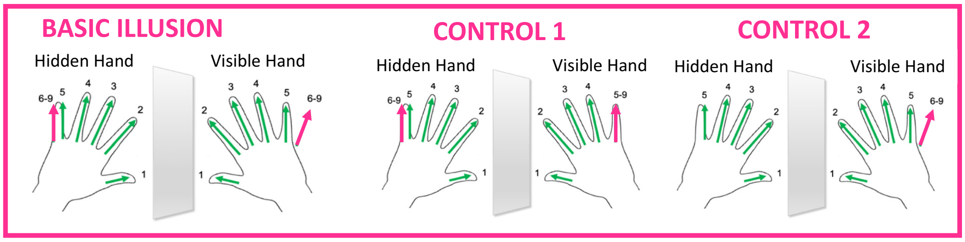
Mean Likert scores and standard deviations for the responses on Statements 1, 4, and 5 are reported in Figure 3 (see the online supplemental material for additional statements and analyses).

We first examined whether each novel variant elicited the illusion, comparing Likert scale ratings in each condition to the original control condition (Control 1).[1] Ratings for perceiving a sixth finger (Statement 1) were significantly greater for nearly all experimental conditions versus the control condition (see Table 3; see the starred

[1] Similar results for Statement 1 were also obtained comparing each experimental condition with Control 2 (see Table 1 in the Online Supplemental Material).

Figure 1

Induction Procedure of the Basic Illusion and Control Conditions



Note. The green arrows (1–5) depict the stroking direction, while the numbers represent stroke order. The pink arrow (6) indicates the important strokes for illusion creation or control conditions. See the online article for the color version of the figure.

conditions in Figure 3). For the vast majority of these novel conditions, Likert scale ratings for perceiving a sixth finger were above zero. Given that participants do not experience sixth fingers in everyday life, these results suggest that illusory finger perception was generated in most of these conditions. This can also be seen in Figure 3 by examining the response distributions. Note that for the majority of novel, noncontrol conditions, over 50% of participants agreed that they experienced a sixth finger, with many strongly agreeing with the statement (see the dark blue).

That said, there were a few conditions that did not significantly differ from the Control 1 condition: the 120° sixth finger condition and the fifth finger elongation condition (see Table 3). Given that no sixth finger was expected in the fifth finger elongation condition, this was expected. Furthermore, the sensation of an additional arm was not induced, as participants did not show a significant difference in perceiving an extra arm compared to the control condition.

As one may argue that the order effect may have contributed to these results, we ran a mixed linear model analysis and tested whether a model including condition and trial order could better account for a model including only the experimental conditions. The analysis was run using the lmer4 package, and models were compared using the ANOVA function. The results showed that a model including condition as a fixed factor was a better predictor of the scores in Statement 1 than a model with only subjects as random intercept, logLik $= -1{,}005$, $\chi^2(10) = 133$, $p < .001$. However, adding trial order did not improve significantly model fit, logLik $= -1{,}000$, $\chi^2(11) = 10.7$, $p = .46$, suggesting that trial order did not significantly account for the observed effects.

Participants perceived a touch that was not on their body (Statement 4) in all conditions ($p < .0025$, $r > .5$), except for the arm ($W_{33} = 202$, $p = .0026$, 95% confidence interval (CI) [1, 4], $r = .67$). There were no significant differences between the experimental and control conditions for the statement regarding feeling an extra hand (Statement 5).

Finally, there were no significant differences between the two control conditions in any of the statements (Statement 1: $W_{33} = 96$, $p = .36$, 95% CI [−1, 3.4], $r = .15$; Statement 4: $W_{33} = 47.5$, $p = .29$, 95% CI [−3.5, 1], $r = .17$; Statement 5: $W_{33} = 39.5$, $p = .23$, 95% CI [−1.4, 3.9], $r = .20$), suggesting that vision of the touch alone was not enough to induce the illusion of the sixth finger.

For our second analysis, we examined whether illusion variants differed in Likert scale ratings from the basic illusion, using the subset of participants who experienced the illusion (24 out of 34 participants). We did this by computing the difference from the basic illusion to these variants and tested whether the computed difference differed from zero. Doing this, we only found two experimental conditions in which the illusion significantly decreased compared to the first control condition: fifth finger elongation ($W_{23} = 164$, $p < .001$, 95% CI [2.49, 5.49], $r = .70$) and the additional arm ($W_{23} = 210$, $p < .001$, CI [2.50, 4.99], $r = .80$) condition (see Figure 4). As noted earlier, fifth finger elongation would not be expected to create a sixth finger; hence only two conditions led to a reduction in illusory strength.

The prior analysis examines the alternative hypothesis of whether illusion variants significantly differed from the basic illusion. However, this does not examine whether there is evidence for the null hypothesis: That performance on the illusion variants is the same as performance on the basic illusion. To examine this, we used Bayesian statistics (BF10 score) to examine the strength of evidence in support of the alternative hypothesis (H1) or null hypothesis (H0). Using standard guidelines, BF10 of 3–10 is considered moderate evidence for H1, BF10 greater than 10 strong evidence for H1, BF10 from one third to one tenth moderate evidence for H0, and BF10 less than one tenth strong evidence for H0. Although there were four conditions with strong evidence for H1 and four with moderate evidence for H1 (see Table 3), there was no moderate or strong support for the null hypothesis for any condition.

Discussion

This study examined the limits of embodiment using the Anne Boleyn illusion. Contrary to our expectations, nearly all conditions led to significantly higher ratings for feeling a sixth finger compared to a control condition with only a few exceptions: the 120° sixth finger condition and the additional arm condition. A sixth finger was often perceived when the shape of the illusory sixth finger did not correspond to typical fingers (e.g., vertical), and when it was presented far from the body and/or in an implausible position (3 in. from the body and parallel to the fifth finger). We confirmed the results of Cadete et al. (2022) showing that the illusion persists with a sixth finger curved laterally toward the fifth finger and extended these results to a sixth finger curving in the opposite direction, away from the body. We were also able to induce the sensation of numerous fingers in empty space: 10 fingers on one hand, with five of them being invisible, and two fingers in empty space at the same time. The perception of the sixth finger was also observed in conditions in which stroking, or hand position was not

Table 1
Experimental Manipulation and Stroking Procedure Used to Induce the Sensation of the Sixth Finger

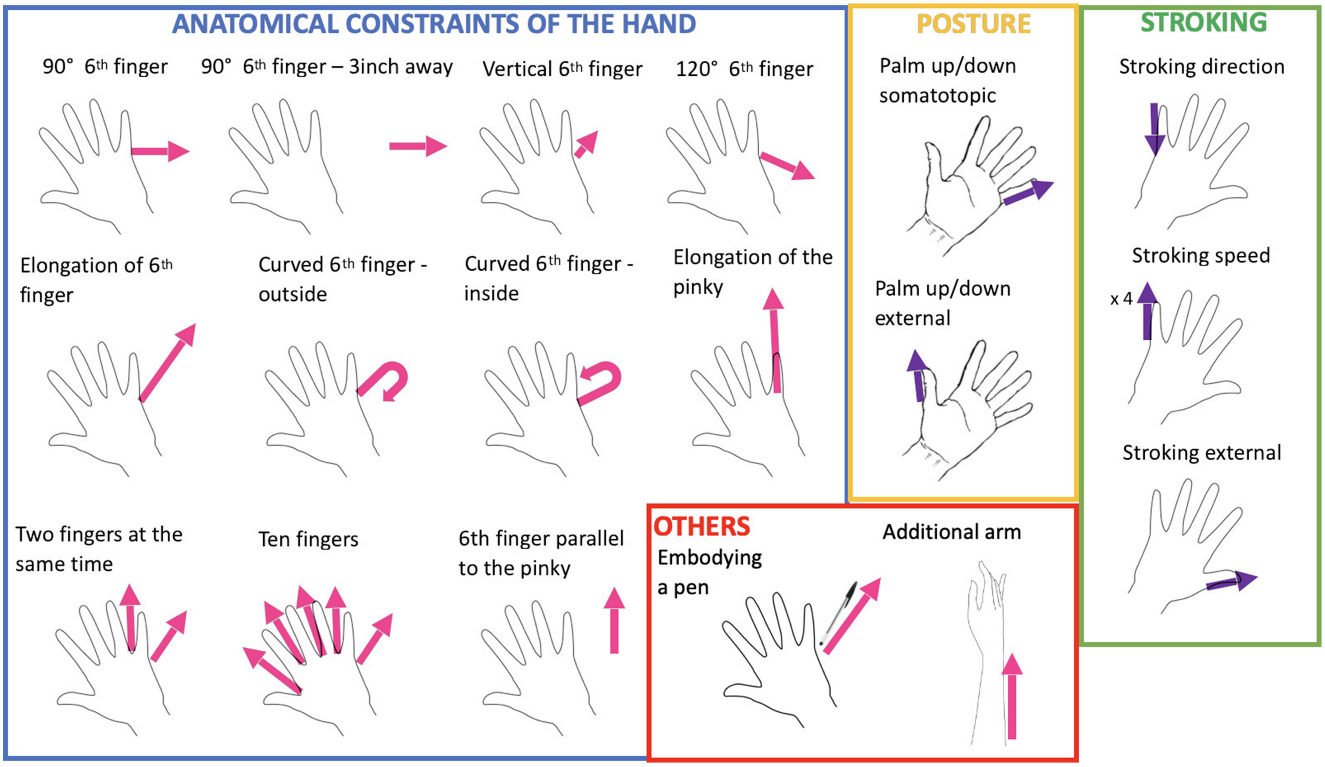
Factor manipulated	Sixth finger manipulation	Condition
Anatomical constraints	Location/orientation	*90° sixth finger* (sixth finger strokes started at the fifth metacarpophalangeal joint and were perpendicular to the fifth finger)
		90° sixth finger—3″ away (same as above, but stroking began 3″ lateral to the fifth metacarpophalangeal joint)
		Vertical sixth finger (sixth finger strokes were made vertically, starting at the fifth metacarpophalangeal joint toward the ceiling)
		120° sixth finger (sixth finger strokes started at the fifth metacarpophalangeal joint and were 120° lateral to the fifth finger orientation about 1″ away)
		Sixth finger parallel to the fifth (sixth finger strokes were parallel to the fifth finger about 1″ away)
		Sixth finger parallel to the fifth—3″ away (sixth finger strokes were parallel to the fifth finger, 3″ lateral to the pinky)
		Two fingers at the same time (a variant of the basic illusion in which the fourth and fifth fingers of the hidden hand were stroked on the hidden hand, with two additional fingers created via stroking empty space)
		Ten fingers (in this condition, we used the same logic as in the traditional illusion on the sixth finger: Stroking occurred on the medial and lateral portion of each finger—two strokes per each finger—from the thumb to fifth finger for the hidden hand, while each finger and the empty space next to it were stroked on the visible hand)
	Length/shape (the hidden hand stroke started from the edge of the palm to the tip of the pinky)	*Elongation of the sixth finger* (stroking of the hidden hand proceeded from the edge of the palm—top side of the wrist—to the pinky, while the sixth finger strokes were double the length of the fifth finger)
		Curved sixth finger—outside (the initial stroke was angle at ~45° from the fifth with and curved laterally)
		Curved sixth finger—inside (the initial stroke was angle at ~45° from the fifth with and curved medially)
		Elongation of the fifth finger (the stroking of the hidden hand proceeded from the edge of the palm—top side of the wrist—to the pinky, while visible hand strokes 6–9 proceeded from the fifth finger and continued into empty space past the tip, about the length of the fifth finger)
Stroking manipulations		*Direction* (stroking direction was incongruent, going from the fingertip to the metacarpophalangeal joint on the hidden hand; and in the opposite direction on the visible hand)
		Speed (four 2 Hz strokes occurred on the hidden hand while one corresponding 0.5 Hz stroke occurred on the visible hand)
		External frame of reference (in the hidden hand, the stroking proceeded from the fifth finger to the thumb and the illusion was created stroking the thumb, while in the visible hand the stroking occurred as in the basic illusion)
Postural manipulations		*Palm up/palm down somatotopic* (the hidden hand was positioned palm up, the stroking occurred from the thumb to the fifth finger, and the illusion was elicited stroking the inner/outer portion of the fifth finger; the visible hand was positioned and stroked as in the basic illusion)
		Palm up/palm down external (the hidden hand was positioned palm up, the stroking occurred from the fifth finger to the thumb, and the illusion was elicited stroking the inner/outer portion of the thumb; the visible hand was positioned and stroked as in the basic illusion)
Additional manipulations		*Embodying a pen* (sixth finger strokes started at the fifth metacarpophalangeal joint and proceed over a pen placed as a possible sixth finger)
		Additional arm (stroking occurred over the dorsum of the arm; the last four induction strokes, 6–9, occurred in lateral portion of the hidden arm and in empty space near the visible arm)

congruent, another unexpected result given the importance of postural and spatiotemporal congruence in other illusions. These findings are inconsistent with past rubber hand illusion studies in which the rubber hand illusion breaks during incongruent stroking or when there is a postural mismatch between the real and rubber hand (Costantini & Haggard, 2007; Tsakiris, 2010; Tsakiris & Haggard, 2005). This will be revisited in the general discussion.

However, there may be some influence of anatomical constraints and posture. Illusory perception of a sixth finger significantly decreased compared to the control when the sixth finger was rotated at 120°, which was the most biologically implausible of the conditions that involved sixth finger position. Furthermore, when comparing our novel illusory variants which violated various body perceptual constraints with the basic illusion, average illusion ratings were lower—though not significantly so (see Figure 4).

One possibility is that we were underpowered to detect these body representational constraints. A second possibility is that our conditions were not sufficiently aberrant to result in a clearly detectable decrease in illusory sixth finger perception. Therefore, in Experiment 2, we varied

Figure 2
Procedures for Induction Strokes 6–9 for Each Experimental Condition



Note. Pink arrows (in the “Anatomical Constraints” and “Others” panels) indicate strokes on the visible hand to induce the illusory embodiment, while purple arrows (in the “Posture” and “Stroking” panels) show strokes on the unseen hand. For simplicity, this figure only depicts the aspects that vary with respect to the basic illusion. See the online article for the color version of the figure.

the Anne Boleyn illusion along three dimensions: sixth finger orientation, shape, and location. We presented participants with more extreme (i.e., more atypical compared to a normal hand) conditions to observe whether these conditions would reduce illusion strength. In addition, we noted that our manipulations induced the perception of a sixth finger but not perceived as part of the body (see Figure 3, Statement 4), suggesting that two different processes may occur in this illusion: one related to the perception of the sixth finger and another related to localization of the touch in empty space. To examine this observation further, we created ad hoc statements to test for ownership and localization of both the sixth finger and feeling touch in empty space.

Experiment 2

Participants

Forty-three undergraduate students (35 women; $M_{age} = 19.18$, $SD_{age} = 1.09$) took part in the present study. Participants’ recruitment, informed consent, and IRB procedure were the same as Experiment 1. This study was not preregistered. Data of this experiment was collected during 2020–2021.

General Procedure

The overall procedure was like Experiment 1 in that all experiments were composed of a simple touch phase, an induction phase (specific for every condition), followed by a questionnaire.

The order of all conditions was randomized across participants.

Simple Touch Phase. This phase was the same as in Experiment 1.

Induction Phase. In this experiment, there were three condition categories: orientation, shape, and location (see Figure 5 and handout of Experiment 2 for more details). For the orientation conditions, the sixth–ninth induction strokes were angled 45° (i.e., basic illusion), 120°, or 180° from an axis defined by the angle of the fifth finger. For the shape conditions, the hidden fifth finger was first touched in the inner portion of the fifth finger (Induction Stroke 5), then in the outer portion from the palm to the tip (Induction Strokes 6–9). These last four induction strokes corresponded to a single straight stroke (canonical shape), or two strokes (each stroke the length of the fifth finger) creating a finger bent at a 90° or 135° angle. To control for stroke length across these three conditions, the length of the single stroke for the straight sixth finger condition was elongated with respect to the basic illusion (twice the size of the fifth finger) and the hidden hand stroke proceeded from the edge of the palm—top side of the wrist—to the tip of the sixth finger. The experimenter took as much care as possible for the touch on both hands to occur at the same time. For the location conditions, the sixth finger stroke was angled 135° laterally from the fifth finger with the stroke originating 3″ or 6″ laterally from the metacarpophalangeal joint of the fifth finger.

In addition to the two control conditions of Experiment 1, we added a third control condition with no touch on the visible hand

Table 2

General and Specific Statements Used in All the Experimental Manipulations and Aspects Examined in Each Statement

General statements	Aspects examined
1. It felt like I had six fingers on my left hand[a]	Sixth finger perception
2. It felt like I had two pinkies on my left hand[b,c]	Perception of additional fifth finger
3. I felt a touch where I do not normally feel a touch	Localization of the tactile sensation
4. I felt a touch that was not on my body	Embodiment of the touch
5. I felt like I had an extra hand[c]	Control statement: perception of an additional hand
6. I felt a larger or longer fifth finger[d]	Perceived changes in size or length of the fifth finger
7. I felt a larger or longer sixth finger[c]	Perceived changes in size or length of the sixth finger
Specific statements	**Experimental manipulation**
8. I felt my pinky positioned at 90°—1 or 3 in. (or 120°) from my hand	Sixth finger oriented at 90° or 120°
9. I felt my sixth finger oriented at 90° (or 120°)	
10. I felt a sixth finger that was pointing upward	Vertical sixth finger
11. I felt a vertically oriented sixth finger	
12. I felt a curved sixth finger	Curved sixth finger inside/outside
13. I felt that my sixth finger was bent inward/outward	
14. I felt two additional fingers at the same time	Two fingers at the same time
15. I felt that the pen was part of my body	Pen as sixth finger
16. I felt a touch on the pen	

[a] This question was modified for the 10 fingers (It felt like I had 10 fingers on my left hand), two fingers at the same time (It felt like I had seven fingers on my left hand), and arm (I felt like I had an extra arm) conditions. [b] This question was modified for the 10 fingers ("It felt like I had two thumbs, two index, two middle, two rings, and two pinkies on my left hand") and two fingers at the same time ("It felt like I had two pinkies and two ring fingers on my left hand") conditions and was not presented for the arm. [c] These questions were not presented for the arm condition. [d] This question was modified for the arm condition ("I felt a larger or longer arm").

to observe if simple sensation without the illusory stroking could also induce the illusion. Experiment 1 showed that vision of the sixth finger, without corresponding somatosensory input on the hidden hand, was not sufficient to induce the sixth finger sensation. With the present control condition, we tested whether the illusion can be created with tactile stimulation or whether multisensory integration between tactile and somatosensory inputs can induce the illusion of the sixth finger. In this condition (Control 3), the hidden hand was stroked as in the basic illusion, but no strokes were presented to the viewed hand on Induction Strokes 6–9 (see Figure 6). Therefore, the last stroke on the fifth finger was perceived but not seen (Figure 6).

Questionnaire. First, participants were then presented with a modified version of the questionnaire presented in Experiment 1, in which they were asked to rate the level of agreement with each statement (Table 4 using a Likert scale from −3 to 3).

Data Analysis. First, we analyzed whether changes in orientation, shape, and location influenced questionnaire responses. Shapiro–Wilk tests showed that normality assumption was violated for our variables of interest and Likert scores were analyzed using a Friedman Test (a nonparametric test similar to a repeated-measures analysis of variance), in which the three levels of condition complexity were the within-subjects conditions. Any significant Friedman tests were followed up with Wilcoxon post hoc tests (p values are reported uncorrected).

As in Experiment 1, we selected individuals who showed the perception of the sixth finger in the basic illusion (score on Q1 for the basic illusion of +1 or greater) and tested whether the difference between the basic illusion and the other conditions for Statement 1 differed from zero.

In the results section, we focused on Statement 1 that assessed perception of a sixth finger, and Statement 3 on embodiment of empty space. Additional analyses of the other statements can be found in the online supplemental material.

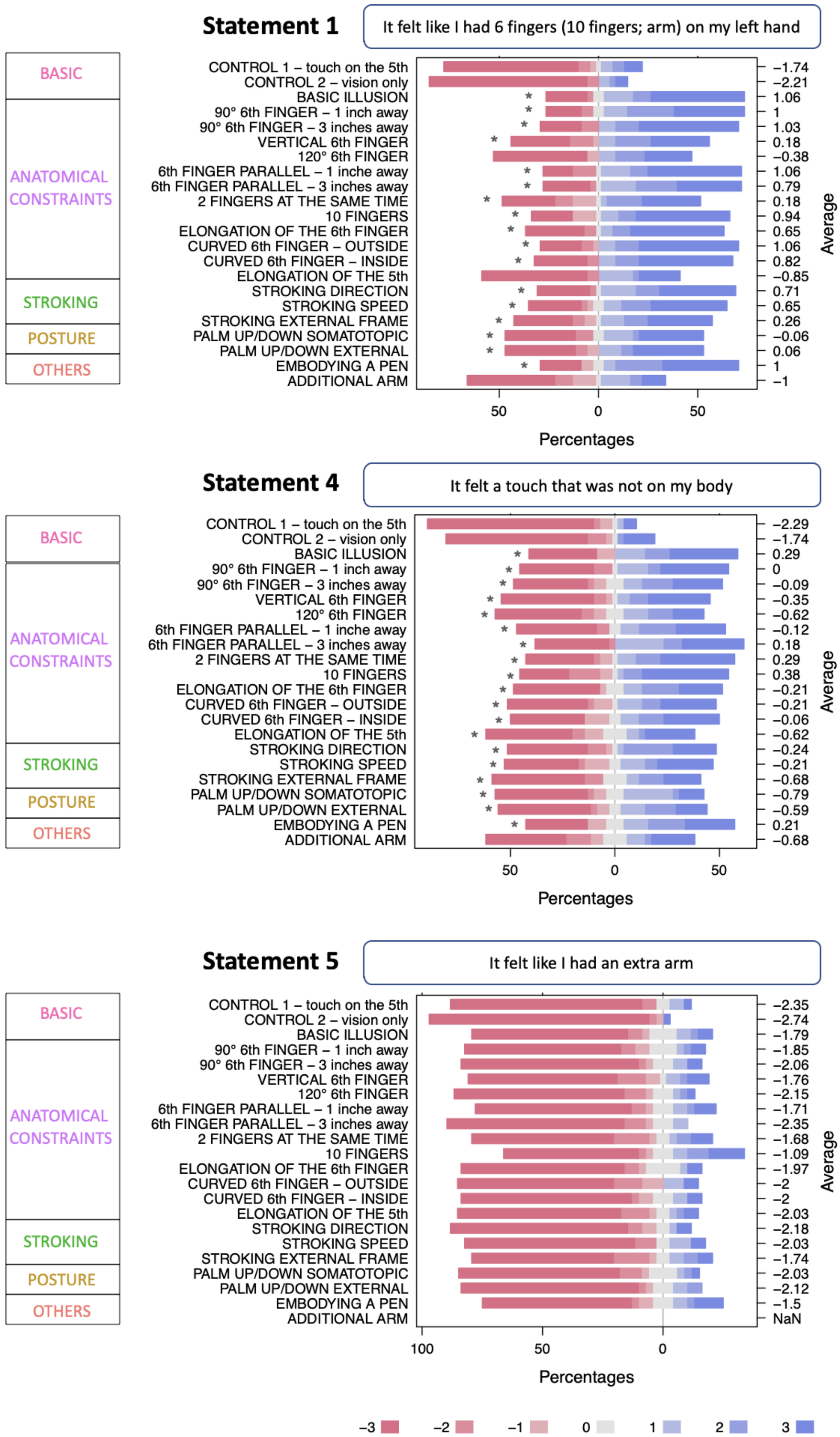
Results

Friedman's tests carried out on each experiment independently showed a significant effect of *Orientation* ($\chi^2 = 18.02$, $p < .001$), but not shape ($\chi^2 = .97$, $p = .61$) or distance manipulations ($\chi^2 = 2.36$, $p = .30$) on responses to Statement 1 ("It felt like I had six fingers on my left hand"). The perception of the sixth finger was stronger in the 45° condition (basic illusion) than the 120° ($W_{42} = 191$, $p = .008$, 95% CI [0.5, 3.5], $r = .40$) and 180° condition ($W_{42} = 238$, $p = .002$, 95% CI [1, 4.9], $r = .46$) (see Figure 7). Looking at individuals that perceived the sixth finger in the basic illusion ($n = 24$), the only conditions that significantly differed from zero were the 6 in. away ($W_{42} = 115$, $p = .002$, CI [1.99, 4.99], $r = .64$) and the 180° sixth finger ($W_{42} = 133$, $p < .001$, 95% CI [2.5, 5.5], $r = .69$) conditions (see Figure 8). For Statement 3, Friedman's tests did not show significant results for *Orientation* ($\chi^2 = 2.97$, $p = .22$), shape ($\chi^2 = .97$, $p = .61$), or distance manipulations ($\chi^2 = 3.5$, $p = .17$).

Comparing responses for the control conditions, Friedman test showed a main effect of condition for Statement 1 ($\chi^2 = 12.2$, $p = .002$) and Statement 3 ($\chi^2 = 19.1$, $p < .001$). The perception of a sixth finger was higher in Control 3-no touch, in which the touch occurred only in the hidden hand and was not presented in the visible hand ($W_{42} = 266$, $p < .001$, 95% CI [2.29, 4.49], $r = .59$) than in Control 2-vision, where participants observed stroking in the empty space without their hidden hand being stroked. There was a significant difference between Control 1-touch and 2 ($W_{42} = 149$, $p = .005$, 95% CI [0.99, 3.50], $r = .42$), but not between Control 1 and Control 3-no touch in statement 1 ($W_{42} = 62.5$, $p = .02$, 95% CI [−3, −6.3], $r = .35$). Interestingly, Control 3 differed from both control conditions for Statement 3 (in both comparisons, $W_{42} > 55$, $p < .007$, $r > .50$), suggesting that this condition induced a certain degree of embodiment of the empty space (see Figure 7).

Figure 3

Response Distributions and Averages of the Likert Scales Scores in Response to Statements 1 (Sixth Finger Perception), 4 (Feeling a Touch Not on the Body), and 5 (Feeling an Extra Arm)



Note. Responses are Displayed with Positive Likert Scale Responses Positioned to the Right of Zero, with Negative Likert Scale Responses to the Left of Zero. See the online article for the color version of the figure.
* marks any conditions that were significantly different from the control condition (using a Bonferroni corrected $\alpha = .05$).

Table 3

Summary of Test Statistics and Bayes Factors (BF10) for Statement 1 for the Overall Sample (Second Column) and Participants Who Showed the Illusion (Third and Fourth Columns)

Condition	All participants: Comparison with control condition	Novel versus basic illusion: Wilcoxon test	Novel versus basic illusion: Bayes factor (BF10)
Basic	$W = 295$, $p < .001$; 95% CI [2.99, 5]; $r = .71$***		
90° sixth finger	$W = 312.5$, $p < .001$; 95% CI [2.5, 5]; $r = .60$***	$W = 50$, $p = .13$; 95% CI [−0.5, 3.4]; $r = .31$	0.71
90° sixth finger—3″ away	$W = 285$, $p < .001$; 95% CI [2.9, 5.5]; $r = .66$***	$W = 25.5$, $p = .32$; 95% CI [1.4, 4]; $r = .21$	0.40
Vertical sixth finger	$W = 215$, $p < .001$; 95% CI [1.5, 4.9]; $r = .59$***	$W = 88$, $p = .03$; 95% CI [0.4, 4.9]; $r = .45$	3.65*
120° sixth finger	$W = 160.5$, $p = .04$; 95% CI [−4.2, 5]; $r = .35$	$W = 135$, $p = .005$; 95% CI [1.9, 5.9]; $r = .57$	28.31**
Sixth finger parallel to the fifth	$W = 318$, $p < .001$; 95% CI [2.9, 5]; $r = .72$***	$W = 44$, $p = .34$; 95% CI [−1.4, 3.4]; $r = .20$	0.41
Sixth finger parallel to the fifth—3″ away	$W = 276.5$, $p < .001$; 95% CI [2.9, 4.9]; $r = .62$	$W = 59.5$, $p = .11$; 95% CI [−1.9, 3.4]; $r = .33$	0.84
Two fingers at the same time	$W = 198.5$, $p < .001$; 95% CI [2, 4.4]; $r = .59$***	$W = 116$, $p = .01$; 95% CI [0.9, 4.4]; $r = .51$	7.19*
Ten fingers	$W = 299.5$, $p < .001$; 95% CI [2.9, 5]; $r = .63$***	$W = 58.5$, $p = .13$; 95% CI [−0.9, 3.4]; $r = .90$	0.73
Elongation of the sixth finger	$W = 219.5$, $p < .001$; 95% CI [2.9, 5.5]; $r = .62$***	$W = 48$, $p = .50$; 95% CI [−1.4, 3.4]; $r = .14$	0.46
Curved sixth finger—outside	$W = 286.5$, $p < .001$; 95% CI [3, 5.5]; $r = .67$***	$W = 43$, $p = .39$; 95% CI [−1, 2.5]; $r = .39$	0.37
Curved sixth finger—inside	$W = 242.5$, $p < .001$; 95% CI [2.5, 5.5]; $r = .65$***	$W = 64$, $p = .20$; 95% CI [−0.9, 3]; $r = .26$	0.6
Elongation of the fifth finger	$W = 124.5$, $p = .09$; 95% CI [−0.5, 3.99]; $r = .28$	$W = 164$, $p < .001$; 95% CI [2.4, 5.4]; $r = .70$***	445**
Stroking direction	$W = 251.5$, $p < .001$; 95% CI [2.4, 5]; $r = .59$***	$W = 43$, $p = .12$; 95% CI [−0.4, 3.9]; $r = .32$	0.89
Stroking speed	$W = 260$, $p < .001$; 95% CI [2, 5]; $r = .63$***	$W = 55.5$, $p = .05$; 95% CI [−4.7, 4.9]; $r = .41$	1.72
Stroking external frame of reference	$W = 228.5$, $p < .001$; 95% CI [1.5, 4.9]; $r = .57$***	$W = 70.5$, $p = .01$; 95% CI [0.9, 4]; $r = .50$	4.61*
Palm up/palm down somatotopic	$W = 170.5$, $p = .0024$; 95% CI [1.5, 4.9]; $r = .52$***	$W = 109$, $p = .005$; 95% CI [0.9, 4.4]; $r = .57$	11.6**
Palm up/palm down external	$W = 172.5$, $p = .002$; 95% CI [1.5, 5]; $r = .53$***	$W = 73$, $p = .008$; 95% CI [1, 5.9]; $r = .54$	8.30*
Embodying a pen	$W = 269$, $p < .001$; 95% CI [3, 5.4]; $r = .68$***	$W = 53$, $p = .27$; 95% CI [−0.5, 3.4]; $r = .22$	0.54
Additional arm	$W = 139$, $p = .08$; 95% CI [−4.4, 3]; $r = .30$	$W = 210$, $p < .001$; 95% CI [2.5, 4]; $r = .80$***	13,020**

Note. CI = confidence interval. For Wilcoxon-tests, *** $p < .0025$. For Bayes factors, * —moderate evidence for H1 and ** —strong evidence for H1.

Experiment 2 Discussion

In Experiment 2, we varied the illusion along three dimensions: orientation, distance, and shape, making sure to present conditions that were more extreme (i.e., divergent from typical body representations) than in Experiment 1. We found that more divergent changes in sixth finger orientation result in a significant decrease in perception of a sixth finger, but that changes in perceived finger shape and location did not significantly modulate the illusion. In addition, we also observed a significant modulation of the strength of the illusion only for the manipulation of the orientation and location. The strength of the illusion diminished when the sixth finger was oriented at 180° and 6 in. away compared to the basic illusion.

Changes observed based on sixth finger location and orientation are in line with studies showing that ownership over the rubber hand does not occur when it is rotated in implausible positions (Ehrsson et al., 2004; Ferri et al., 2013; Holle et al., 2011; Kalckert & Ehrsson, 2012; Pavani et al., 2000) or positioned far away from the participants' body (Lloyd, 2007). In line with these studies, our results provide evidence that typical body representations do influence illusion strength, though at more extreme conditions than originally hypothesized. However, we found that changes in the shape of the sixth finger did not diminish the strength of the illusion, even in cases in which a "broken" finger was presented. We return to this in the general discussion.

Interestingly, in both studies, the performance was consistent for the control conditions of touch only (in which the touch was applied on the fifth finger of the visible hand) and vision only (strokes presented on the visible hand as if there were a sixth finger, but no tactile stimuli were presented in the hidden hand). This evidence is important as it shows that vision only is not sufficient to induce the illusion of the sixth finger but the association between tactile and visual input is driving the illusion. Similarly, touch only without vision (Control 3) was also not able to induce the illusion, supporting the idea that the illusion is driven by the integration of both touch and visual inputs. However, touch only without vision (Control 3) was significantly more effective than the vision of touch alone (Control 2) in the perception of a sixth finger (Statement 1). This evidence suggests differential weighting of tactile and visual inputs in the Anne Boleyn Illusion, with tactile information playing a more prominent role. The touch-only condition (Control 3) led to stronger feelings of ownership of empty space compared to the other control conditions in Statement 3, suggesting that tactile information alone in the context of the illusion could lead to illusory ownership. Taken together, these findings suggest that the combination of visual and tactile input is necessary to induce the embodiment and sensation of the sixth finger, but a tactile input alone presented at an ambiguous location (in the outer portion fifth finger) without corresponding visual stimulation may play a more prominent role in the emergence of the illusion and induce a sensation of embodiment in the empty space.

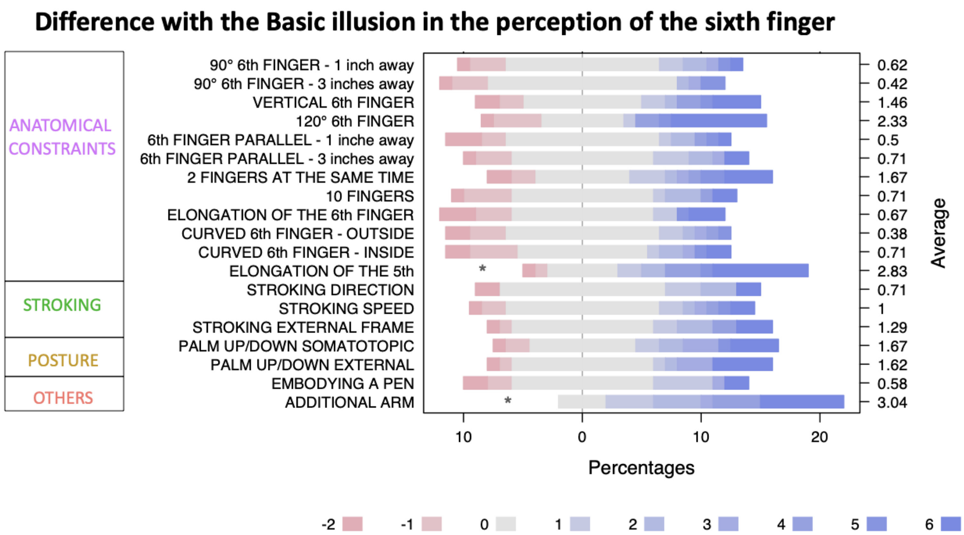
General Discussion

This study demonstrated that the Anne Boleyn illusion can occur in a variety of conditions, even those that violate typical body constraints. This includes conditions in which finger orientation and shape differ substantially from the typical orientation of existing fingers, and even in variants in which seven, or even 10 fingers, are created. The illusion still occurs when the stroking direction is incongruent, even if the posture of the viewed hand differs from the posture of the touched hand. We do find some evidence that the illusion can be weakened in conditions with relatively large differences from a typical body (a finger angled 120°–180° away from the typical fifth finger, a sixth finger that is detached from the hand by 6″). However, the Anne Boleyn illusion occurs even in conditions in which other embodiment illusions cease.

We propose that the illusion is robust for two reasons: bottom-up processes from visuotactile stimulation, and top-down processes

Figure 4

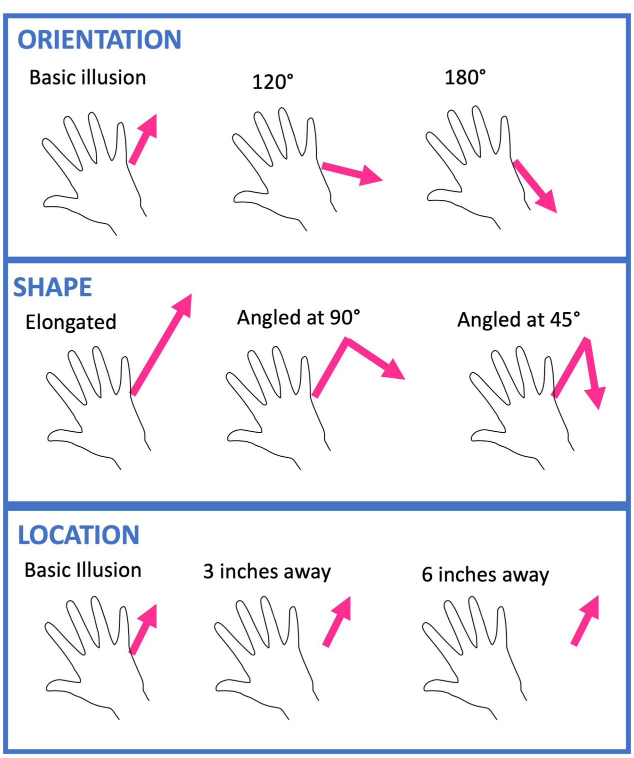
Response Distributions and Averages of the Difference *in Likert Scale Responses of the Novel Variants of the Illusion From the Basic Illusion for Statement 1 (Illusory Sixth Finger)*



Note. Positive numbers indicate higher values for the basic illusion. * marks any conditions that were significantly different from zero (using a Bonferroni corrected $\alpha = .05$). See the online article for the color version of the figure.

Figure 5

The Locations of the Final Four Induction Strokes (6–9) for Orientation, Shape, and Location Manipulations in Experiment 2

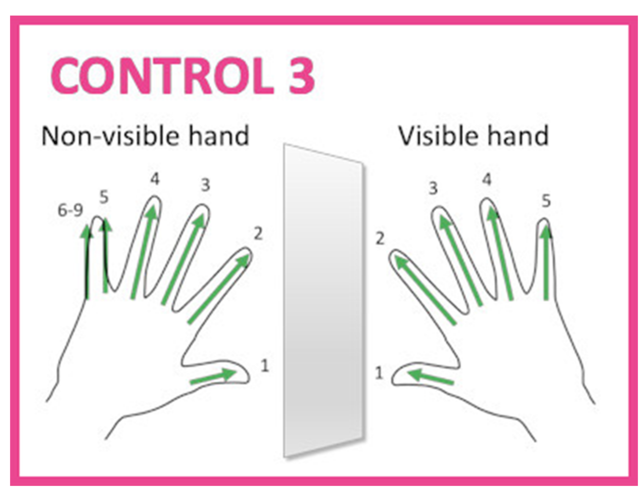


Note. The arrows indicate stroking on the visible hand to induce the feeling of a sixth finger. See the online article for the color version of the figure.

related to stored body representations. Typically, when a moving touch is presented to the hand along with the concurrent movement of someone delivering the touch, the tactile and visual information come from the same source. This preexisting relationship between viewed and felt touch is in line with spatial and temporal rules of multisensory integration (Holmes & Spence, 2005) and provides somewhat strong evidence that the two inputs come from the same

Figure 6

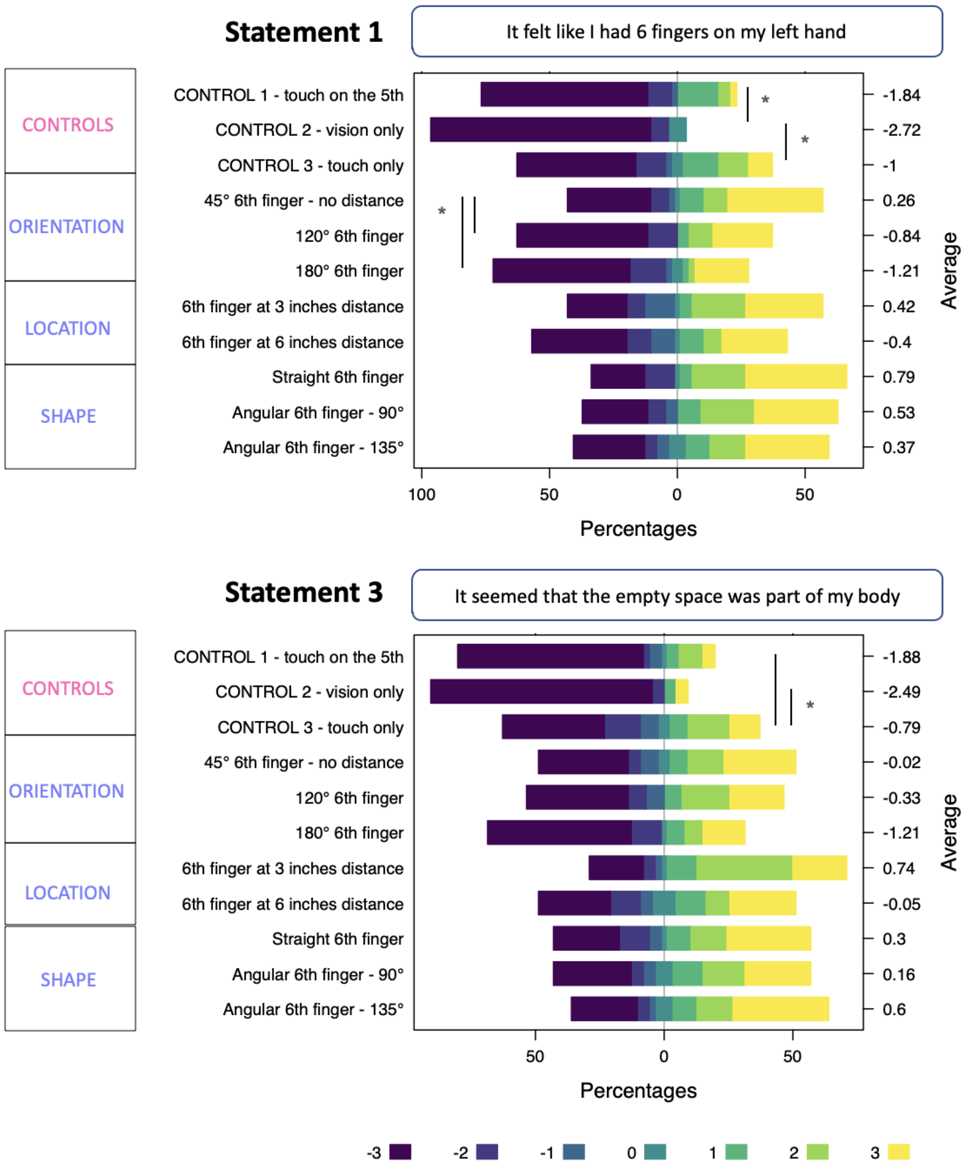
Induction Procedure of Control 3 in Which There is No Touch Occurring in the Empty Space



Note. The arrows depict the stroking direction, while the numbers represent stroke order. See the online article for the color version of the figure.

Figure 7

Percentages and Average of the Likert Scales Scores in Response to Statements 1 and 3



Note. Bonferroni corrected in the Wilcoxon test. See the online article for the color version of the figure.
* $p < .05$.

source and are bound (see Armel & Ramachandran, 2003). This underlies illusions such as the rubber hand illusion, which causes perceived embodiment of a hand that is not one's own. However, the rubber hand illusion is not as robust as the Anne Boleyn illusion. For example, conditions in which the rubber hand and real hand are in incongruent postures significantly reduce or abolish the rubber hand illusion (Ide, 2013; Kalckert & Ehrsson, 2012; Tsakiris & Haggard, 2005), as does incongruence in the location of viewed and felt strokes (Costantini & Haggard, 2007), or attempting to embody a non-hand-shaped object (Guterstam et al., 2013; Tsakiris et al., 2010; Tsakiris & Haggard, 2005). In our experiments with the Anne Boleyn illusion, we found a strong illusory sense of a sixth finger when the viewed and hidden hand were in different postures (palm up vs. palm down), incongruent stroking locations (stroking the hidden left thumb, on the right side of the hand, while creating an illusory sixth finger on the left side of the hand), and with a noncorporeal object (embodying a pen).

In the invisible hand illusion (Guterstam et al., 2013), concurrent stroking of participants' hidden hand and empty space (with strokes occurring in a hand-shaped manner) resulted in perception of an "invisible hand" where the stroking occurred. This illusion was modulated by many of the same factors as the rubber hand illusion, as incongruent stroking direction and the presence of a

Table 4
General Statements Used in All the Experimental Manipulations

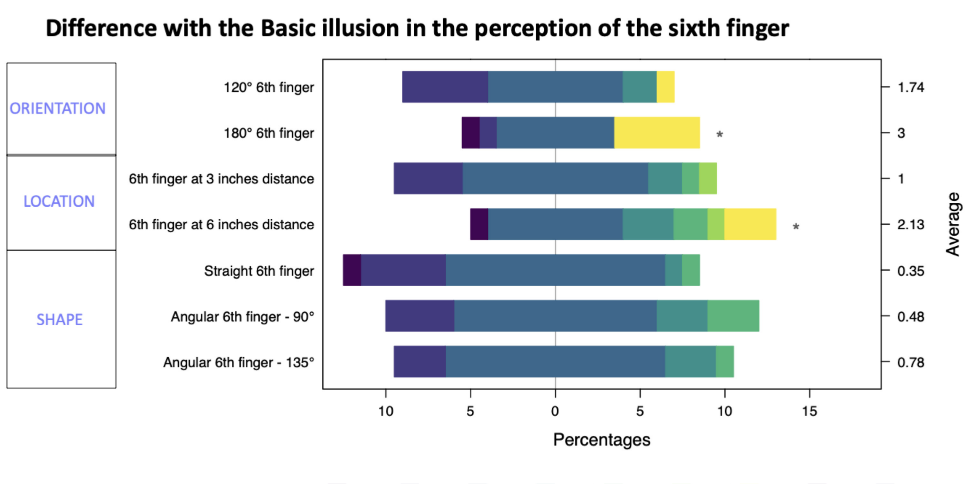
General statements	Aspects examined
1. It felt like I had six fingers on my left hand	Sixth finger perception
2. I felt a sixth finger that was part of my body	Embodiment of the fifth finger
3. It seemed that the empty space was part of my body	Embodiment of the empty space
4. The touch in the empty space did not feel as part of my body	Localization and embodiment of the tactile sensation
5. I felt touch where the examiner was stroking in the empty space	Localization of the tactile sensation
6. I felt like I had an extra hand	Control Statement: perception of an additional hand
7. I felt a larger or longer sixth finger	Perceived changes in size or length of the sixth finger
Specific statements	Experimental manipulation
8. I felt a sixth finger positioned at 120° (or 180°) from my hand	120° (or 180°) Sixth finger
9. I felt a sixth finger curved at 90° (or 45°) from my hand	Elongation of the sixth—90° (or 45°)

Note. Questions that differ from Experiment 1 are shown in bold.

non-hand-shaped object significantly reduced the illusion. As noted above, these restrictions seem not to influence the Anne Boleyn illusion. A critical distinction between the Anne Boleyn illusion and the invisible hand illusion is that the Anne Boleyn illusion is "anchored" to an existing hand. Seeing a hand in the same space as your own hand that looks like your own hand may weigh the system toward accepting nearly anything "finger-like." On a related note, in most of our illusion variants, there are no constraints from the actual body or a body-shaped visual stimulus. In the Anne Boleyn illusion, a new body part is created "out of thin air." Although we hypothesized that constraints from stored body representations would diminish the illusion, it may be that novel body parts are less constrained by these rules. As an example, a sixth finger could be more easily represented as vertical compared to other fingers as it is not part of a "canonical" hand representation. This combination of strong bottom-up cross-modal processes from visuotactile synchrony combined with the lack of constraints provided by empty space may lead to an illusion that works under a surprising number of conditions.

Bottom-up multisensory processing alone cannot account for our results. Top-down processing from stored body representation also plays a role in this illusion, as demonstrated by the evidence that this illusion is not replicated using other body parts (i.e., the arm) and is disrupted when the anatomical configuration of the hand is severely altered, as in conditions when the sixth finger is in extremely implausible positions (a sixth finger angled 120° or 180° lateral to the fifth finger, a sixth finger far from the hand). We suggest that the illusory perception in this and other ownership illusions involves differential weighting of top-down versus bottom-up information in deciding on whether to embody the stimulus, whether it be a rubber hand, mirror image of a hand, or an extra finger. In this illusion, congruent visuotactile stimulation combined with limited constraints from the body (given that the illusion does not involve the body) leads to a relatively robust illusion.

Figure 8
Percentages and Average of the Difference in the Likert Scales Scores From the Baseline Illusion in Response to Statement 1



Note. Positive numbers indicate higher values for the basic illusion. See the online article for the color version of the figure.
* marks any conditions that were significantly different from zero (using a Bonferroni corrected α = .05).

We highlight one additional, surprising result from our experiments. For visuotactile binding to occur, the typical assumption is that the stroking of the real and other hand must be congruent. For example, Costantini and Haggard (2007) demonstrated that stroking direction of the real and rubber hand needs to be congruent in a hand-centered frame of reference for the illusion to occur (see also Gentile et al., 2013; Guterstam et al., 2013). Surprisingly, we found that an illusory sixth finger was still experienced even when the viewed and felt touch were in a different direction (toward the metacarpophalangeal joint on the hidden hand, toward the fingertip on the illusory sixth finger) or with differences in timing (four quick strokes on the hidden hand along with one stroke on the illusory sixth finger). One possibility is that in this illusion, only spatial or temporal congruence is sufficient to cause binding an illusory sixth finger. A second possibility is that the experience of an illusory sixth finger on earlier blocks may have led to carry-over effects that made binding more likely. Unfortunately, our design was not set to address this question. Future work can examine this question in more detail. On a methodological note, our paradigm combined the original procedure of the illusion, consisting of a stroking phase followed by an induction phase (Newport et al., 2010), and additional stroking in empty space that has been shown to induce stronger and long-lasting effects of the illusion (Cadete & Longo, 2020). This procedure aimed at enhancing embodiment and optimizing the illusion while minimizing experiment length. It is not clear if the additional strokes (7–9) are what lead to seeing the illusion across these implausible postures, or whether the illusion would occur in all observed conditions with only a sixth stroke.

Caveats and Critiques

In our design, the primary evidence for the existence of the illusion (i.e., perception of a sixth finger) is via comparing Likert scale ratings in the experimental condition versus a control condition. This method is commonly used in illusions like the rubber hand illusion, in which questionnaire ratings in the condition in which the illusion is expected (synchronous stroking) are compared to ratings in a control condition (asynchronous stroking). Using this metric, we found evidence that the illusion existed under a variety of different manipulations. However, the average illusion ratings, when taken in isolation, may not seem as convincing. For example, the mean questionnaire response on perceiving a sixth finger for the basic illusion is only +1.06 (Experiment 1), which most closely corresponds to "slightly agree." We suggest that simply examining mean performance may not be the best way to characterize the results. A subgroup of participants do not experience the illusion (no Likert ratings for perception of a sixth finger > 0) under any condition (5/34 in Experiment 1, 9/43 in Experiment 2). When participants provide ratings on the illusion, they tend to be ones in which they strongly agree (or strongly disagree) with the statement. As an example, for Statement 1 (on perceiving a sixth finger) in Experiment 1, 66.5% of responses were strongly agree/disagree, compared to 17% for agree/disagree, and 13.8% for slightly agree/disagree. These results suggest that when the illusion occurs, it is strongly felt, but that many participants do not experience the illusion. Unfortunately, it is unclear whether this is due to participant-specific characteristics or other factors, but we hope to examine this in future studies.

Given the ubiquity of these effects, an additional concern is whether these results are simply due to demand characteristics (see Lush et al., 2020 for a discussion regarding demand characteristics and the rubber hand illusion; for an opposing view, Ehrsson et al., 2022; Slater & Ehrsson, 2022). Although participants' compliance cannot be totally excluded, multiple pieces of evidence suggest that this was not the case. First, as noted in the previous paragraph, participants are not likely to equivocate with regard to their experience, with +3 (strongly agree) responses outnumbering other positive responses. This suggests a strong, real experience.

Second, performance varied such that participants did not always report an illusory sixth finger (e.g., the fifth finger elongation and arm conditions in Experiment 1, the 180° sixth finger condition in Experiment 2), providing evidence that the participants were not simply responding that they felt the illusion under any condition. Third, other statements did not differ between most experimental conditions and the control condition, such as questions about feeling an extra hand (Statement 5) or feeling a larger/longer fifth finger (Statement 6; see the online supplemental material). Fourth, the Anne Boleyn illusion in previous literature has been quite robust, with an 85%–90% success rate when presented to over 3,500 participants (Newport et al., 2016). Although we do not believe that demand characteristics or participants' suggestibility is the primary cause of the illusion, the role of these factors cannot be totally excluded. We did not measure trait suggestibility, and it is possible that the contributions of individuals with high trait suggestibility may contribute to some extent to the illusion. Although we maintain that this is not the cause of the illusion, we believe that future work examining the role of suggestibility in this illusion will identify if this factor plays any role in this illusion.

One limitation in our study is the lack of objective illusion measures, akin to measures such as galvanic skin response used to measure embodiment in the rubber hand illusion (Armel & Ramachandran, 2003; Hägni et al., 2008; Yuan & Steed, 2010). The goal of our study was to understand the limits of the Anne Boleyn illusion, as (to our knowledge) there are no studies of this illusion using objective measures. If objective measures are found that are as (or more) sensitive than Likert scale ratings, these could be an important tool in examining the relationship between various constraints and illusory finger perception. An additional limitation is all our manipulations were contrasted with control condition (s) specifically designed to test for the sixth finger illusion. For the exploratory nature of Experiment 1, we used this approach to be able to test our manipulation with respect to the original illusion and explore a variety of manipulation at the same time. This control condition might not have been as adequate to test the effect of other manipulation, such as the additional arm, the 10 fingers conditions, or the additional two fingers.

Finally, our sample was composed of undergraduate female students and, therefore, limited in the degree of generalizability to other populations. Previous research has shown that the Anne Boleyn illusion is also often observed in children and in individuals of different ages (Newport et al., 2016); however, future research should address whether the constraints of the illusion are as stable as in other populations as in young undergraduate students.

To conclude, our work demonstrated that the Anne Boleyn illusion can lead to illusory ownership of a sixth finger, even in conditions that break other body illusions. We propose that the influence of visuotactile synchrony combined with limited constraints from a typical body representation result in a strong illusion. Finally, this demonstrates the importance of using novel illusions to examine embodiment, as constraints demonstrated in more commonly used illusions may not always hold.

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