RUNNING HEAD: LANGUAGE ENVIRONMENT AND BODY REPRESENTATIONS

Does language environment shape part-based representations of the body?

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ABSTRACT

Tactile perception is referenced to, and modulated by, body parts and their boundaries. For example, tactile distances presented over the wrist are perceptually elongated relative to those presented within the hand or arm. This phenomenon is argued to result from a segmentation of tactile space according to body parts and their boundaries, i.e., touches presented within a body part are perceived as being more similar, and therefore closer together, whereas those that straddle a body part boundary (e.g. presented over the wrist) are perceived as more distinct and thus further apart. We tested the hypothesis that language shapes such a segmentation effect by providing consolidatory labels for categories and boundaries. We examined the perceptual elongation of distance over the wrist in a group of Croatian adults (n = 37) whose first language does not in everyday noun terms, differentiate between hand and arm at the wrist (instead, the Croatian word "*ruka*" encompasses the entire limb). Croatian adults, like UK adults reported in a previous study (Le Cornu Knight, Longo & Bremner, 2014), perceived distances presented proximodistally over the wrist boundary as longer than those presented mediolaterally, whereas the reverse was found for both the hand and the arm. This is striking evidence that visual, functional and/or anatomical body part boundaries modulate tactile perception, despite differences in the linguistic distinctions of such body parts made by one's first language.

1. Introduction

The body is at the centre of our experience of ourselves and the world around us (de Vignemont & Alsmith, 2018; Bermúdez, 1998; James, 1890; Longo, 2017). Representations of various aspects of our bodies (e.g., their configural structure and layout in space) thus play critical roles in perception and skilled action, as well as identity and self-esteem (Bermúdez, Marcel, & Eilan, 1995; de Vignemont, 2010; Longo, 2017; Longo, Azañón, & Haggard, 2010; Tsakiris, 2010). The precise nature of representations of our bodies and body parts has drawn significant recent interest and empirical research in healthy and impaired adults (e.g., Brugger, Lenggenhager, & Giummarra, 2013; Buxbaum & Coslett, 2001; Linkenauger et al., 2015; Longo & Haggard, 2010; Longo, 2017; Longo & Golubova, 2017; Treasure, Claudino, & Zucker, 2010). A number of recent studies demonstrate that tactile perception is modulated by body parts and their boundaries, specifically that the perception of tactile distance is elongated when presented over the body part boundary (e.g., de Vignemont, Majid, Jola, & Haggard, 2009; Le Cornu Knight, Longo, & Bremner, 2014; Le Cornu Knight, Cowie, & Bremner, 2017). One explanation of these body part boundary effects is that tactile space is modulated by the influence of body part nouns (de Vignemont et al., 2009). Here we report a study that tests account by investigating the generality of the tactile body part boundary effect across linguistic environments in which body parts are delineated in different ways.

Recent findings indicate that healthy adults' internal body representations are subject to substantial and consistent distortions (e.g., Longo, 2015; Longo & Golubova, 2017; Longo & Haggard, 2010). Such distortions can be measured by asking participants to estimate tactile spatial dimensions and locations, and are considered to provide clues as to the various stages of processing in which touch is referenced to internal body models (for a review see Longo, 2017). One such distortion of tactile perception is considered to result from the structuring influence of body parts and their boundaries. De Vignemont and colleagues (2009) were the first to show that perceived tactile distance is elongated across a body part boundary (the wrist). They reported that adults' tactile distance estimations between two points presented proximodistally down the arm/hand were significantly elongated when those points were presented over the wrist boundary compared to when they were presented within either the hand or within the forearm. De Vignemont et al. interpreted this finding as demonstrating the influence of a category boundary effect on tactile spatial perception. They argue that, in contrast to pairs of tactile stimuli that are presented within one body part category (which appear similar in location, and therefore closer together), those that cross over the body part boundary are perceived as more distinct and therefore further apart. This effect has been replicated subsequently in adults using a modified task (designed to test an alternative interpretation of the distortion, more detail below; see also Le Cornu Knight, Longo & Bremner, 2014), and also in young children (Le Cornu Knight, Cowie & Bremner, 2016).

That body *parts* play a central role in structuring perceptual body representations (see also Chen & Fan, 2008; Longo, Azañón & Haggard, 2010) is commensurate with findings of body part-specific impairments following acquired brain injury (e.g., autotopagnosia; Buxbaum & Cosslett, 2001; Sirigu, Grafman, Bressler, & Sunderland, 1991), and evidence of distinct neural regions being devoted to body parts and their spatial relations, in unimpaired adults (Interparietal sulcus; Corradi-Dell'Acqua, Hesse, Rumiati, & Fink, 2008; Corradi-Dell'Acqua, Tomasino, & Fink, 2009).

Here we report an investigation into potential ontogenetic factors driving part-based representations of the body. There are a number of natural modes of delineation of body parts within the body that may contribute to the part-based structure of body representations, including visual featural differences, functional distinctions, and sensorimotor articulations around joints. Whereas these seem likely to be universal, there exists considerable cultural variation in the delineation of body part categories seen in different languages (for comprehensive reviews see Enfield, Majid, & van Staden, 2006, and Majid, 2010). For instance, whilst English provides a clear linguistic distinction between hand and arm, around one third of the world's languages label the entire upper limb as one (Brown, 2008). There is a rich tradition of investigation into the influential effects of cross-cultural variations in linguistically derived categories on perception across a range of domains (e.g., colour, affect perception; Roberson & Davidoff, 2000; Roberson, Davidoff, Davies, & Shapiro, 2005; Winawer, Witthoft, Frank, Wu, Wade, & Boroditsky, 2007), and spatial cognition (Majid, Bowerman, Kita, Haun, & Levinson, 2004), and yet this has not yet been addressed in the domain of body perception/representation. Given this, an investigation of cross-cultural variations in body part representations is a promising avenue of research into the cultural ontogeny of body representations.

In this study, we took advantage of linguistic differences in upper limb terminology between the English and Croatian languages to examine the effects of language on the segmentation of tactile space on the arm (Croatian is a standardised variety of Serbo-Croatian). In Croatian, the term “ruka” is typically used to denote the entire upper limb, from shoulder to fingertip. More specific terms for parts such as forearm, upper-arm and wrist do exist in Croatian (and Serbo-Croatian), but are typically used exclusively in medical contexts, rather than in everyday dialogue. We used a two-forced-choice tactile distance estimation task (previously used with British participants, Le Cornu Knight et al., 2014), to probe the hand-arm category boundary effect on tactile space across the wrist. In UK participants, tactile distances presented across the forearm and hand are perceived as larger if they are presented in the mediolateral axis than if in the proximodistal axis. This anisotropy is reduced at the wrist, due to a specific elongation of tactile distance in the proximodistal axis when crossing the hand/forearm boundary. This task thus provides complimentary evidence for the effect of the hand-arm boundary on tactile distance perception (and thus the structuring role of body parts in body representations). It also provides the added advantage of overcoming an alternative account of the perceived elongation of distance across the wrist based on localised increases in acuity around anatomic landmarks (Cholewiak & Collins, 2003; Weber, 1834/1996), which would predict that non-specific increases in acuity at the wrist would perceptually elongate distance in both axes (for discussion see Le Cornu Knight et al., 2014).

In the present study, if linguistic body part terminology <u>does</u> contribute to the structuring of the body representation underlying tactile spatial segmentation, the mediolateral anisotropy at the wrist should be similar to those at the forearm and hand in Croatian participants (unlike the pattern found in our UK sample). If linguistic body part terminology <u>does not</u> contribute to this structuring of tactile spatial representation, we should find a reduction in the anisotropy at the wrist similar to that previously observed in our UK sample. The Croatian sample of participants that were tested varied in their exposure to English as a second language. Thus we also examined whether we would find a relationship between the tactile category boundary effect at the wrist and individuals' degrees of expertise with English as a second language. In order to gain a measure of how individuals' conceptualisations of body part terminology differed across languages (e.g. whether the English term 'hand' mapped directly onto the Croatian term 'ruka') and whether they mapped onto the wrist boundary, we also asked participants to complete a body part colouring task probing Croatian and English terminology.

2. Method

2.1. Participants

Thirty-seven Croatian adults participated (10 female, mean age = 35 years and 5 months, *sd* = 7 years and 3 months). Sample size estimation using *Gpower*, based on effect size, h^2_p = .23, (obtained on the same task with British participants; Le Cornu Knight, Longo & Bremner, 2014), *a* = .01 and power at .99, indicates that a sample size, n = 18, would be required. The larger sample size used here was gathered in order to capture any variance due to the variable levels of second language exposure. All of the tasks were conducted in Croatian with the assistance of a native Croatian-speaking researcher. The background information was also gathered in Croatian. All of the participants had normal or corrected-to-normal vision. Of the Croatian participants, six were left-handed (all of the UK participants were right-handed).

The participants were interviewed according to a schedule of five questions probing foreign language experience and proficiency throughout their lives. We found variation in levels of second language (L2) expertise; English was the most commonly spoken additional language. Table 1 indicates the participants' subjective rating of their current level of additional language expertise. They were given a table of languages commonly spoken in Croatia and asked to specify which additional languages they spoke, and to what level (Beginner, Intermediate or Expert). They were also asked to answer for any languages that were not presented in the table. If a language was not spoken the participant left the table blank.

=== INSERT TABLE 1 APPROX HERE ===

In colour perception, effects of a second language are dependent upon recent experience with it, and the availability of its terminology in semantic memory (Athanasopoulos et al., 2009; Thierry et al., 2009). Hence, we also asked the participants specifically about their additional language experience over the past five years. Therefore, participants were asked to repeat the above exercise specifically about languages they had spoken in the previous 5 years. A variable representing recent second language experience (L2R) was created, in which: no responses were scored 0 (None; n = 9); Beginner (n = 7) were scored 1; Intermediate (n = 11) were scored 2; and Expert (n = 10) were scored 3.

For the purpose of making the cross-linguistic comparison, we compared the Croatian-speaking adults' data from the tactile distance estimation task with a previously collected and reported (Le Cornu Knight et al., 2014) sample of 14 UK English-speaking adults (8 female, Mean Age = 25 years and 5 months, SD = 3 years and 4 months). The larger number of Croatian participants were recruited in order to examine the effect of variations in English-language expertise within that group.

Written informed consent was obtained from all participants. The experimental procedures were approved by the Research Ethics Committees of: the Department of Psychology, Goldsmiths, University of London; the Department of Psychology, University of Zagreb; and the Croatian Ministry of Science, Education and Sports.

2.1. Materials and procedure

All participants completed four tasks presented in the following order: (i) brief language interview (reported above in the Participants section); (ii) tactile distance estimation task; (iii) body-part colouring task; (iv) body-part naming task. All of the four tasks detailed below were performed in Croatian with the assistance of a native Croatian speaking researcher.

2.1.1. Tactile distance estimation

The participants were blindfolded and seated at a table with their left hand extended comfortably in front of them, with the ventral surface facing up. The tactile stimuli comprised two rounded points (~1mm tip width) fixed at distances of 2, 3, and 4 cm. In each trial, two pairs of punctuate stimuli were presented sequentially; one in the proximodistal orientation and one in the mediolateral orientation, both centred on the same presentation point (see Fig. 1 for presentation points). The presentation points were centralized visually in the mediolateral axis on three body parts (the forearm, the wrist and the hand). The Wrist presentation point was taken as the narrowing between the ulna bone and the hand; Hand was measured as the central point between the line of the wrist and the proximal line of the middle finger; and Forearm was placed proximally from Wrist at an equal distance from wrist-to-hand presentation points.

The presentation of the tactile stimuli on the three body parts was made in blocks of 20 trials using an ABCCBA design. The order of body parts in this design was counterbalanced across participants. Each block comprised 5 pairs of stimuli presented 4 times in a pseudo-randomised order. The 5 pairs within each block were selected according to the relative size and order of each orientation (Mediolateral:Proximodistal); 2:4, 2:3, 3:3, 3:2, 4:2 cm. The order of mediolateral (ML) and proximodistal (PD) stimuli was randomised across trials. The experimenter presented stimuli manually ensuring that the two points of each pair touched the skin simultaneously at the same pressure. Each presentation lasted approximately one second, with an inter-stimulus interval (ISI) of approximately one second. Participants indicated which of the pairs they perceived to be larger by verbally responding either “first” or “second” in Croatian.

We measured the proportion of responses in which the ML stimulus was judged to be larger, as a function of the ratio of the length of the ML to the PD stimuli. Cumulative Gaussian curves fitted to the data using R 2.8.0. Points-of-Subjective-Equality (PSEs) were calculated as the ratio of ML and PD stimuli at which the psychometric function crossed 50%. In this way, PSEs give a measure of the anisotropy of tactile distance perceived along vs. across the hand/wrist/forearm. Smaller (more negative) PSEs indicate ML stimuli are perceived as greater than PD stimuli. For the statistical analysis PSE ratios were log-transformed. The interquartile range (IQR), calculated as the difference between the points on the x-axis where the curve crosses .25 and .75, was taken as a measure of the precision of the participants’ judgments. Lower IQR scores indicate more consistency in responses across trials, and therefore suggest that the participant is more precise in their estimates.

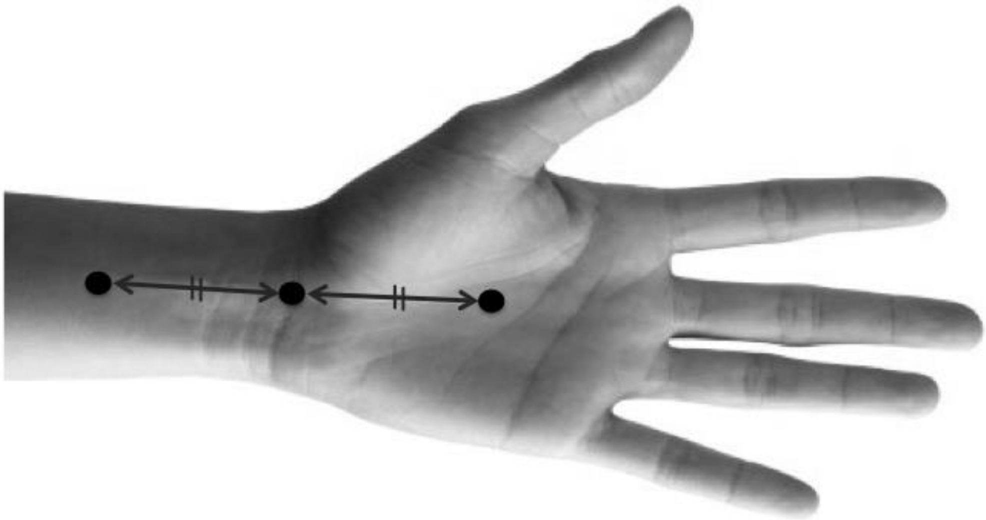

Figure 1. The presentation points at the forearm, wrist and hand are represented as black circles. The arrows between the presentation points are of equal lengths.

2.2.2. Body part colouring task

In a task adapted from van Staden and Majid (2006), the participants were provided with a colouring pen and a small booklet with outlines of a gender-neutral human body, and the name of a body part written centrally in capitals at the top on each pages. The participants were instructed to colour the area that best represented the named body part, and to clearly indicate the boundaries. They were instructed not to move onto the next page until they had finished on the current page, and were also told that they were not permitted to return to a previous page once they had moved on. All of the participants were presented with the word "*RUKA"* to begin with in order to avoid priming responses to this question with the English delineation. The words

"ARM" and *"HAND"* followed (the order of these were counterbalanced between participants). The participants were instructed to pass on any page if they did not understand the words presented. We coded colouring responses in the following way: a score of 1 was recorded each time the wrist was used as the boundary line for the coloured region; 0 was recorded for all other responses. Summing measures across *'RUKA'*, *'HAND'*, and *'ARM'*, yielded a score out of 3 for each participant ("wrist boundary colouring score"; WBCS). A score of 3 therefore suggested a consolidated conceptualization of the wrist boundary, whereas 0 represented no conceptualization of the wrist boundary.

2.2.3. Body part naming task

Finally, participants were given the *Body Part Naming* subtest of "NEPSY: A developmental neuropsychological assessment", to complete in English. It was explained that the experimenter would point to 14 body parts (the 3 body parts, 'arm', 'wrist' and 'hand', of interest were added to the 11 original NEPSY task) on a cartoon image of a boy's body. The participants were asked to name the body part in English if they knew it, and to state '*pass'* if not. In accordance with the NEPSY scoring, 2 points were scored for correct body part naming, 1 point if a prompt was required, and 0 for an incorrect response or pass. The task was terminated if 3 passes or misses occurred in a row. This resulted in a variable named NEPSY score.

3. Results

3.1. *Language: Body Part Colouring & Naming Tasks*

The Body Part Colouring task was used to assess the participants' conceptual representations of the Croatian term "ruka", and the English terms "hand", and "arm". Three participants passed (declined to answer) on the English terms. Figure 2.

summarises common responses for these three terms. For the term “ruka” (Fig. 2a), responses were largely consistent indicating that the term “ruka” is an established category that encompasses the entire upper limb. Colouring responses to the terms ‘hand’ and ‘arm’ varied. For “hand” (Fig. 2b), 19 participants coloured the fingertips to the wrist boundary; for “arm" (Fig. 2c) 15 participants coloured fingertips to shoulder. Other responses included wrist to shoulder, wrist to biceps, fingertips to biceps, and fingertips to mid-forearm, and were considerably more varied for “arm”. This variation indicates that English body part categories were not well established across Croatian-speaking participants.

=== INSERT FIGURE 2 APPROX HERE ===

Six participants achieved a wrist boundary colouring score (WBCS) of 2 (segmenting at the wrist for both English terms); 16 participants scored 1; and 15 participants did not segment at the wrist boundary, scoring 0. The mean score was 0.76 (*SD* = 0.72). The results from the body part naming task, the NEPSY, showed substantial variation in scores, with a mean of 15.62 and a standard deviation = 10.24.

In order to assess the relationship between recent second language experience (L2R), body part terminology in English (NEPSY), and the conceptual representation of the wrist (WBCS) three Spearman’s ranked correlations were run with one-tailed significance (as we expected English language experience, production and English-like conceptualisations to be positively associated). All correlations revealed significant positive relationships: WBCS revealed moderate correlations with L2R and NEPSY, (r_s = .35, p = .017, and r_s = .41, p = .006 respectively); L2R correlated more strongly with NEPSY, r_s = .69, p < .001. These results suggest that recent second language experience is associated to a greater extent with understanding of

English language terminology relating to body parts, than it is with an English-like conceptual representation of those parts as measured by a body part colouring task.

3.2. Tactile perception

Figure 3a illustrates the cumulative Gaussian functions fitted to the data for each Body Part condition. The R-squared statistics of response curves at the Forearm, Wrist and Hand were calculated for each participant as a measure of goodness of fit of the data. R-squared statistics averaged across participants were .95 (sd = .02), .97 (sd = .01) and .99 (sd = .00) for Forearm, Wrist and Hand, respectively.

=== INSERT FIGURES 3 a) b) APPROX HERE ===

=== INSERT FIGURES 4 a) b) APPROX HERE ===

1.1.1. *Points of Subjective Equality (PSEs)*

Points of Subjective Equality (PSEs) were derived from all three body part conditions and log-transformed (Fig 3b). We compared log-transformed PSE for each condition against 0 in order to detect significant anisotropies, using one-sample t-tests with the Holm-Bonferroni correction applied. PSE values significantly below 0 indicate a tendency to perceive distance running mediolaterally across the body part as larger than those presented proximodistally along the body part (mediolateral bias), while those greater than 0 indicate the opposite (proximodistal bias). The Forearm and Hand conditions both revealed significant mediolaterally-biased anisotropies [Forearm: M = -.06 (.11), t (36) = 3.40, p = .002, d = 1.13; Hand: M = -.02 (.05), t (36) = 2.80, p = .008, d = .93], whereas the Wrist condition revealed a significant proximodistally-biased anisotropy [M = .03 (.07), t (36) = 2.66, p = .012, d = .89]. Next, we compared log-transformed PSEs across body part conditions (Hand, Wrist, and Forearm) with a one-way repeated measures ANOVA with a Huynh-Feldt correction. This revealed a significant main effect of Body Part, F (1.69, 60.77) = 14.62, $p < .001$, $n_p^2 = .29$. Using a Holm-Bonferroni correction paired samples t-tests revealed significant differences between Wrist and Forearm, t (36) = 4.68, $p < .001$, d = 1.00; Wrist and Hand, t (36) = 4.38, $p < .001$, d = .88; and Forearm and Hand t (36) = 2.05, p = .048, d = .44. Taken together the PSE results suggest that the mediolateral bias (i.e., tactile distances presented across the limb are perceived as greater than those presented along the limb) at the forearm was significantly larger than that at the hand, which was more accurate and closer to veridical. The opposite anisotropy was observed at the wrist, such that distances presented proximodistally along the limb were perceived as greater than when presented mediolaterally across the limb. In accordance with the category boundary effect, this indicates a significant elongation of tactile space over the wrist boundary between hand and forearm.

1.1.2. *Interquartile Range (IQR)*

Mean IQR scores (sd) for the Forearm, Wrist and Hand were .16 (.13), .13 (.14), and .08 (.06) respectively. A Shapiro-Wilk test indicated that the IQRs were not normally distributed. Log-transformation did not resolve this and so Friedman's non-parametric test was used to examine differences between IQR scores at the three Body Parts. This revealed a significant effect of Body part, X^2 (2) = 14.74, p = .001. Wilcoxon signed-rank tests with a Holm-Bonferroni correction demonstrated that this effect was driven by differences between the Hand and Wrist, Z = 2.71, p = .007, and the Hand and Forearm, Z = 4.04, $p < .001$, but not between the Forearm and Wrist, Z = 1.19, p = .23. These findings are broadly consistent with the observation that tactile precision increases proximodistally from forearm to hand (Hamburger, 1980; Le Cornu Knight et al., 2014; Weinstein, 1968).

1.2. The role of language in tactile perceptual distortions

1.2.1. English language expertise and tactile perceptual distortions

In order to determine whether English language experience influenced the category boundary effect, the above ANOVA of body part on PSE was repeated, adding the three language variables (L2R, WBCS, and NESPY) as covariates. The main effect Body Part remained significant, F (1.87, 61.53) = 5.38, p = .008, n_p^2 = .14. None of the language variables represented significant covariates (Fs < 1.08, ps > .34). English language expertise in the Croatian sample did not, therefore, affect tactile perceptual distortions.

1.2.2. Comparison of Croatian and British participant tactile distance anisotropies

Finally, in order to determine whether linguistic environment made a significant contribution to the perceptual elongation of distance over the wrist, our Croatian sample was compared to a sub-sample of UK native English-speaking adults (n = 14) previously tested on the same tactile estimate task (Le Cornu Knight et al., 2014). Figure 4 displays PSE and IQR comparisons between nationalities at each body part site. A 3 x 2 mixed ANOVA (Body Part x Native language) was performed on PSEs, with a Huynh-Feldt correction applied. We observed main effects of Body Part, F (1.77, 86.55) = 7.92, p = .001, n_p^2 = .14, and Native language, F (1, 49) = 6.91, p = .011, n_p^2 = .12, with no significant interaction effect (F = 2.01, p = .146). T-tests confirmed that PSEs at the wrist were significantly more biased towards the proximodistal axis than those at the arm, and hand [t (50) = 4.53, p < .001, d = .82; and t (50) = 4.50, p < .001, d = .71 respectively]. No difference was found between PSEs at the arm and hand (t = 1.81, p = .08). The main effect of Native Language revealed that UK participants presented more mediolaterally biased anisotropies overall.[1]

2. Discussion

2.1. Summary of findings

Here we find that adults who speak a first language (Croatian) that does not make a linguistic distinction between hand and arm at the wrist nonetheless demonstrate an elongated perception of tactie distance over the wrist boundary. Thus disputing the hypothesis that linguistic body part categories play a structuring role in tactile spatial body representations. This perceptual elongation across the body part boundary is a) unrelated to English language proficiency, and b) equivalent to that observed in native English language speakers. Previous findings have demonstrated such an effect in UK adults (de Vignemont et al., 2009; Le Cornu Knight, Longo & Bremner, 2014), and UK children (from 5 years of age; Le Cornu Knight, Cowie & Bremner, 2016) who do grow up in a linguistic environment that differentiate hand and arm. This is the first time that such an effect has been observed in a linguistic environment which does not generally draw such a distinction. This represents a robust replication of the finding that body parts play an important structuring role in tactile spatial representations of the body.

2.2. The category boundary effect of tactile perception

[1] Whilst we had no reason to expect differences in IQRs between UK and Croatian speaking participants, we checked this via a further 3 x 2 mixed ANOVA (Body Part x Native Language) performed on IQR scores which revealed a significant main effect of Body Part, F (1.66, 81.35) = 9.38, $p < .000$, $n_p^2 = .16$, confirming previous findings. Wilcoxon sign ranked tests revealed that IQRs at the hand were significantly smaller than those at the wrist and forearm [$Z = 3.23$, $p = .001$; and $Z = 7.71$, $p < .001$ respectively]. No further effects were significant (all $Fs < 1.33$, $ps > .25$).

In this sample of Croatian participants, we found patterns of spatial biases in tactile distance estimation on the hand, wrist and forearm, that are consistent with a number of previous findings in partcipants who primarily spoke English (de Vignemont et al., 2009; Le Cornu Knight, Longo & Bremner, 2014; Le Cornu Knight, Cowie & Bremner, 2016). On the forearm and hand we observed that perceived tactile distance was elongated in the mediolateral axis relative to the proximodistal axis. This finding is consistent with findings on the dorsal and palmar surfaces of the hand in English-speaking adults (Longo & Haggard, 2010), the dorsal and ventral surface of the forearm (Le Cornu Knight, Longo & Bremner, 2014), the forehead (Longo, Ghosh & Yahya, 2015), and the leg (Green, 1982). Longo and Haggard (2010) have argued that this mediolateral bias reflects the shape of somatosensory neurons' receptive fields, which tend to be oval shaped, elongated in the proximodistal axis (Alloway et al., 1989; DiCarlo et al., 1998). Somatosensory neurons with oval shaped receptive fields produce anisotropies in the proximodistal axis because the amount of skin for which a neuron is excited is enlarged along this axis, allowing for less fine-grained discrimination of tactile location.

When tactile stimuli were presented over the wrist boundary, the spatial bias was reversed such that the same distances were perceived to be greater in the proximodistal axis. We take this to demonstrate that whilst we have an overall bias to perceive tactile distance presented mediolaterally across the limb as larger, the perceptual elongation of distance over the wrist boundary overrides this. These findings then might reveal an interaction between bottom-up perceptual distortions, originating from somatosensory neurons, and top-down representations of body structure concerned with the configural layout of body parts, and the boundaries between the parts.

This finding is not only consistent with other reports of the category boundary effect of tactile distance, but also corroborates the structural influence of the wrist on other tasks of tactile perception. For instance, Cody, Gaarside, Lloyd, and Poliakoff (2008) report increased accuracy for tactile localisation around body part boundaries, including the wrist (see also Cholewiak & Collins, 2003). More recently, Longo (2017) reported that biases in tactile localisation present on the hand and arm are locked to the body part, and do not cross over the wrist boundary. It is possible that for single-stimulus judgements, stimuli close to the boundary become more accurate because they benefit from a more precise point of comparison. This evidence taken together corroborates the suggestion that tactile perception is referenced to, and modulated by body-part boundaries (de Vignemont et al., 2006; de Vignemont et al., 2009).

2.3. The role of language and other potential contributors

Crucially, we set out to explore the potential structural role of language in the perceptual elongation of distance over the wrist boundary, by making use of lingustic differences between Croatian and English in the noun-term delineation of the upper limb. To date, studies of the modulatory effects of body part boundaries on tactile perception have been performed with English-speaking participants. In English, the category boundary is consolidated in language both by the distinction between “hand” and “arm” as separate entities, and by “wrist” as the boundary. In Croatian, hand and arm are linguistically contained within one term, “ruka”. There is a Croatian term for the wrist boundary is a compound noun “ručni zglob” (‘manual joint’), but this is very rarely used in everyday language, and thus provides a far less salient linguistic boundary than the single English word ‘wrist’. This tendency for Croatian participants to perceive the arm and hand as one unit was confirmed using a body part colouring task designed to evaluate participants’ conceptualisation of the body parts with special reference to the wrist boundary. For the term ‘ruka’, 36 of 37 participants coloured from fingertip-to-shoulder: only one participant’s colouring showed a wrist boundary. This is comparable to Majid and van Staden’s (2004) findings from Indonesian participants, whose language also has one singular term for hand and arm. Conceptualisations of the English terms ‘hand’ and ‘arm’ were less consistent across Croatian participants. Sixteen of the 37 Croatian participants used an English-like conceptualisation of the term ‘hand’ colouring to the wrist boundary, whilst only four coloured ‘arm’ to the wrist boundary. Interestingly, higher levels of recent English language experience were associated more strongly with better performance on a body part naming task, than with performance on the body part colouring task. This might suggest that the cultural conceptualisation of linguistic body structure is fairly stable in spite of second language proficiency, which was very high in the expert group.

Importantly, despite these clear linguistic differences, we found a similar pattern in the anisotropy at the wrist in Croatian and English-speaking participants. In order to account for the variation in English language expertise (some speaking fluent English), we tested English language experience with regard to its influence on the category boundary effect of tactile distance, in two ways. The perceptual elongation of distance across the wrist boundary remained stable a) when accounting for differences in English language experience and English-like conceptualisations of body part terms with our Croatian sample, and b) when comparing to native English language speakers. Referring to the classical debate on how linguistic category sets influence perception (see Kay & Kempton, 1984), our findings suggest that language does not make a significant contribution to tactile distance perception. Our findings suggest that the structural body representation, underlying tactile perceptual biases, exists independent of cultural variations in the nomenclature of the body. Whilst we take this as convincing evidence of a culturally universal system of structural body representation, it is possible that we may observe an effect in an earlier developmental population, for whom second language experience will be minimal.

So what processes do underlie the structural role of body parts in body representations? A number of alternative lines of delineation have the potential to contribute to the differentiation of body part categories, and thus the elongation of tactile distance over body part boundaries. Visual discontinuities mark some body part boundaries and therefore may contribute to a differentiation of categories (Biederman, 1987; Brown, 1976). The differing functional roles of different body parts may also play a driving role in their categorisation (Morrison & Tversky, 2005; Reed et al., 2004). The modulation of tactile distance may not be top-down, and instead may arise from the organisation of the somatosensory cortex, which is indeed somatotopically structured according to fine-grained anatomical subdivisions (Akselrod, Martuzzi, Serino, Van Der Zwaag, Gassert, & Blanke, 2017; Kurth et al., 2000; Penfield & Boldrey, 1937). It also seems likely that a combination of these means of delineation may contribute to the categorisation of body parts in concert. The hand for example, is visually quite distinct from the arm, likewise its functional role is quite separate.

2.4. Conclusion

Here we set out to examine the influence of language on the category boundary effect. We found convincing evidence of the category boundary effect in a Croatian sample. The fact that the category boundary effect is present in spite of cultural differences in the way the Croatian language delineates the upper limb suggests that language does not make a marked contribution to the structuring of a topological body representation to which touch is referenced. There is agreement within the field that tactile perception involves a process of referencing touch to a higher-order conceptual body representation (Le Cornu Knight, Cowie & Bremner, 2016; Le Cornu Knight, Longo & Bremner, 2014; Mancini et al., 2011; Margolis & Longo, 2015), however here we find no evidence that the structuring of such a representation has its base in linguistic categorisation.

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4. Context

The current research sits within a series of studies aimed at investigating the nature of topological body representations and the perception of tactile body space, funded by AJB's ERC grant investigating Human Embodied Multisensory Development (HEMSDEV). In collaboration with AJB and DC (examining the development of own-body perception), FLCK examines tactile perceptual distortions in order to scrutinise the categorical and coordinate-based nature of topological body representations through development. Our collaboration has replicated De Vignemont et al.'s (2009) finding of a category-boundary effect of tactile distance in children (Le Cornu Knight, Cowie & Bremner, 2016) and adults (Le Cornu Knight, Longo & Bremner, 2014), and ruled out an alternative acuity-based interpretation of this finding. The present study was developed as a natural continuation of this work, probing language as a potential contributor to the perceptual elongation of tactile distance across the body part boundary. Language influences perception in other sensory domains (e.g. categorical perception of colour). Speaking Croatian, DC, highlighted that the Croatian language does not make a linguistic distinction between hand and arm. Going forward, we aim to investigate developmental effects, making a comparison between Croatian- and English-speaking children on an analogous task.

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