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When one part feels, the whole belongs: associations between local touch referral and illusory full-limb ownership in individuals with leg amputation

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ABSTRACT

The rubber limb illusion (RLI) describes a perceptual phenomenon where synchronous stroking of a hidden real and a visible artificial limb induces ownership for the fake limb, i.e., the sensation as if it belongs to one's body. Previous research suggests that the induction of ownership in the RLI is closely related to the referral of touch, i.e., the perception that the observed touch on the artificial limb causes the tactile sensation. However, the ultimate importance of touch referral for eliciting limb ownership remains unclear. To help answer this question, the present study re-analyzed the data from a recently introduced RLI paradigm for individuals with lower limb amputation. In 34 participants, synchronized touches were used to induce ownership for an artificial leg, with both the real amputated and non-amputated leg as targets. Crucially, participants were also asked for ownership of a non-touched artificial foot that was either connected (intact condition) or disconnected (impaired condition) to the artificial leg. Touch referral reliably predicted the occurrence of ownership for the touched leg regardless of the artificial limb being intact or impaired. A series of mediation analyses revealed that leg ownership significantly mediated the relationship between touch referral and foot ownership, but only if an intact artificial counterpart was used. This indicates that touch applied to a given body part indirectly relates to the perception of adjacent but non-touched body parts, even when those areas are physically absent. These findings may motivate studies testing whether sensory feedback promoting touch referral can support prosthesis embodiment.

1. Introduction

The perception of the body as belonging to oneself, referred to as the sense of body ownership, relies on complex multisensory integration processes (Ehrsson, 2020). Empirical evidence (Chancel et al., 2022; Ehrsson & Chancel, 2019) indicates that the central nervous system combines visual and somatosensory inputs via a causal inference process, estimating the likelihood that concurrent sensory signals derive from a shared source. For example, in body perception, the brain estimates the probability that an observed touch on a given body part (visual input) relates to a felt touch on the same body part (tactile input). This process is considered a prerequisite for the generation of a unified multisensory percept (e.g., Rohe & Noppeney, 2015) which, in the context of multimodal body representation, ultimately manifests as the sense of body ownership.

A well-established experimental approach to studying this process is the so-called rubber limb illusion (RLI) paradigm (Riemer et al., 2019). In its classical form, introduced for the hands (Botvinick & Cohen, 1998), synchronous touches applied simultaneously to a visible fake hand and the participant's real but hidden hand elicits the compelling perception that the artificial limb both feels the observed touch (the referral of touch phenomenon) and belongs to the individual (the body ownership phenomenon). Although both phenomena are closely linked (Reader et al., 2021), psychometric analysis suggests that they represent distinct facets of the RLI (Tosi et al., 2024). This is further underscored by empirical findings suggesting that touch referral is neither necessary nor sufficient for eliciting body ownership (Kalckert et al., 2019; Smit et al., 2018; Tsakiris et al., 2010). Nevertheless, the frequent co-occurrence of touch referral and body ownership in the RLI has raised questions about how one phenomenon relates to the other. Based on theoretical considerations, previous authors (Makin et al., 2008; Tsakiris, 2010; Valenzuela Moguillansky et al., 2013) hypothesized that

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touch referral may precede the experience of body ownership in the RLI.

The ability to experimentally dissociate the location of touch stimulation from the ownership percept provides a means to examine how local tactile sensations contribute to bodily self- experiences in the RLI. For instance, visuo-tactile stimulation applied simultaneously to a real body part and its artificial counterpart can induce a sense of ownership not only for the stimulated region of the fake limb but also for adjacent, non-stimulated areas (Gentile et al., 2015). However, the visual coherence of the artificial limb is critical for this touch-induced transfer of ownership: when an artificial limb lacking anatomical continuity is used – for example, by presenting a detached hand or foot –, synchronous visuo-tactile stimulation of the real and artificial distal extremities typically fails to elicit a sense of ownership for the artificial one (Perez-Marcos et al., 2012).

This issue may be particularly relevant in cases where the target body part is partly absent. Building on previous work (Ehrsson et al., 2008), Bekrater-Bodmann and Ruttorf (2026) recently introduced a novel RLI paradigm for individuals with lower limb amputation that applies tactile stimulation to either the hidden residual or non-amputated leg while manipulating the appearance of a visible artificial leg (intact vs. impaired) that is touched on a corresponding site. In this experiment, most amputated participants reported artificial leg ownership, independent of the artificial limb's appearance. In contrast, when assessing ownership for a non-stimulated detached (impaired condition) versus attached foot (intact condition), participants experienced a stronger sense of foot ownership in the latter case. This effect was consistent across both body sides (amputated vs. non-amputated). Touch referral was also assessed; however, its relationship to ownership ratings was not further analyzed. It thus remains unclear which cognitive mechanisms elicit a multisensory-mediated transfer of ownership when the target body part (here: the foot) is neither touched nor physically present.

Based on recent findings that highlight a positive relationship between touch referral and illusory body ownership (Reader et al., 2021), as well as considerations regarding their order of occurrence (Makin et al., 2008; Tsakiris, 2010; Valenzuela Moguillansky et al., 2013), the present study re-analyzed the perceptual dataset from a previous RLI experiment in individuals with lower limb amputation (Bekrater-Bodmann & Ruttorf, 2026). The present investigation focuses on the link between local touch perception and body ownership across body parts. It is hypothesized that the relationship between touch referral and the experience of ownership of a non-stimulated foot is mediated by the perceived ownership of a stimulated leg (Fig. 1). This model was tested by a series of mediation and path analyses for both the amputated and the non-amputated leg, taking into account the intactness or impairment of the artificial limb.

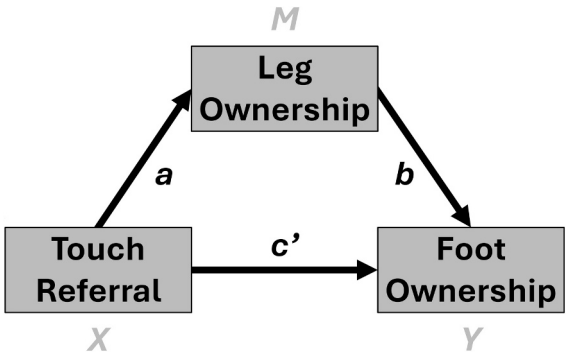

Fig. 1. Hypothesized model for the link between touch referral and foot ownership, with leg ownership mediating the relationship. Path *a* and *b* represent the *X* – *M* and *M* – *Y* relationships, respectively; the product of the regression coefficients of paths *a* and *b*represents the magnitude of the indirect relationship (i.e., the actual mediation), which quantifies how much of the total relationship between variable *X* and variable *Y* is mediated by the mediator variable *M*. In this framework, *c'* denotes a potential direct relationship of *X* on *Y* after including the mediator in the model.

2. Methods

2.1. Participants and setting

$N = 34$ individuals with unilateral major lower limb amputation were included. Eligibility criteria included an age between 18 and 80 years, fluent German proficiency, and regular prosthesis use. Most participants (79.4%) identified as male, with no non-binary or gender-diverse participants. Mean age was 55.85 years (with a standard deviation of 9.33). Twenty-two participants had left-leg amputations; $n = 19$ were amputated at the transfemoral level and the remainder at the transtibial level. All participants reported acquired limb loss which had occurred on average 32.33 years prior to study participation (with a standard deviation of 13.70). The majority (64.7%) identified injury (unspecified) as the primary cause of amputation, followed by infection (with or without a preceding injury; 20.6%) and malignancy (14.7%).

Participants took part in a functional magnetic resonance imaging experiment targeting their body perception. To this aim, a newly developed RLI paradigm was implemented to alter participants' sense of body ownership (neurophysiological data are reported elsewhere; Bekrater-Bodmann & Ruttorf, 2026). The present study focuses on the perceptual data from the original investigation's Experiment 2 (see below). The study was approved by the Ethics Committee of the Medical Faculty Mannheim, Heidelberg University (reference number: 2016-658N-MA), conducted in accordance with the current Declaration of Helsinki. Written informed consent was obtained from all participants.

2.2. Rubber limb illusion experiment

The experiment employed a 2 × 2 design with the factors *body side* (amputated vs. non-amputated) and *artificial limb* (intact vs. impaired), resulting in four conditions presented in randomized order (Fig. 2; see also Supplementary Fig. 1 for a more detailed visualization of the experimental setup). Artificial lower limbs were prepared at life-size scale, comprising left and right intact legs, residual limbs on the transfemoral or transtibial level, and single feet. Participants observed an individualized subset of these artificial lower limbs from a first-person perspective via a mirror. To this aim, a customized wooden structure concealed the real lower limbs, created space for the application of tactile stimulation, and allowed the placement of an artificial intact (Fig. 2A, B) or impaired limb (Fig. 2C, D). In the latter two conditions, the level of amputation for a given participant was matched by the impaired artificial limb (transfemoral or transtibial), and a single foot was positioned to match its natural anatomical location but remained visually disconnected from the artificial leg. Together with the participant, the experimenter defined the stimulation site on the residual limb and a corresponding area on the prosthetic limb (see red circles in Fig. 2A-D). The stimulation site was chosen as distally as possible, avoiding scar tissue, numb regions, or areas eliciting referred sensations. If several sites were suitable, the most ventrally located one, providing optimal visibility, was selected. Using brushes, a trained experimenter applied synchronous visuo-tactile stimuli at approximately 0.5 Hz, synchronized with a jittered auditory signal. Each trial lasted approximately five minutes and consisted of alternating stimulation and rest blocks of equal duration. Participants were instructed to observe both the stimulated artificial leg and the non-stimulated artificial foot throughout each trial.

After each condition, participants verbally evaluated statements (two items per category) regarding *Touch Referral* (i.e., 'I felt the touch in the artificial leg' and 'The touch I observed felt like a real touch') as well as ownership experiences related to both the artificial leg (*Leg Ownership*; 'I felt as if the artificial leg was part of my body' and 'It seemed as if the artificial leg belonged to me') and the artificial foot (i.e., *Foot Ownership*; 'I felt as if the artificial foot was part of my body' and 'It

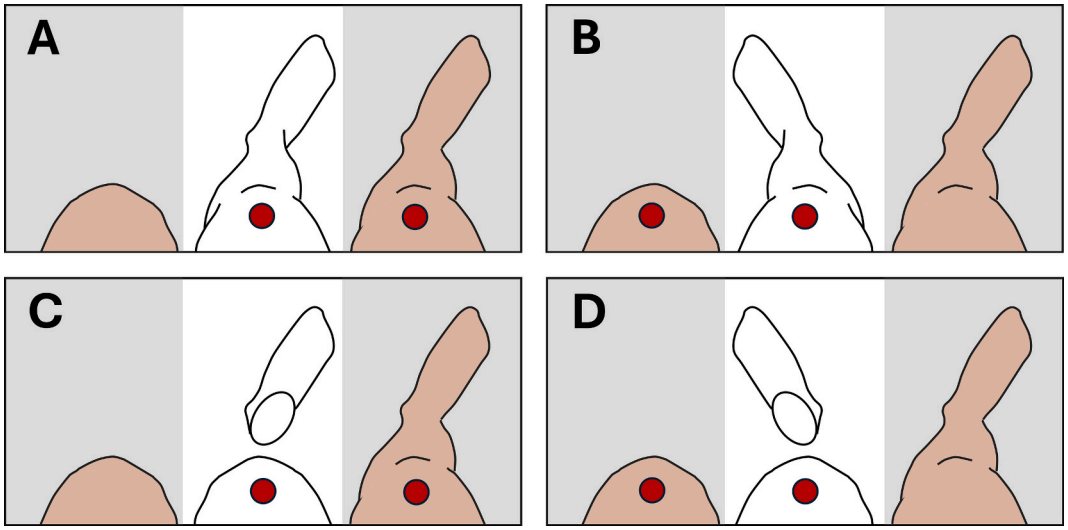

Fig. 2. Schematic experimental setup. Given are the conditions for an individual with a left-sided amputation at the transfemoral level. The real limbs are depicted in skin color, the artificial limbs are depicted in white (note that this differentiation is only for illustrative purposes; in the experiment, the artificial limb was also skin-colored). The conditions differed regarding the side of illusion induction (non-amputated vs. amputated) and the type of artificial limb (intact vs. impaired). A) Non-amputated side, intact artificial limb; B) Amputated side, intact artificial limb; C) Non-amputated side, impaired artificial limb; D) Amputated side, impaired artificial limb. Grey-shaded areas are hidden from the participant's view during the experiment and red circles represent the regions where synchronous visuo-tactile stimulation was applied. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

seemed as if the artificial foot belonged to me'). Note that the items of both ownership categories were identically worded and differed only with respect to the target body part (leg vs. foot). Participants rated each item using a 7-point Likert scale ranging from 0 'strongly disagree' to 6 'strongly agree'. Mean scores per dimension (Touch Referral, Leg Ownership, Foot Ownership) were entered into subsequent statistical analyses. For completeness, it should be noted that two additional items assessing perceived body integrity were also administered; however, these were not relevant to the present study purposes and have been reported elsewhere (Bekrater-Bodmann & Ruttorf, 2026).

2.3. Statistical analysis

Mean rating scores with standard deviation are reported. For each of the four conditions, a separate simple mediation analysis was performed to investigate whether Leg Ownership (*M*) mediated the relationship between Touch Referral (*X*) and Foot Ownership (*Y*) (see Fig. 1). The analyses employed the PROCESS macro (v5.0; Model 4; Hayes, 2022) for IBM SPSS (v.29.0). Direct relationships (paths *a*, *b*, *c'*) were assessed through unstandardized regression coefficients. The indirect relationship, calculated as the product of coefficients (*ab*), was examined to test for the presence of mediation. Previous simulation studies indicate that mediation analysis can yield valid results even with small sample sizes, as in the present study, provided that the associations between model variables (*X* on *M*, *M* on *Y*) are large and bootstrapping is applied (Fritz & MacKinnon, 2007). Consistent with this assumption, prior findings support the presence of strong associations (Reader et al., 2021), and we used PROCESS with bootstrapped inference (50,000 samples) to obtain robust significance tests and confidence intervals (CI_{Boot}) for all paths. A custom random-number seed (12345) was set to ensure replicability of the bootstrap results within and across analyses. For each analysis, we report the regression coefficient B_{Boot} with its standard error (SE_{Boot}). Note that unstandardized bootstrapped coefficients were prioritized for substantive interpretability and stability given sample size constraints. To reduce the risk of false positives arising from multiple mediation tests, and since each analysis tested the same underlying hypothesis, the 99% (rather than 95%) CI_{Boot} was used for all associations, providing a Bonferroni-like level of protection against Type I errors. Relationships were considered statistically significant when the 99% CI_{Boot} did not include zero.

To further substantiate the validity and specificity of our results, we conducted complementary analyses. First, within-subject path analyses were conducted using the SPSS MEMORE macro (v3.0, Model 1; Montoya & Hayes, 2017) which accounts for the within-subject dependencies of our repeated-measures design. The model evaluates change by utilizing difference scores (intact minus impaired artificial limb) for both the mediator (Leg Ownership) and the outcome (Foot Ownership). This allows us to test whether individual differences in the change of Leg Ownership significantly predicted individual differences in the change of Foot Ownership (i.e., the *b*-path). Inferential tests and confidence intervals for the individual path coefficients were based on standard parametric *t*-distributions. Second, to evaluate the robustness and directionality of the proposed mediation pathway, simple mediation (SPSS PROCESS Model 4, using the analytical settings as described above) was conducted to test the indirect relationships in a reversed mediation model, treating Foot Ownership as the predictor *X* and Leg Ownership as the outcome *Y*. Third, as a further test of specificity, we applied simple mediation (SPSS PROCESS Model 4, using the analytical settings as described above) to an appropriate control condition corresponding to that one using an intact artificial limb on the amputated side (Fig. 2B). While all conditions analyzed so far involved synchronous visuo-tactile stimulation between the artificial and real limb, this newly included control condition – taken from the original Experiment 1 (Bekrater-Bodmann & Ruttorf, 2026) with the same participants – used asynchronous stimulation, which represents the typical RLI control setup (e.g., Riemer et al., 2019). Applying mediation analysis to this condition thus allowed us to test whether the indirect relationship of Touch Referral on Foot Ownership via Leg Ownership remained robust even under conditions characterized by reduced multisensory concordance. To account for the heightened variance inherent to within-subject difference-score architectures and to maintain statistical consistency across these complementary testing frameworks, all additional analyses were evaluated using a standard significance threshold of $\alpha = 0.05$ (95% *CIs*).

3. Results

3.1. Perceptual outcomes

Descriptive results for Leg Ownership, Foot Ownership, and Touch Referral in each condition are provided in Table 1. The inferential statistical analyses of the mean comparisons are reported in detail elsewhere (Bekrater-Bodmann & Ruttorf, 2026) and are summarized here only for context. According to these analyses, Leg Ownership showed a significant main effect for body side (amputated > non-amputated), whereas Foot Ownership was influenced by the type of artificial limb (intact > impaired). For Touch Referral, there was a significant main effect for body side (amputated > non-amputated). However, this main effect must be interpreted in the context of a significant body side × artificial limb interaction, which was mainly driven by higher ratings when the illusion was induced on the amputated compared with the non-amputated side using an impaired artificial limb (see Fig. 2, D > C).

3.2. Mediation analyses

3.2.1. Mediation A: Non-amputated side, intact artificial limb

A simple mediation analysis was conducted to examine whether Touch Referral (*X*) predicts Foot Ownership (*Y*) and whether this relationship is mediated by Leg Ownership (*M*) during RLI induction on the non-amputated side using an intact artificial limb (Fig. 2A). The *X* on *M* path explained approximately $R^2 = 50\%$ of the variance in *M* ($F(1,32) = 32.60$, $p < .001$). The full model (*X* + *M* on *Y*) explained approximately $R^2 = 74\%$ of the variance in *Y* ($F(2,31) = 43.03$, $p < .001$). Touch Referral predicted Leg Ownership (i.e., the mediator) significantly ($B_{Boot} = 1.00$, $SE_{Boot} = 0.15$, 99% CI_{Boot} [0.64, 1.58]), which in turn significantly predicted Foot Ownership ($B_{Boot} = 0.94$, $SE_{Boot} = 0.12$, 99% CI_{Boot} [0.72, 1.43]). While the direct relationship between Touch Referral and Foot Ownership was non-significant ($B_{Boot} = -0.12$, $SE_{Boot} = 0.16$, 99% CI_{Boot} [−0.77, 0.22]), the indirect relationship, that is, the mediation, became significant ($B_{Boot} = 0.91$, $SE_{Boot} = 0.21$, 99% CI_{Boot} [0.55, 1.72]).

3.2.2. Mediation B: Amputated side, intact artificial limb

Subsequently, the same analysis was performed for the condition where the RLI was induced for the amputated side using an intact artificial limb (Fig. 2B). The *X* on *M* path explained approximately $R^2 = 32\%$ of the variance in *M* ($F(1,32) = 14.85$, $p < .001$) and the full model (*X* + *M* on *Y*) explained about $R^2 = 47\%$ of the variance in *Y* ($F(2,31) = 13.68$, $p < .001$). Touch Referral predicted Leg Ownership significantly ($B_{Boot} = 0.68$, $SE_{Boot} = 0.17$, 99% CI_{Boot} [0.03, 1.03]), which in turn significantly predicted Foot Ownership ($B_{Boot} = 0.95$, $SE_{Boot} = 0.16$, 99% CI_{Boot} [0.63, 1.56]). While the direct relationship was non-significant ($B_{Boot} = -0.20$, $SE_{Boot} = 0.22$, 99% CI_{Boot} [−0.88, 0.55]), the indirect relationship became significant ($B_{Boot} = 0.64$, $SE_{Boot} = 0.22$, 99% CI_{Boot} [0.03, 1.37]).

Table 1
Perceptual results. Participants rated each dimension in each condition on a 7-point Likert scale ranging from 0 'strongly disagree' to 6 'strongly agree'.

	Non-amputated side, intact artificial limb		Amputated side, intact artificial limb		Non-amputated side, impaired artificial limb		Amputated side, impaired artificial limb	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Leg Ownership	3.69	2.12	4.01	1.82	3.06	2.04	4.01	1.99
Foot Ownership	2.97	2.20	3.13	2.24	1.26	1.74	1.12	1.77
Touch Referral	4.85	1.55	4.88	1.46	4.35	1.73	5.01	1.37

M = mean; *SD* = standard deviation.

3.2.3. Mediation C: Non-amputated side, impaired artificial limb

For the non-amputated side using an impaired artificial limb (Fig. 2C), the *X* on *M* path explained about $R^2 = 30\%$ of the variance in *M* ($F(1,32) = 13.39$, $p < .001$). The full model (*X* + *M* on *Y*) explained approximately $R^2 = 21\%$ of the variance in *Y* ($F(2,31) = 4.09$, $p = .03$). Touch Referral predicted Leg Ownership significantly ($B_{Boot} = 0.64$, $SE_{Boot} = 0.16$, 99% CI_{Boot} [0.15, 1.08]), which, however, did not significantly predict Foot Ownership ($B_{Boot} = 0.33$, $SE_{Boot} = 0.14$, 99% CI_{Boot} [−0.05, 0.69]). Neither the direct relationship between Touch referral and Foot Ownership ($B_{Boot} = 0.11$, $SE_{Boot} = 0.11$, 99% CI_{Boot} [−0.19, 0.50]) nor the indirect relationship was significant ($B_{Boot} = 0.21$, $SE_{Boot} = 0.10$, 99% CI_{Boot} [−0.05, 0.55]).

3.2.4. Mediation D: Amputated side, impaired artificial limb

For the mediation analysis for the amputated side using an impaired artificial limb (Fig. 2D), the *X* on *M* path explained approximately $R^2 = 20\%$ of the variance in *M* ($F(1,32) = 7.78$, $p = .01$). However, the full model (*X* + *M* on *Y*) explained only about $R^2 = 8\%$ of the variance in *Y* and missed significance ($F(2,31) = 1.30$, $p = .29$). As in all analyses before, Touch Referral predicted Leg Ownership significantly ($B_{Boot} = 0.67$, $SE_{Boot} = 0.26$, 99% CI_{Boot} [0.05, 1.67]), but Leg Ownership did not significantly predict Foot Ownership ($B_{Boot} = 0.21$, $SE_{Boot} = 0.13$, 99% CI_{Boot} [−0.21, 0.55]). Again, neither the direct relationship between Touch Referral and Foot Ownership ($B_{Boot} = 0.10$, $SE_{Boot} = 0.18$, 99% CI_{Boot} [−0.43, 0.69]) nor the indirect relationship was significant ($B_{Boot} = 0.14$, $SE_{Boot} = 0.11$, 99% CI_{Boot} [−0.15, 0.55]). The results of the mediation analyses are summarized in Table 2.

3.2.5. Complementary analyses

3.2.5.1. Within-subject path analyses. Within-subject path analyses evaluated the statistical pathways between the artificial limb conditions (intact vs. impaired) via difference scores, examined separately for the non-amputated (Analysis 1) and the amputated side (Analysis 2). Note that positive regression coefficients indicate higher values in the intact condition.

For Analysis 1 (non-amputated side), artificial limb type showed a significant overall relationship with Foot Ownership difference scores ($B = 1.71$, $SE = 0.40$, 95% *CI* [0.90, 2.51]). The first stage of the model representing the relationship with Leg Ownership difference scores was non-significant ($B = 0.63$, $SE = 0.36$, 95% *CI* [−0.11, 1.37]). However, the second-stage path (*b*-path) was statistically significant ($B = 0.55$, $SE = 0.17$, 95% *CI* [0.22, 0.89]), indicating that the difference scores of Leg Ownership significantly predicted the difference scores of Foot Ownership. For Analysis 2 (amputated side), artificial limb type also showed a significant overall relationship with the Foot Ownership difference scores ($B = 2.01$, $SE = 0.35$, 95% *CI* [1.30, 2.73]). In the first stage of the model, the artificial limb condition was not significantly associated with the difference scores for Leg Ownership ($B = 0.00$, $SE = 0.33$, 95% *CI* [−0.67, 0.67]). Mirroring the pattern of the non-amputated side, the second-stage regression coefficient (*b*-path) was statistically significant ($B = 0.45$, $SE = 0.17$, 95% *CI* [0.10, 0.80]), showing that changes in Leg Ownership were robustly associated with changes in Foot Ownership.

3.2.5.2. Reversed mediation models. To assess the specificity of the hypothesized mediation sequence, we tested the reversed models (PROCESS Model 4) for each significant mediation analysis (Mediation A and B: *X* = Foot Ownership, *M* = Leg Ownership, *Y* = Touch Referral). Compared to the initially hypothesized models (Mediation A: $R^2 = 74\%$; Mediation B: $R^2 = 47\%$), the proportion of explained full-model variance decreased in the reversed models (R^2 of 51% and 33%, respectively); nevertheless, both proportions remained statistically significant in magnitude (both $F(2,31) \geq 7.66$, both $p \leq .002$). While bidirectional relationships are expected in cross-sectional data, reversed Mediation A showed a significant but substantially smaller indirect relationship

Table 2
Summary of the mediation analyses results.

	Non-amputated side, intact artificial limb	Amputated side, intact artificial limb	Non-amputated side, impaired artificial limb	Amputated side, impaired artificial limb
Path *a* (*X* on *M*)	×	×	×	×
Path *b* (*M* on *Y*)	×	×	–	–
Direct relationship *c'*	–	–	–	–
Indirect relationship *ab*	×	×	–	–

× significant; –– not significant.

($B_{Boot} = 0.49$, $SE_{Boot} = 0.17$, 95% CI_{Boot} [0.18, 0.83]) compared to the hypothesized original model ($B_{Boot} = 0.91$), reflecting a reduction of approximately 46%. The indirect relationship for reversed Mediation B ($B_{Boot} = 0.30$, $SE_{Boot} = 0.14$, 95% CI_{Boot} [0.05, 0.60]) was significant but approximately 53% smaller than the original model ($B_{Boot} = 0.64$). These results suggest superiority of the hypothesized perceptual sequence across reversed models, indicating empirical robustness despite cross-sectional limitations.

3.2.5.3. Mediation of exemplary control condition. To address questions regarding the specificity of the mediation pathway for synchronous visuo-tactile stimulation, we additionally conducted the same PROCESS Model 4 mediation analysis for the amputated side using an intact limb under asynchronous visuo-tactile stimulation in a complementary manner. The full model explained variance of approximately $R^2 = 66\%$ ($F(2,31) = 29.62$, $p < .001$). Although two-sided *t*-tests revealed that perceptual ratings in the asynchronous condition (Leg Ownership: $M = 2.13$, $SD = 1.98$; Foot Ownership: $M = 1.93$, $SD = 1.83$; Touch Referral: $M = 1.96$, $SD = 2.19$) were significantly lower than in the respective synchronous condition (all $T(33) \geq 4.33$, all $p < .001$, all Cohen's *d* between −0.74 and − 1.21), the indirect relationship remained significant ($B_{Boot} = 0.52$, $SE_{Boot} = 0.17$, 95% CI_{Boot} [0.25, 0.92]). This indicates that the observed mediation structure is not uniquely restricted to synchronous visuo-tactile stimulation conditions but also occurs under weaker multisensory integration.

4. Discussion

In the present study, we re-analyzed perceptual data from a recently introduced rubber limb illusion (RLI) variation conducted with a sample of individuals with lower limb amputation (Bekrater-Bodmann & Ruttorf, 2026). The experimental manipulation induced ownership over an artificial foot, even though only an artificial leg was subjected to visuo-tactile stimulation together with the participant's real amputated or non-amputated leg. Mediation analyses were used to test a theoretical model proposing that tactile sensation and foot ownership may be linked only indirectly via leg ownership. The results are consistent with the model, both for the non-amputated and the amputated limb as target, but only when an intact artificial limb was used. These findings are thus compatible with the idea that tactile stimulation applied to one body part relates indirectly to the perception of anatomically adjacent, non-stimulated regions, even in cases where those body parts are physically absent.

4.1. Interpretation of results

The results may provide insights into the perceptual organization underlying the sense of limb ownership in individuals with leg amputation. Previous authors have concluded that fundamental body perception mechanisms, including sensory integration capabilities (Ehrsson et al., 2008) and subsequent causal inference processes (Bliek et al., 2021), remain preserved even decades after amputation. Our findings are thus compatible with a previously hypothesized hierarchical sequence of processing where touch referral precedes the experience of local body ownership (see Makin et al., 2008), which in a second probabilistic step elicits ownership also for adjacent body parts (see Chancel et al., 2022; Ehrsson & Chancel, 2019). Remarkably, the present results suggest that the absence of the physical foot does not substantially alter these perceptual processes. This indicates compensatory mechanisms in which local sensory signals (e.g., tactile and visual information) may activate integrated whole-limb representations of the missing body part, despite the lack of sensory feedback from the distal segment. Body experience in individuals with limb amputation may therefore rely more heavily on internal body models that compensate for the absence of direct sensory input. The present findings further suggest that the strength of the mediating relationship between leg-related and foot-related ownership may be specifically modulated by the availability and coherence of external visuo-tactile input associated with anatomical continuity.

The complementary analyses help interpret the results. The within-subject path analyses show that while the mean difference scores for leg ownership did not significantly covary with the artificial limb type on either side, the regression coefficient linking leg ownership difference scores to foot ownership difference scores was highly significant across both the non-amputated and amputated sides. This statistical pattern suggests functional coupling between the changes in proximal and distal body representations: fluctuations in leg ownership between the two conditions seem to translate into corresponding changes in foot ownership. Crucially, this covariance suggests that the structural configuration of the presented limb determines the strength of this internal link. This is compatible with the theoretical perspective that anatomical continuity does not merely induce a global, unspecific shift in ownership levels, but specifically shapes how local, leg-related ownership representations are used to inform and update extended, foot-related ownership percepts. The reversed mediation models lend additional support to the hypothesized perceptual sequence, showing smaller, non-preferred indirect relationships when the proposed direction of influence is reversed. This suggests that the processes underlying the mediation are asymmetric, with touch referral potentially exerting a stronger association with leg ownership, which in turn relates to foot ownership, rather than the reverse sequence. Finally, the complementary mediation analysis of an asynchronous control condition indicates that the observed mediation structure is not uniquely tied to synchronous visuo-tactile stimulation but also occurs under weaker multisensory integration conditions. This suggests that the pathway is robust across varying levels of visuo-tactile coherence, and that the key moderator (i.e., artificial limb continuity) acts upon rather than replaces this more general multisensory-related limb ownership formation process. Consequently, the statistical association within the embodiment cascade appears to be partly sustained by top-down visual and structural cues, such as visual capture and pre-existing body schemata (e.g., Tsakiris, 2010), allowing the relationship between proximal and distal components to persist without synchronous multisensory reinforcement.

4.2. Multisensory integration and limb ownership

The current findings are consistent with the principles of multimodal sensory integration and their importance for the conscious experience of the body. Referral of touch may be particularly relevant in this process

(Reader et al., 2021). It is essential, however, to distinguish between touch referral and ownership as two phenomena that frequently co-occur but conceptually remain distinct: while touch referral reflects the perceptual consequence of spatiotemporally corresponding visuo-tactile stimulation (e.g., Kalckert et al., 2019), body ownership represents the phenomenological outcome of a causal inference process through which sensory signals are attributed to *one's own body part* as their source (e.g., Samad et al., 2015). Notably, previous studies suggested that tactile input is not necessarily required for this process (e.g., Coppi et al., 2024; Crucianelli & Ehrsson, 2022; Kalckert & Ehrsson, 2012; Walsh et al., 2011); rather, combining information from at least two senses may suffice to elicit the sense of body ownership (Reader et al., 2021). However, recent evidence underscores the particular significance of touch for conscious body experience, as visuo-tactile congruence evokes stronger RLI sensations than visuo-proprioceptive congruence (Bartoletti et al., 2023), and touch referral has been shown to be especially important for actions that rely on dynamic body representations (Sabek et al., 2025).

The present findings may contribute to our understanding of ownership processing within a single limb. Recent work using a whole-body illusion paradigm (O'Kane, Chancel and Ehrsson, 2024) suggests hierarchical interactions between local body-part ownership and global full-body ownership, potentially following Gestalt principles (Koffka, 1935). The current leg-to-foot mediation pattern may represent a limb-level instance of such hierarchical integration, warranting further investigation of how local ownership signals combine within limbs and potentially across the body. It should be noted, however, that recent criticism has emerged concerning the prevailing interpretation of the RLI as a bottom-up sensory phenomenon. For example, Lush et al. (2020) presented data on the relationship between RLI outcomes and hypnotizability, which the authors interpreted as evidence that illusory body ownership primarily depends on demand characteristics. In contrast, other researchers have argued, based on empirical results, that the RLI is still better explained by multisensory mechanisms (Ehrsson et al., 2022; Slater & Ehrsson, 2022). The present authors contend that the touch referral percept in particular can be understood as a basic phenomenon consistent with established models of sensory integration, in which suggestibility or hypnotizability are unlikely to exert significant influence (Marotta et al., 2016). This interpretation is further supported by RLI paradigms successfully adapted for use in animal models (Kawashima & Ikeda, 2025; Wada et al., 2016). In this context, the current RLI paradigm offers advantages over classical RLI experiments by enabling the use of intact vs. impaired limb conditions as more specific controls, rather than relying solely on asynchronous visuo-tactile stimulation. As asynchronously applied touches reliably attenuate ownership experiences in the RLI, it represents one of the most frequently implemented control conditions (Riemer et al., 2019), though it has also been particularly criticized for its association with varying demand characteristics (Lush, 2020). In our original Experiment 2 (Bekrater-Bodmann & Ruttorf, 2026), synchronous visuo-tactile stimulation was applied in all conditions, and thus, an illusion of ownership was consistently induced, only differing in its spatial extent (leg ownership in impaired conditions vs. leg-and-foot ownership in intact conditions). This procedure likely reduces the confounding influence of varying demand characteristics associated with asynchronous control conditions. Nevertheless, the present study's differential outcomes for intact versus impaired artificial limbs suggest interplay between bottom-up sensory integration and top-down modulatory processes, a dynamic already proposed by previous authors (e.g., Tsakiris, 2010). It should be noted, however, that the exclusively subjective measures employed in the present study leave the data susceptible to potential response-related biases. Future research on this topic should therefore incorporate behavioral or physiological indices (Riemer et al., 2019) to test their suitability as mediators or outcomes in mediation analyses.

4.3. Limitations

Several limitations of the present work must be acknowledged. First, the sample size was relatively small, potentially constraining interpretability and statistical power. However, while small for path analyses generally, the sample size is comparatively large for an experimental study examining multisensory processes of body representation in individuals with limb amputation, who represent an intriguing model for investigating the boundaries of body-related sensory integration. Simulation studies further demonstrate that bootstrapping yields valid mediation results with comparable sample sizes (Fritz & MacKinnon, 2007). Nonetheless, future studies with larger samples should verify the proposed processes.

A second limitation concerns methodological and measurement constraints. Intact artificial limb models explained substantial full-model variance (74%, 47%), whereas impaired artificial limb models accounted for much less proportions (21%, 8%; non-significant for Mediation D). Interestingly, the intact models demonstrated total explained variance exceeding the *a*-path variance in the mediator, whereas the impaired models showed the reverse pattern. These results align with the theoretical logic of the proposed model but may limit the interpretative strength and external validity particularly for the impaired conditions. In these conditions, floor effects in foot ownership ratings may have further restricted the range and attenuated indirect effects. However, our within-subject path analyses indicate that systematic variance across conditions was sufficiently preserved within the present sample. Specifically, the regression coefficient linking leg ownership difference scores to foot ownership difference scores (*b*-path) was statistically reliable on both sides, suggesting that variance was sufficiently distributed to evaluate the regression pathways across both artificial limb conditions. Finally, the use of only two items per construct may have reduced reliability. On the other hand, the similarity between leg and foot ownership items likely enhances true effect detection rather than inflating correlations (as evidenced by condition-specific differentiation, see Table 1 as well as the main and within-subject path analyses). In future research, however, expanded rating scales and larger item sets could help disentangle whether the findings primarily reflect measurement constraints or genuine differences in limb ownership processing.

Third, there are limitations regarding design and external validity. The absence of a control group prevents conclusions about generalizability. Although the non-amputated limb serves as within-subject control for the amputated limb and vice versa, the lack of an independent control group leaves open the possibility that the findings reflect amputation-specific perceptual phenomena. However, this alternative explanation appears unlikely, as the observed mediation patterns align more closely with general sensory-cognitive principles. Future studies should nevertheless explicitly test the generalizability of these findings, for instance across specific subgroups of individuals with limb absence. Thus, it remains open whether the associations observed here can be extended to individuals with upper limb amputation. The fundamentally similar sensory integration principles underlying the RLI for upper and lower limbs (Flögel et al., 2016) suggest that this may indeed be the case. The situation, however, may differ in congenital limb deficiency, as these individuals appear to possess a different representation of their body (Diers et al., 2025). As the sample in the present study consisted exclusively of individuals with acquired limb loss, these questions remain to be addressed in future research.

Finally, although it may be tempting to interpret the mediation results in causal terms (e.g., touch referral leads to leg ownership, which in turn leads to foot ownership), such causality cannot be inferred from the current data. All variables were obtained as parallel outcomes of a single experimental manipulation, precluding conclusions about their temporal sequence. To address this limitation, the manuscript systematically avoids causal terminology (e.g., “effect”) when referring to the mediation analyses, in favor of formulations that emphasize mere statistical

associations (e.g., "relationship"). Nevertheless, the data suggest empirical plausibility of the proposed model; whether the observed relationships, however, reflect actual causal mechanisms remains to be determined in future research.

5. Conclusion and outlook

The present study provided initial evidence that local body ownership experiences could mediate the association between touch referral and full-limb ownership in the RLI, provided that an intact artificial counterpart is used. Whether the target limb is amputated or not appears to play a minor role for phenomenology. Assuming the RLI reflects an experimental model for prosthesis embodiment (e.g., Ehrsson et al., 2008; Marasco et al., 2011; Niedernhuber et al., 2018; but see Zbinden & Ortiz-Catalan, 2021), describing the cognitive incorporation of a prosthesis into an amputated individual's body representation (Bekrater-Bodmann et al., 2024), utilizing the fundamental principles of multisensory body perception could be relevant for rehabilitation processes following limb amputation. Prosthesis embodiment has been associated with several positive rehabilitative outcomes (e.g., Bekrater-Bodmann, 2021; Bekrater-Bodmann, 2025; Bekrater-Bodmann et al., 2021). Sensory-enabled prostheses providing somatosensory feedback have been proposed, among other factors, to enhance prosthesis embodiment (Rognini et al., 2019). Our findings may motivate future studies testing whether sensory feedback that promotes touch referral can support prosthesis embodiment, for instance by promoting the embodiment of the prosthesis socket to strengthen the incorporation of the entire device. This would represent a novel application of sensory feedback systems, which have so far primarily been investigated for their functional benefits (Raspopovic et al., 2021), with embodiment enhancement being often regarded as a secondary or incidental effect (e.g., Petrini et al., 2019). However, prospective studies examining the sequential dynamics between sensory and cognitive processes as well as evaluating their clinical importance in real-life settings are still needed.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work, the authors used Perplexity for proofreading, correcting grammar, and enhancing the English phrasing. The authors reviewed and edited the output as needed and take full responsibility for the content of the published article.

CRediT authorship contribution statement

Robin Bekrater-Bodmann: Writing – original draft, Visualization, Validation, Supervision, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Merkur Alimusaj:** Writing – review & editing, Writing – original draft, Resources.

Consent for publication

The authors gave their consent for the publication of this work.

Ethics approval and consent to participate

The study was approved by the ethics review board of the Medical Faculty Mannheim, Heidelberg University (reference number: 2016-658N-MA), and was carried out in accordance with the Declaration of Helsinki in its current form. Written informed consent was obtained from all individuals prior to study participation.

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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. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.concog.2026.104089.

Data availability

Data will be made available on request.

References

Bartoletti, R. L., Denis-Noël, A., Boulvert, S., Lopez, M., Faure, S., & Corveleyn, X. (2023). Visuo-tactile congruence leads to stronger illusion than visuo-proprioceptive congruence: A quantitative and qualitative approach to explore the rubber hand illusion. *Multisensory Research, 36*(6), 477–525. https://doi.org/10.1163/22134808-bja10101

Bekrater-Bodmann, R. (2021). Factors associated with prosthesis embodiment and its importance for prosthetic satisfaction in lower limb amputees. *Frontiers in Neurorobotics, 14*, Article 604376. https://doi.org/10.3389/fnbot.2020.604376

Bekrater-Bodmann, R. (2025). The German adaptation of the amputee body image scale and the importance of psychosocial adjustment to prosthesis use. *Scientific Reports, 15*, 6204. https://doi.org/10.1038/s41598-025-90737-2

Bekrater-Bodmann, R., Kehl, I., Giordano, A., & Franchignoni, F. (2024). Rasch validation of the German version of the prosthesis embodiment scale for lower limb amputees and proposal of a revised version. *Disability and Rehabilitation, 46*(7), 1400–1407. https://doi.org/10.1080/09638288.2023.2199220

Bekrater-Bodmann, R., Reinhard, I., Diers, M., Fuchs, X., & Flor, H. (2021). Relationship of prosthesis ownership and phantom limb pain: Results of a survey in 2383 limb amputees. *Pain, 162*(2), 630–640. https://doi.org/10.1097/j.pain.0000000000002063

Bekrater-Bodmann, R., & Ruttorf, M. (2026). Feeling (in)complete: Neural correlates of perceived body integrity in individuals with lower limb amputation. *Journal of Neuroengineering and Rehabilitation, 23*(1), 38. https://doi.org/10.1186/s12984-025-01817-3

Bliek, A., Bekrater-Bodmann, R., & Beckerle, P. (2021). Cognitive models of limb embodiment in structurally varying bodies: A theoretical perspective. *Frontiers in Psychology, 12*, Article 716976. https://doi.org/10.3389/fpsyg.2021.716976

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

Chancel, M., Iriye, H., & Ehrsson, H. H. (2022). Causal inference of body ownership in the posterior parietal cortex. *Journal of Neuroscience, 42*(37), 7131–7143. https://doi.org/10.1523/jneurosci.0656-22.2022

Coppi, S., Jensen, K. B., & Ehrsson, H. H. (2024). Eliciting the rubber hand illusion by the activation of nociceptive C and Aδ fibers. *Pain, 165*(10), 2240–2256. https://doi.org/10.1097/j.pain.0000000000003245

Crucianelli, L., & Ehrsson, H. H. (2022). Visuo-thermal congruency modulates the sense of body ownership. *Communications Biology, 5*, 731. https://doi.org/10.1038/s42003-022-03673-6

Diers, M., Schredl, M., Flor, H., & Bekrater-Bodmann, R. (2025). Body representation in dreams of congenital and early-life amputees. *Scientific Reports, 15*, 9919. https://doi.org/10.1038/s41598-024-83000-7

Ehrsson, H. H. (2020). Multisensory processes in body ownership. In K. Sathian, & V. S. Ramachandran (Eds.), *Multisensory perception* (pp. 179–200). Academic Press.

Ehrsson, H. H., & Chancel, M. (2019). Premotor cortex implements causal inference in multisensory own-body perception. *Proceedings of the National Academy of Sciences, 116*(40), 19771–19773. https://doi.org/10.1073/pnas.1914000116

Ehrsson, H. H., Fotopoulou, A., Radziun, D., Longo, M. R., & Tsakiris, M. (2022). No specific relationship between hypnotic suggestibility and the rubber hand illusion. *Nature Communications, 13*, 564. https://doi.org/10.1038/s41467-022-28177-z

Ehrsson, H. H., Rosén, B., Stockselius, A., Ragnö, C., Köhler, P., & Lundborg, G. (2008). Upper limb amputees can be induced to experience a rubber hand as their own. *Brain, 131*(12), 3443–3452. https://doi.org/10.1093/brain/awn297

Flögel, M., Kalveram, K. T., Christ, O., & Vogt, J. (2016). Application of the rubber hand illusion paradigm: Comparison between upper and lower limbs. *Psychological Research, 80*(2), 298–306. https://doi.org/10.1007/s00426-015-0650-4

Fritz, M. S., & MacKinnon, D. P. (2007). Required sample size to detect the mediated effect. *Psychological Science, 18*(3), 233–239. https://doi.org/10.1111/j.1467-9280.2007.01882.x

Gentile, G., Björnsdotter, M., Petkova, V. I., Abdulkarim, Z., & Ehrsson, H. H. (2015). Patterns of neural activity in the human ventral premotor cortex reflect a whole-body multisensory percept. *Neuroimage, 109*, 328–340. https://doi.org/10.1016/j.neuroimage.2015.01.008

Hayes, A. F. (2022). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach (Vol. 3)*. The Guilford Press.

Kalckert, A., Bico, I., & Fong, J. X. (2019). Illusions with hands, but not with balloons–comparing ownership and referral of touch for a corporal and noncorporal object after visuotactile stimulation. *Perception, 48*(5), 447–455. https://doi.org/10.1177/0301006619839286

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

Kawashima, S., & Ikeda, Y. (2025). Rubber arm illusion in octopus. *Current Biology, 35*(14), R702–R703. https://doi.org/10.1016/j.cub.2025.05.017

Koffka, K. (1935). *Principles of gestalt psychology, Harcourt, Brace*.

Lush, P. (2020). Demand characteristics confound the rubber hand illusion. Collabra: Psychology, 6(1), 22. https://psycnet.apa.org/doi/https://doi.org/10.1525/collabra.325.

Lush, P., Botan, V., Scott, R. B., Seth, A. K., Ward, J., & Dienes, Z. (2020). Trait phenomenological control predicts experience of mirror synaesthesia and the rubber hand illusion. *Nature Communications, 11*, 4853. https://doi.org/10.1038/s41467-020-18591-6

Makin, T. R., Holmes, N. P., & Ehrsson, H. H. (2008). On the other hand: Dummy hands and peripersonal space. *Behavioural Brain Research, 191*(1), 1–10. https://doi.org/10.1016/j.bbr.2008.02.041

Marasco, P. D., Kim, K., Colgate, J. E., Peshkin, M. A., & Kuiken, T. A. (2011). Robotic touch shifts perception of embodiment to a prosthesis in targeted reinnervation amputees. *Brain, 134*(3), 747–758. https://doi.org/10.1093/brain/awq361

Marotta, A., Tinazzi, M., Cavedini, C., Zampini, M., & Fiorio, M. (2016). Individual differences in the rubber hand illusion are related to sensory suggestibility. *PLoS One, 11*(12), Article e0168489. https://doi.org/10.1371/journal.pone.0168489

Montoya, A. K., & Hayes, A. F. (2017). Two-condition within-participant statistical mediation analysis: A path-analytic framework. *Psychological Methods, 22*(1), 6. https://doi.org/10.1037/met0000086

Niedernhuber, M., Barone, D. G., & Lenggenhager, B. (2018). Prostheses as extensions of the body: Progress and challenges. *Neuroscience & Biobehavioral Reviews, 92*, 1–6. https://doi.org/10.1016/j.neubiorev.2018.04.020

O'Kane, S. H., Chancel, M., & Ehrsson, H. H. (2024). Hierarchical and dynamic relationships between body part ownership and full-body ownership. *Cognition, 246*, Article 105697. https://doi.org/10.1016/j.cognition.2023.105697

Perez-Marcos, D., Sanchez-Vives, M. V., & Slater, M. (2012). Is my hand connected to my body? The impact of body continuity and arm alignment on the virtual hand illusion. *Cognitive Neurodynamics, 6*(4), 295–305. https://doi.org/10.1007/s11571-011-9178-5

Petrini, F. M., Valle, G., Bumbasirevic, M., Barberi, F., Bortolotti, D., Cvancara, P., & Raspopovic, S. (2019). Enhancing functional abilities and cognitive integration of the lower limb prosthesis. *Science Translational Medicine, 11*(512), Article eaav8939. https://doi.org/10.1126/scitranslmed.aav8939

Raspopovic, S., Valle, G., & Petrini, F. M. (2021). Sensory feedback for limb prostheses in amputees. *Nature Materials, 20*(7), 925–939. https://doi.org/10.1038/s41563-021-00966-9

Reader, A. T., Trifonova, V. S., & Ehrsson, H. H. (2021). The relationship between referral of touch and the feeling of ownership in the rubber hand illusion. *Frontiers in Psychology, 12*, Article 629590. https://doi.org/10.3389/fpsyg.2021.629590

Riemer, M., Trojan, J., Beauchamp, M., & Fuchs, X. (2019). The rubber hand universe: On the impact of methodological differences in the rubber hand illusion. *Neuroscience & Biobehavioral Reviews, 104*, 268–280. https://doi.org/10.1016/j.neubiorev.2019.07.008

Rognini, G., Petrini, F. M., Raspopovic, S., Valle, G., Granata, G., Strauss, I., & Blanke, O. (2019). Multisensory bionic limb to achieve prosthesis embodiment and reduce distorted phantom limb perceptions. *Journal of Neurology, Neurosurgery & Psychiatry, 90*(7), 833–836. https://doi.org/10.1136/jnnp-2018-318570

Rohe, T., & Noppeney, U. (2015). Cortical hierarchies perform Bayesian causal inference in multisensory perception. *PLoS Biology, 13*(2), Article e1002073. https://doi.org/10.1371/journal.pbio.1002073

Sabek, H., Heurley, L. P., Brunel, L., Vanborren, H., Brouillet, T., & Dru, V. (2025). Visuotactile correlation increases the integration of visual body-related effects into action representation. *Journal of Experimental Psychology: Human Perception and Performance, 51*(4), 445–456. https://doi.org/10.1037/xhp0001285

Samad, M., Chung, A. J., & Shams, L. (2015). Perception of body ownership is driven by Bayesian sensory inference. *PLoS One, 10*(2), Article e0117178. https://doi.org/10.1371/journal.pone.0117178

Slater, M., & Ehrsson, H. H. (2022). Multisensory integration dominates hypnotisability and expectations in the rubber hand illusion. *Frontiers in Human Neuroscience, 16*, Article 834492. https://doi.org/10.3389/fnhum.2022.834492

Smit, M., Brummelman, J. T. H., Keizer, A., van der Smagt, M. J., Dijkerman, H. C., & van der Ham, I. J. M. (2018). Body ownership and the absence of touch: Approaching the rubber hand inside and outside peri-hand space. *Experimental Brain Research, 236*(12), 3251–3265. https://doi.org/10.1007/s00221-018-5361-9

Tosi, G., Kalckert, A., Sivasubramanian, A. K., & Romano, D. (2024). The rubber hand illusion questionnaire: An exploratory graph analysis of ownership, referral of touch, and control statements. *Attention, Perception, & Psychophysics, 86*(8), 2866–2876. https://doi.org/10.3758/s13414-024-02964-w

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., Carpenter, L., James, D., & Fotopoulou, A. (2010). Hands only illusion: Multisensory integration elicits sense of ownership for body parts but not for non-corporeal objects. *Experimental Brain Research, 204*(3), 343–352. https://doi.org/10.1007/s00221-009-2039-3

Valenzuela Moguillansky, C., O'Regan, J. K., & Petitmengin, C. (2013). Exploring the subjective experience of the "rubber hand" illusion. *Frontiers in Human Neuroscience, 7*, 659. https://doi.org/10.3389/fnhum.2013.00659

Wada, M., Takano, K., Ora, H., Ide, M., & Kansaku, K. (2016). The rubber tail illusion as evidence of body ownership in mice. *Journal of Neuroscience, 36*(43), 11133–11137. https://doi.org/10.1523/jneurosci.3006-15.2016

Walsh, L. D., Moseley, G. L., Taylor, J. L., & Gandevia, S. C. (2011). Proprioceptive signals contribute to the sense of body ownership. *Journal of Physiology, 589*(12), 3009–3021. https://doi.org/10.1113/jphysiol.2011.204941

Zbinden, J., & Ortiz-Catalan, M. (2021). The rubber hand illusion is a fallible method to study ownership of prosthetic limbs. *Scientific Reports, 11*, 4423. https://doi.org/10.1038/s41598-021-83789-7