Beyond Vision: The Müller-Lyer Illusion Reveals Geometric Biases in Passive Touch and Haptic Exploration

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Running head: Tactile and haptic Müller-Lyer Illusion

The Müller-Lyer Illusion has been extensively studied in the visual modality and, to a lesser extent, in haptic exploration. However, with the exception of an early descriptive study in the 1930s, no reports have investigated the illusion during passive tactile stimulation. Previous research uses the terms “tactile” and “haptic” interchangeably, despite exclusively examining active exploration. The present study investigated whether the illusion emerges during passive tactile stimulation, and whether its expression differs from that observed during haptic exploration with sensorimotor engagement. Twenty participants completed a manual bisection task of Müller-Lyer stimuli in a haptic exploratory or passive tactile form. Reliable illusory bias was observed in the haptic condition, with midpoint judgments shifted towards the arrow wings. Notably, this effect was mediated by the effector, with stronger bias when responses were made using the right index finger. In the tactile condition, a configuration-dependent effect emerged, in that distally pointing arrows on the forearm elicited significant illusory midpoint shifts, whereas proximal and neutral configurations did not. These findings show that the Müller-Lyer illusion arises under passive tactile stimulation, specifically, we show that contextual geometric cues bias somatosensory spatial perception in the absence of voluntary exploration.

Introduction

Spatial perception encompasses an active process of interpretation through which we can construct object properties such as length, orientation, and spatial extent. Across sensory modalities, systematic discrepancies between physical properties and subjective perceptual experience are well documented. Notably, perceptual illusions provide a unique and valuable window into the mechanisms by which the brain constructs spatial experiences, revealing divergence between objective stimulus properties and subjective perceptual judgements (Gillam, 1980). The Müller-Lyer Illusion stands as a widely used example of such geometric distortion, first discovered by Franz Carl Müller-Lyer (1889). In its classic form, two identical line segments appear unequal in length depending on the outward or inward orientation of the arrow fins attached to the ends of the lines. Although traditionally presented in the visual domain, evidence has also shown that the illusion can emerge in the haptic modality (Bean, 1938; Gentaz et al., 2004; Heller et al., 2002; Mancini et al., 2010; Mancini et al., 2011; Révész, 1934), raising critical questions about how spatial information is encoded and integrated during haptic exploration compared to passive tactile stimulation.

Within the visual domain, several mechanistic explanations for such an illusion have been proposed. In an early theoretical account, Gregory (1963) argued that the illusion arises from inappropriate size constancy scaling. According to this view, the visual system uses converging lines as depth cues to infer three-dimensional structure, therefore allowing accurate size perception in natural environments. As such, inward or outward-oriented arrow fins resemble perspective cues and are interpreted as receding or protruding in depth, respectively. In this case, systematic distortions in line length result from the misapplication of size constancy mechanisms in the visual system. However, this explanation has been challenged by some, given that the illusion can persist when depth cues are minimised (see,

for example, Howe & Purves, 2005; McGraw & Stanford, 1994), suggesting that more general principles of spatial encoding may better explain the illusion.

Indeed, neuroimaging evidence has shown that the strength of the visual Müller-Lyer illusion correlates with activity in bilateral lateral occipital cortex as well as in the right superior parietal cortex in both functional magnetic resonance imaging (fMRI; Weidner & Fink, 2007) and magnetoencephalography (MEG; Weidner et al., 2010) studies, implicating the cortical regions involved in object-based spatial encoding.

Two alternative influential accounts base themselves on fundamental principles of the sensory systems. The first attributes the effect to lateral inhibition (Coren, 1970; see also Von Békésy, 1967), whereby converging and diverging arrow fins generate differential inhibitory interactions with neural populations encoding the central shaft. Specifically, neurons coding outward-pointing fins reduce inhibitory overlap at the line endpoints, leading to perceived expansion of length, whereas inward-pointing fins increase inhibitory interactions, therefore compressing perceived extent (Coren, 1970). Overall, Coren (1970) suggested that lateral inhibition is a key contributing mechanism in the visual Müller-Lyer illusion; however, other mechanisms also play a significant role. A complementary account further emphasises orientation-selective coding in primary visual cortex (V1; Hubel & Wiesel, 1968; Gilbert & Wiesel, 1990), suggesting neural populations responding to angled fins interact with those coding the horizontal shaft, thereby biasing the encoded position of the shaft endpoints (Coren, 1988; Coren & Girgus, 1978).

Although these accounts have been developed primarily in the visual domain, the principles they invoke, such as lateral inhibition and population-based spatial coding, are not modality independent. Investigating the illusion within the somatosensory domain provides a theoretically powerful opportunity to examine whether similar mechanisms operate beyond

vision. Indeed, previous studies have shown the presence of the Müller-Lyer illusion during haptic exploration tasks (Over, 1967; Mancini et al., 2010), as well as in crossmodal contexts (Gallace & Spence, 2005; Mancini et al., 2010). Importantly, complementary evidence from repetitive transcranial magnetic stimulation (rTMS) further suggests that haptic and visual versions of the illusion may engage overlapping cortical substrates. Specifically, Mancini and colleagues (2011) showed that disruption of the occipito-temporal cortex by rTMS modulated the magnitude of the illusion across visual, haptic, and visuo-haptic task variations, supporting the involvement of shared object-based processing mechanisms.

To the best of our knowledge, no study has systematically tested the illusion in the tactile modality under purely passive tactile stimulation. Moreover, the distinction between "haptic" and "tactile" has been conflated in the literature, with both terms being used interchangeably to refer to exclusively haptic exploration. An early exception to this is a descriptive report by Révész (1934), which attempted to isolate passive from active tactile variants of the task. Nonetheless, systematic comparisons between haptic exploration (active) and externally driven tactile input (passive) remain lacking.

In Revesz's early investigation (Revesz, 1934), raised Müller-Lyer configurations were applied directly to the skin without active exploration. It was reported that, although the illusion was present under passive tactile stimulation, the effect was weaker and less consistent than during haptic exploration. These observations led to the suggestion that movement and kinaesthetic feedback may lead to enhanced spatial distortions. Such a comparison is theoretically important as it allows the perceptual (cutaneous) component of touch to be dissociated from the sensorimotor processes inherent to haptic exploration.

The present study sought to investigate whether the Müller-Lyer illusion influences perceived midpoint locations under two distinct somatosensory conditions: haptic

exploration (active) and passive tactile stimulation. While the illusion has been reliably demonstrated across both the visual and haptic sensory domains, little is known about whether it emerges during passive touch. In this way, we aimed to isolate the contributions of active sensorimotor processes from purely perceptual tactile processing.

To this end, we employed a manual bisection task using three-dimensional printed arrow stimuli. Previous studies have shown that when participants are instructed to indicate the midpoint of a Müller-Lyer figure, judgements are systematically biased away from the arrowhead and toward the wings (e.g., Mon-Williams & Bull, 2000). We used the Judd variant of the illusion (Gillam, 1980; Mancini et al., 2010), in which both fins are oriented in the same direction (Figure 1). In the haptic condition, stimuli were oriented leftward or rightward on a stimulus board. In the tactile condition, stimuli were applied along the proximal-distal axis of the forearm, with arrowheads pointing distally (towards the wrist) or proximally (towards the elbow). A neutral control condition consisted of a line terminated by vertical bars rather than arrow fins (Figure 1).

The study hypotheses were twofold. First, in the haptic condition, we predicted that participants would exhibit reliable Müller-Lyer bias, consistent with previous findings (e.g. Heller et al., 2005; Millar and Al-Attar, 2002). Specifically, midpoint judgements would be systematically shifted toward the arrow wings (i.e. away from the arrowhead), reflecting an overestimation of the shaft length in the direction of outward-pointing fins. Second, in the tactile condition, given the limited evidence in the passive tactile domain, it was predicted that if the Müller-Lyer illusion operates independently of active sensorimotor contributions, midpoint judgments would show a comparable shift toward the arrow wings. Conversely, if active exploration is critical, then no systematic midpoint estimation error was predicted under passive tactile stimulation.

Material and Methods

Participants

Twenty participants ($Mean_{Age}$ ± SD_{Age} = 26.9 ± 8.1 years; 16 females, 4 males) took part, voluntarily recruited in exchange for monetary payment at a rate of £7.50 per hour. All participants indicated normal or corrected-to-normal vision and normal sensation of touch to the hands and arms, as indicated through free self-report. Eighteen participants were right-handed and two left-handed, as indicated on the Edinburgh Handedness Inventory (Oldfield, 1971; Mean = 61, range -100 - 100). A priori power analysis using G*Power 3.1 (Faul et al., 2009), with an alpha of 0.5 and a power of .90, based on a previous study testing the Müller-Lyer Illusion in the haptics domain (Mancini et al., 2010), indicated that 6 participants were needed to replicate the illusion. Given that we further tested a novel paradigm of the illusion in the tactile domain, we increased our sample to 20 participants, which gave us a power of > .90 to detect an effect. All procedures were approved by the University of Kent School of Psychology ethics committee.

Stimuli

The stimuli consisted of three-dimensional printed plastic arrows designed to replicate a Müller-Lyer configuration (Figure 1). Each stimulus comprised a central shaft measuring 100 mm in length. For the illusory stimuli, one end of the shaft terminated in an arrowhead, formed by two straight lines (fins) meeting at the centre of the shaft end, with each fin measuring 20 mm in length. At the opposite end, the shaft terminated in outward-pointing wings, consisting of two straight fin segments extending away from the shaft at equal angles, each measuring 20 mm in length. For both the arrowhead and wings, the two fin segments formed a vertex angle of 92.94^{o}, with each segment oriented at 46.47^{o} relative to the shaft in

the inward-pointing arrowhead and 133.53° in the outward-pointing wings. For the neutral stimulus, no arrowhead or wings were present. Instead, each end of the shaft terminated in a single horizontal line segment measuring 30 mm in length, corresponding to the distance between the outer tips of the wings in the illusory stimuli. All stimuli had a depth of 20 mm and were printed from rigid plastic with a thickness of 1 mm. Apart from the configuration of the arrowhead and wings, all other physical properties across the stimuli were identical (Figure 1A).

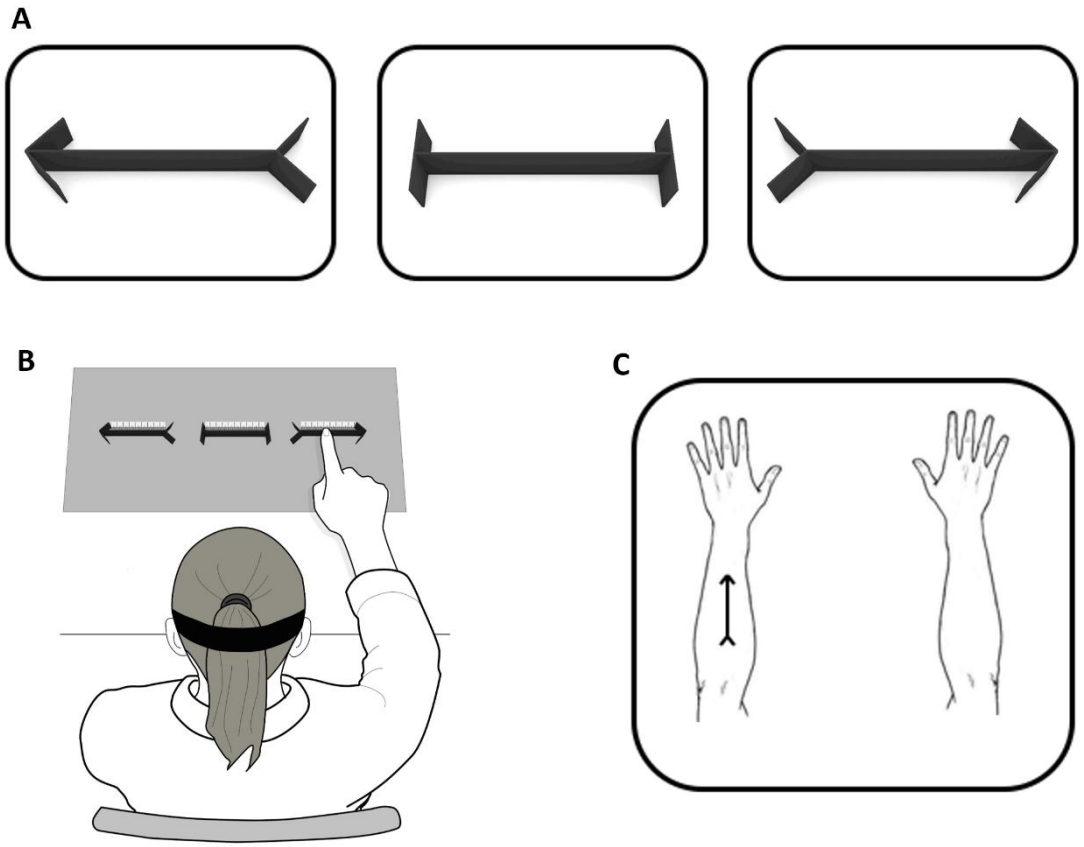

Figure 1. **A** Showing experimental stimuli used for the task. 3D printed plastic arrows comprised 3 different arrow types: two identical illusory arrows comprised of a central shaft, an arrowhead and extending wings, and a neutral "arrow" comprised of a central shaft with identical horizontal ends. **B** Showing experimental set-up and stimulus board for the haptic condition. Whilst blindfolded, participants explored the arrow stimulus with the index finger before making a midpoint judgement. **C** Showing example of experimental trial for the tactile condition. Participants rested their forearms on the desk, and the arrow stimulus was lightly pressed into the top of the forearm before being removed, after which participants indicated the perceived shaft midpoint with the index finger of the contralateral hand.

Procedure

All participants completed both a haptic and a tactile condition in a counterbalanced AB/BA design. Participants were seated comfortably at a desk and were instructed to judge the shaft midpoint of three types of plastic arrow stimuli. Arrow type was defined by the configuration of the arrowhead relative to the shaft (neutral, arrowhead at one end, arrowhead at the opposite end). In the haptic condition, these configurations were presented as arrows pointing left or right on a board, whereas in the tactile condition, they were presented along the proximal-distal axis of the forearm. Participants were briefly shown the experimental stimuli for a few seconds before completing the task, whilst blindfolded for both tactile and haptic conditions. In both conditions, no feedback on accuracy was ever given.

Haptic task.

In the haptic condition, a stimulus board was positioned on the tabletop 30 cm in front of the participant. Three arrow stimuli were fixed to the board, arranged horizontally with the neutral arrow positioned centrally, and the two illusory arrows positioned on either side: the arrow with the arrowhead on the right end of the shaft was placed to the left of the neutral arrow, and the arrow with the arrowhead on the left end of the shaft was positioned to the right of the neutral arrow (Figure 1B). At the start of each trial, participants were verbally instructed to reach for either the left, central or right arrow. Participants first completed 3 to 5 practice trials to familiarise themselves with the spatial layout of the board whilst blindfolded. For the main experimental task, no participants had difficulty or confusion locating the specific arrow type.

On each trial, participants located the perceived midpoint of the arrow shaft using the tip of the index finger. They were free to explore the stimulus actively and without time

constraints, and no restrictions were placed on the direction of finger movement. The task consisted of two blocks of 30 trials (10 trials per arrow type). The trial order was pseudorandomised, such that the same arrow type could not occur on more than three consecutive trials. Each block was completed using either the right or left index finger under a counterbalanced AB/BA design.

For each arrow stimulus, a millimetre-scaled ruler (0-100) was fixed to the stimulus board and aligned with the lower edge of the arrow shaft. The experimenter recorded the participant's response by aligning a thin (0.5 mm diameter) vertical marker with the centre of the fingertip and the ruler scale. The corresponding position on the ruler was then noted.

Tactile task.

In the tactile condition, participants rested one forearm on the tabletop with the palm facing downwards and were blindfolded. At the start of each trial, the experimenter placed one of three configurations of arrow stimuli onto the upper surface of the forearm, oriented along the long axis of the arm. Arrow types were stimulus-centred in that the arrowhead of the illusory stimuli was located either at the distal end of the shaft (towards the wrist) or at the proximal end (towards the elbow).

On every trial, the experimenter lightly pressed the stimulus onto the skin of the forearm for two seconds, after which the stimulus was removed (Figure 1C). The participant then immediately indicated the perceived midpoint of the arrow shaft by pointing to the corresponding location on the forearm using the fingertip of the contralateral index finger. The location of stimulus placement along the forearm was varied randomly across trials to avoid practice effects and/or habituation. The task consisted of 2 blocks of 30 trials (10 trials per arrow type). As in the haptic condition, trial order was pseudorandomised, such that the

same arrow type could not occur on more than three consecutive trials. In each block, stimuli were delivered to either the right or left forearm under a counterbalanced AB/BA design.

Throughout the task, a camera fixed to a tripod positioned exactly 60 cm above the tabletop, directly above the participant's forearm, captured both the placement of the arrow stimulus on the forearm and the participant's pointing response.

Midpoint error

For both task variants, the dependent variable was the midpoint error, defined as the difference (in millimetres; mm) between the participant's estimated midpoint and the veridical midpoint of the arrow stimulus. To ensure that the midpoint error reflected bias relative to arrow structure rather than spatial orientation, errors were re-coded according to arrow configurations. In the raw data, the two illusory arrows would produce deviations from the object midpoint in opposite physical directions. Recoding aligned errors relative to the arrowhead and wings, permitting direct comparison of illusion magnitude across orientations without cancellation effects. For illusory arrows, positive values indicated error in the direction of the arrowhead, whereas negative values indicated error toward the arrow wings. For neutral arrows, positive values indicated error towards the distal (or rightward) end of the shaft and negative values indicated bias towards the proximal (or leftward) end.

In the haptic condition, midpoint error was calculated from the position indicated by the participant along the shaft of the arrow. All arrows were 100 mm in length, with the actual midpoint at 50 mm. The midpoint error was computed as the difference between the indicated position and the midpoint. For example, a midpoint estimation at 70 mm corresponded to a 20 mm error.

In the tactile condition, midpoint error was derived from digital landscape-oriented photographs of stimulus placement and the participant's pointing response on the forearm. Because the arrow shaft was always 100 mm in length, this known dimension was used to calibrate pixel measurements on a trial-by-trial basis. Specifically, using image software (Microsoft Paint, Version 11.2512.211.0), the x-axis pixel coordinates of the two endpoints of the arrow shaft were extracted from the stimulus photograph, and the pixel distance between these two points was calculated. This distance was defined as 100 mm, allowing a pixel-to-millimetre conversion factor for each trial. From the response photograph, the x-axis pixel coordinate corresponding to the centre of the pointing index fingertip was extracted. The pixel distance between the perceived midpoint and the veridical midpoint was then converted to mm using this factor. This calibration was performed on a trial-by-trial basis to account for small variations in the pixel length of the arrow shaft across images arising from minor differences in stimulus orientation and placement on the arm, and therefore the camera's perspective.

As in the haptic condition, midpoint errors were signed such that positive values indicated error towards the arrowhead and negative values indicated bias towards the arrow wings. For neutral arrows, positive values indicated error towards the distal-pointing end of the shaft and negative values towards the proximal-pointing end of the shaft.

Analysis

All analyses were performed in RStudio version 4.4.3 with Linear mixed-effects models (LMMs) fitted using the lme4 package (Bates, 2015) and ANOVA tables obtained using the afex package (Singmann et al., 2024). Degrees of freedom were estimated using the Satterthwaite approximation. Because arrow configurations were defined in conceptually

different reference frames across modalities, i.e. left-right arrowhead orientation on the stimulus board in the haptic condition and proximal-distal arrowhead orientation on the forearm in the tactile condition, arrow configuration could not be treated as a single fully crossed factor. Therefore, haptic and tactile data were analysed separately.

For each modality, midpoint error was analysed using two separate LMMs with fixed effects of Arrow Configuration (*Haptic*: Right, Left, Neutral; *Tactile*: Distal, Proximal, Neutral), and Effector (*Haptic*: Left vs. Right index finger; *Tactile*: Left vs. Right arm), and a random intercept for Participant. More complex random-effects structures resulted in singular fits and were therefore not retained.

To test the presence of the Müller-Lyer illusion, planned contrasts on model-estimated marginal means were conducted to assess deviations from the actual midpoint (0 mm). To examine whether midpoint bias varied as a function of arrow configuration or effector, fixed-effects and interactions from the same LMMs were evaluated.

Results

Haptic condition

The LME examining midpoint estimation in the haptic condition revealed a significant main effect of Arrow Configuration, $F(2, 114) = 8.01$, $p < .001$, $\eta^2p = .12$, no main effect of Effector, $F(1, 114) = 0.44$, $p = .560$, $\eta^2p = .004$, and a significant Arrow Configuration x Effector interaction, $F(2, 114) = 3.44$, $p = .036$, $\eta^2p = .06$.

Post-hoc Tukey-corrected pairwise comparisons, collapsing across effectors, indicated that participants' midpoint estimates differed significantly between illusory and neutral arrows. Specifically, estimates were significantly biased relative to the neutral arrow (M = 0.48mm, SE = 0.95 mm) for both the right-pointing (M = -3.80mm, SE = 0.95mm; $t(95)$ = -

3.203, p = .005, dz = -0.72) and left-pointing arrows (M = -4.44mm, SE = 0.95mm; t(95) = -3.681, p = .001, dz = -0.82). No difference was observed between the two illusory arrows, t(95) = -0.477, p = .882, dz = -0.12).

Given the significant Arrow Configuration x Effector interaction, Tukey-corrected simple main effects were assessed. This revealed that when participants used the right index finger, midpoint estimates differed significantly between the right-pointing (M = -2.6mm, SE = 1.34mm) and neutral arrows (M = 2.02mm, SE = 1.34mm; t(95) = -2.44, p = .043, dz = -0.77), as well as the left pointing (M = -6.09mm, SE = 1.34mm) and neutral arrows (t(95) = -4.29, p < .001, dz = -1.36). In contrast, when using the left index finger, no significant differences between arrow configurations were observed (all ps > .10), indicating a selectively enhanced illusory bias when the task was performed with the right index finger.

Planned contrasts comparing model-estimated marginal means to the actual midpoint (0 mm) revealed significant deviations from zero for both the right-pointing arrow (M = -3.80mm, SE = 0.95mm; t(95) = -4.022, p < .001, dz = -0.64) and left-pointing arrow (M = -4.44mm, SE = 0.95mm; t(95) = -4.697, p < .001, dz = -0.74), indicating a consistent perceptual bias towards the arrow wings (Figure 2). Midpoint estimates did not significantly differ from zero for the neutral arrow type (M = 0.48mm, SE = 0.95 mm, t(95) = 0.508, p = .613, dz = 0.08).

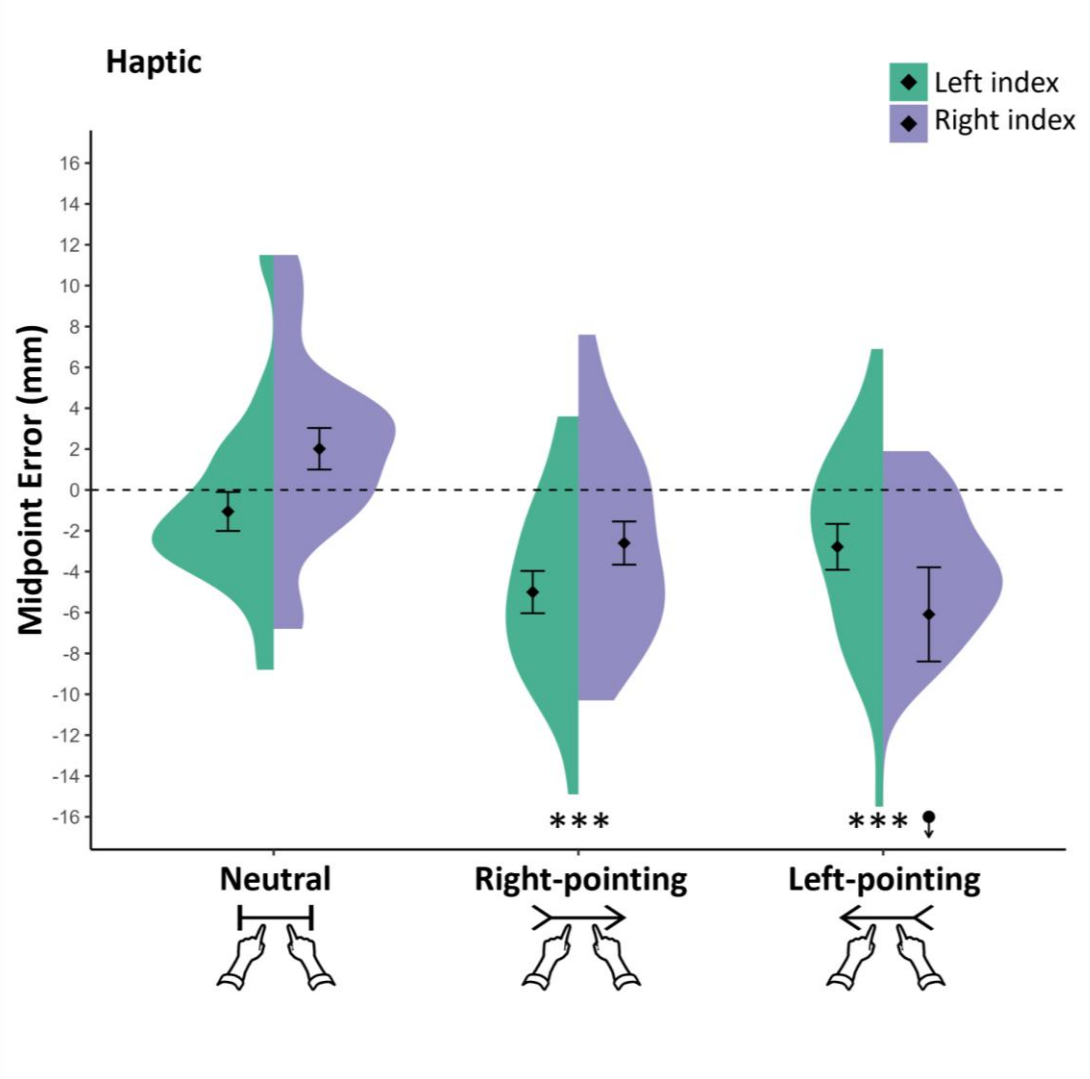

Figure 2*. Haptic task* Midpoint error (mm) as a function of arrow configuration (Neutral, right-pointing, left-pointing) as a function of left and right index fingers for the haptic task. The dashed horizontal line indicated the veridical midpoint (0 mm). Asterisks show significant deviation from 0 mm (shaft midpoint). Negative values indicate a bias towards the arrow wings, positive values indicate a bias towards the arrowhead. Half violin plots illustrate data distribution, diamonds represent mean midpoint error, and error bars show the standard error of the mean (±SEM). One extreme observation (-47.88 mm) is plotted at the lower axis boundary for visibility; the dot with the arrow indicates continuation beyond the plotted image. *** p <.001

Tactile condition

The second LME examining midpoint estimation in the tactile task revealed a significant main effect of Arrow Configuration, $F(2, 114) = 16.33$, $p < .001$, $\eta^2p = .22$, no main effect of Effector, $F(1, 114) = 0.06$, $p = .801$, $\eta^2p = .001$, and no significant Arrow Configuration x Effector interaction, $F(2, 114) = 0.18$, $p = .836$, $\eta^2p = .003$.

Post-hoc Tukey-corrected pairwise comparisons, collapsing across effectors, indicated that midpoint estimates differed significantly across types of arrow configurations. Specifically, midpoint estimates for the proximal arrow configuration (M = -3.73 mm, SE = 1.96 mm) differed significantly from those for the neutral arrow (M = 3.55 mm, SE = 1.96 mm; $t(95) = -2.63$, $p = .027$, $dz = -0.59$). In addition, estimates for the distal arrow configuration (M = -12.28 mm, SE = 1.96 mm) differed significantly from both the neutral arrow, $t(95) = -5.71$, $p < .001$, $dz = -1.28$, as well as the proximal arrow configuration, $t(95) = -3.08$, $p = .008$, $dz = -0.69$.

Planned contrasts comparing model-estimated marginal means to the veridical midpoint (0 mm) revealed significant deviation from zero for distal arrow configuration (M = -12.28 mm, SE = 1.96 mm; $t(95) = -6.26$, $p < .001$, $dz = -0.99$), indicating perceptual bias towards the arrow wings (Figure 3). In contrast, midpoint estimates for the proximal arrow configuration did not significantly differ from zero (M = -3.73 mm, SE = 1.96 mm; $t(95) = -1.91$, $p = .060$, $dz = -0.30$), nor did estimates for the neutral arrows (M = 3.55 mm, SE = 1.96 mm; $t(95) = -1.81$, $p = .074$, $dz = 0.29$).

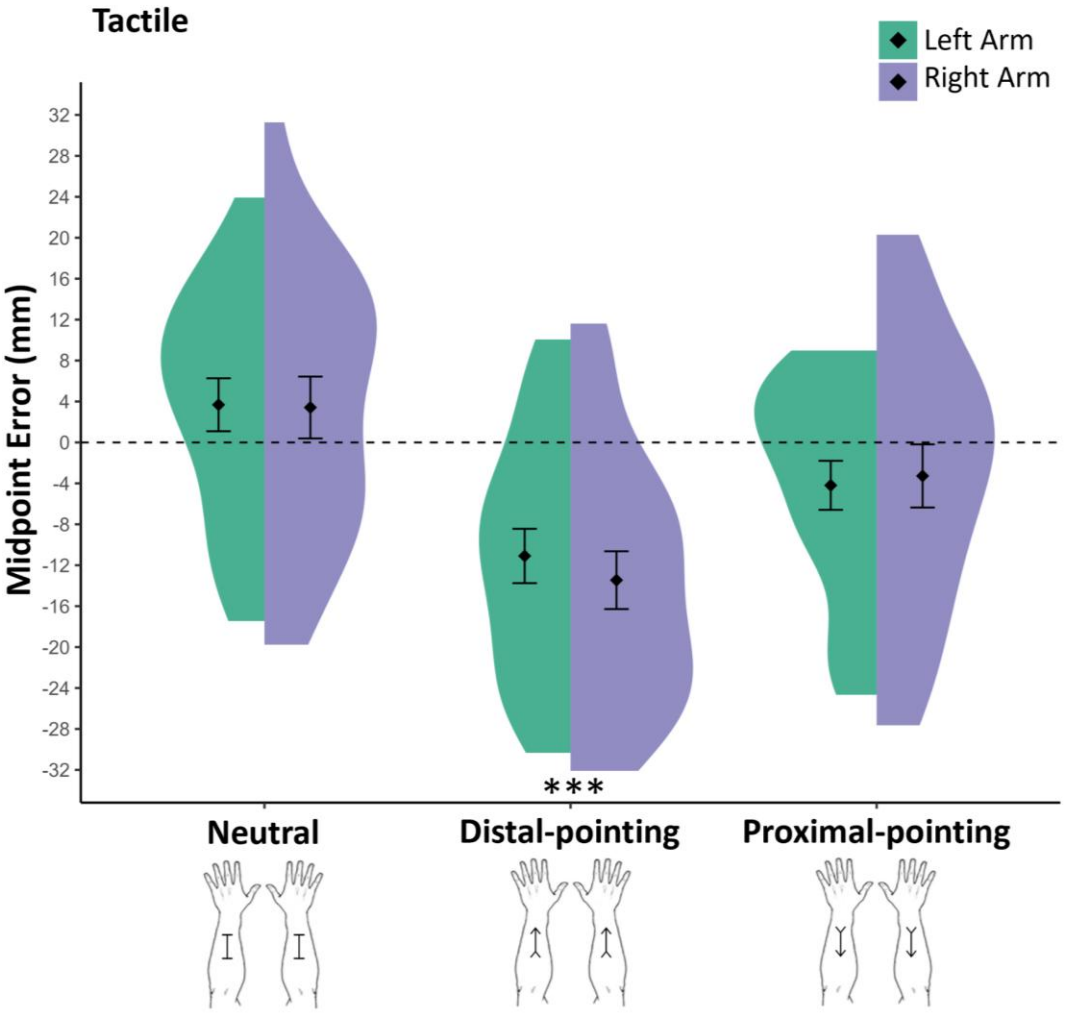

Figure 3. Tactile task Midpoint error (mm) as a function of arrow configuration (Neutral, distally-pointing, proximally-pointing) as a function of the left and right forearms in the tactile task. The dashed horizontal line indicated the veridical midpoint (0 mm). Asterisks show significant deviation from 0 mm (shaft midpoint). Negative values indicate a bias towards the arrow wings, positive values indicate a bias towards the arrowhead. Half violin plots illustrate data distribution, diamonds represent mean midpoint error, and error bars show the standard error of the mean (±SEM). *** p <.001

Discussion

The present study investigated whether the Müller-Lyer illusion influences perceived midpoint location during haptic exploration and passive tactile stimulation. Replicating previous findings (Mancini et al., 2010), the haptic task produced reliable deviations from the

object's actual midpoint, with both left- and right-pointing arrows shifting perceived midpoint location toward the arrow wings. Notably, this effect was modulated by the effector, such that illusory bias was selectively enhanced when judgements were made using the right rather than the left index finger. The tactile task revealed that midpoint bias was strongly dependent on the configuration of the illusory arrows. Specifically, distal arrow configurations elicited robust illusory bias, whereas proximal arrow configurations did not reliably differ from the actual midpoint. In both tasks, no midpoint bias was observed in the neutral stimulus condition, supporting the conclusion that observed shifts were driven by the illusion. Together, these findings demonstrate that the Müller-Lyer illusion operates both in active haptic and passive tactile domains, while also revealing modality-specific constraints on how geometric context influences the spatial representation of object length. In the following paragraphs, we consider the potential mechanisms underlying these effects, with emphasis on the tactile findings, which constitute the primary novel contribution of the present study.

The findings in the haptic task are broadly consistent with previous findings of the Müller-Lyer illusion during active exploration (Heller et al., 2005; Mancini et al., 2010), confirming that geometric context biases length estimation when information is haptically acquired. In addition, we observed that the illusion was mediated by the index finger used to complete the task, with enhanced illusory bias when midpoints were estimated using the right index finger. While Mancini and colleagues (2010) reported Hand x Shaft Length interaction, showing greater overall bisection error with the right hand for shorter (10 cm) compared to longer (12 cm) shafts, they did not observe configuration-dependent modulation (i.e. differential effects for illusory versus neutral stimuli). In contrast, the present findings suggest that the illusion magnitude itself varied as a function of effector, rather than reflecting a general bias in midpoint estimation across stimulus types.

One possible explanation for this difference may concern task constraints. Whereas Mancini and colleagues allowed participants to explore stimuli using the whole hand, participants in the present study were required to explore stimuli using only the tip of the index finger. This more restricted exploratory strategy may have amplified effector-specific sensorimotor dynamics, revealing arrow configuration-dependent modulation of illusion strength. Rather than contradicting previous findings, the present results extend them by showing that effector-related influences may interact with stimulus geometry under different exploratory conditions.

We suggest that, given the majority of participants in the current study were right-handed, this asymmetry may reflect the contribution of motor dominance to spatial encoding during haptic exploration. For example, active haptic perception relies on a combination of cutaneous input alongside proprioceptive and kinaesthetic feedback (Lederman & Klatzky, 2009). Resultingly, it is possible that the dominant hand, typically associated with greater motor precision and sensorimotor integration (Elliott & Roy, 1996), amplifies the integration of geometric cues. This effector-dependent modulation supports the view that the haptic Müller-Lyer illusion may be influenced by sensorimotor factors inherent to active exploration.

The results of the tactile condition indicate that our paradigm was effective in eliciting the Müller-Lyer illusion under passive stimulation. However, this effect was not homogeneous across arrow configurations but instead unidirectional. Specifically, a reliable illusory bias emerged when the arrow was oriented distally (i.e. pointing towards the wrist), producing a shift in the perceived midpoint toward the proximal forearm. In contrast, neither the proximal arrow configuration nor the neutral condition yielded a significant deviation from the veridical midpoint. We propose that this asymmetric pattern reflects two mechanisms, namely

variations in tactile receptive field (tRF) size along the forearm and lateral inhibition within the somatosensory system.

Firstly, it is well established that dimensions of tRFs vary systematically across and within body parts (Weber 1834/1996; Vallbo et al., 1995), with smaller receptive fields in distal areas such as the hands and wrist, and progressively larger fields moving proximally along the forearm (Johansson & Vallbo, 1979; Weber 1834/1996; Vallbo et al., 1995). Accordingly, receptive fields near the wrist are likely to be smaller and more spatially precise than those nearer the elbow. Larger receptive fields in proximal regions may lead to greater spatial pooling and overlap between neighbouring populations. Such increased overlap may enhance the impact of contextual geometric cues under certain directional configurations.

Second, lateral inhibitory mechanisms are known to influence the spatial representation of objects touching the skin. This idea has been characterised by Von Békésy (1967), who described tactile distortions as analogous to visual geometric illusions, attributing them to inhibitory interactions within the somatosensory system. In his demonstrations, rigid stimuli with curved or angled edges were applied to the skin using a gentle rocking motion. Participants reported that peaks or corners of the shape felt displaced or more obtuse than their actual physical structure. Von Békésy interpreted such a distortion as arising from lateral inhibition between neighbouring receptive fields, which shifts the neural representation of stimulus boundaries away from their veridical location. In the context of the current findings, such inhibitory spread could alter the encoded position of the arrow endpoints on the skin, therefore biasing the perceived midpoint location. In this framework, the configuration of the arrow fins would modulate the balance of excitation and inhibition across adjacent neural populations, leading to a directional displacement of perceived spatial extent.

Taken together, we propose that the proximal shift of midpoint judgements observed in the present study reflects the combined influence of receptive field organisation and lateral inhibitory interactions within the somatosensory system. Larger tRFs in proximal regions of the forearm may promote greater spatial pooling and overlap between neighbouring populations, therefore increasing the extent of inhibitory spread. When combined with the geometric configuration of the Müller-Lyer stimulus, this enhanced inhibitory process could shift the encoded position of stimulus boundaries, resulting in a systematic proximal displacement of the perceived midpoint.

The interpretation that the illusion may arise from lower-level sensory mechanisms is supported by recent neuroimaging evidence implicating the primary somatosensory cortex (S1) in tactile distance perception (Tamè et al 2021). This suggests that distortions in object length emerge at early stages of somatosensory processing, rather than only in higher-level cognitive reinterpretation (Tamè & Longo, 2023). Furthermore, given the presence of bias in only the distally-oriented arrow configuration, alongside the absence of systematic error in the neutral condition, the observed effect cannot be fully explained by general biases in tactile localisation along the forearm. For example, established models of forearm localisation predict proximal or distal distortions that are independent of stimulus geometry (Fuchs et al., 2026). However, the present configuration-dependent findings support the view that contextual geometric interactions underlie the observed illusion, rather than baseline localisation bias. Importantly, by ‘low-level’ we refer to early stages of sensory encoding, such as receptive field organisation and inhibitory interactions, that are features of multiple sensory systems. The presence of the Müller-Lyer illusion across sensory systems may therefore reflect shared principles of spatial coding rather than high-level conceptual reinterpretation alone.

Finally, some considerations should be noted when interpreting the current findings. In the tactile task, the stimulus was removed from the skin before midpoint judgments, introducing a brief delay in response. Nonetheless, responses were made immediately following stimulation, thus minimising any potential memory decay or post-stimulus reconstruction. Moreover, the absence of bias in the neutral condition, paired with the overall accuracy of participants' estimations, indicates that performance was not driven by general memory distortion or task difficulty. Furthermore, we acknowledge that between the haptic and tactile tasks, stimulus orientation differed, such that stimuli were positioned horizontally during haptic exploration but aligned along the proximal-distal axis of the vertically positioned forearm in the tactile condition. As such, we cannot wholly dismiss the possibility that spatial orientation may interact with perceptual encoding. Nevertheless, these methodological considerations do not detract from the central finding that the Müller-Lyer illusion emerged under both active and passive somatosensory conditions.

In conclusion, the present findings demonstrate that the Müller-Lyer illusion extends beyond vision and haptic exploration, biasing spatial judgements under passive tactile stimulation. Importantly, these findings do not imply that identical neural mechanisms underlie the illusion across sensory modalities. Rather, they indicate comparable spatial distortions can arise under different sensory constraints, potentially reflecting shared principles of spatial encoding. As such, we show that contextual geometric cues can distort perceived spatial extent in the absence of sensorimotor exploration, while also revealing modality-specific constraints on how such distortions arise. Together, these results contribute to a broader understanding of how fundamental sensory mechanisms shape the spatial perception of somatosensory inputs and highlight the complementary roles of both perceptual and sensorimotor processes in building tactile spatial representations.

Author credit

L.G.: Conceptualisation, analyses, visualisation, writing original draft and editing.
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C.L.: Data collection.
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