RUNNING HEAD: LANGUAGE CATEGORISATION AND BODY PART REPRESENTATIONS

Does the language we use to segment the body, shape the way we perceive it? A study of tactile perceptual distortions

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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 across two body parts) are perceived as more distinct and thus further apart. We tested the hypothesis that language shapes this effect by providing consolidatory labels for categories and boundaries, as it does in other perceptual domains. We examined the perceptual elongation of distance over the wrist in a group of Croatian adults (n = 37) whose first language does not differentiate between hand and arm at the wrist in common noun terms (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 pattern of results was remained when Croatian participants were split into two groups of inexperienced or proficient English-language speakers. This is striking evidence that body part boundaries consistently 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; Eshkevari, Rieger, Longo, Haggard & Treasure, 2014; Linkenauger et al., 2015; Longo & Haggard, 2010; Longo, 2017; Longo & Golubova, 2017). 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, Cowie, & Bremner, 2017; Le Cornu Knight, Longo, & Bremner, 2014). In a similar manner to the way in which linguistic categories influence colour perception, one explanation of these body part boundary effects is that tactile perception is modulated by the existence of linguistic body part categories (de Vignemont et al., 2009). Here we report a study that tests this 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 over 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 linguistic delineation of body part categories across languages (for comprehensive review 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 effects of cross-cultural variations in linguistically derived categories across a range of perceptual domains (e.g., colour perception; Roberson, Davidoff, Davies, & Shapiro, 2005; Winawer, Witthoft, Frank, Wu, Wade, & Boroditsky, 2007) and spatial cognition (Majid, Bowerman, Kita, Haun, & Levinson, 2004), and yet this approach has not been systematically applied to the domain of body perception/representation. Given this, an investigation of cross-cultural variations in linguistic body part categories is a promising avenue of research into the cultural ontogeny of body representations (Majid & van Staden, 2015; Wierzbicka, 2007).

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 has 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 does 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 does not 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 sample of Croatian participants that were tested varied in their exposure to English as an additional language. Hence, 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 an additional 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 (van Staden & Majid, 2006) 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, η_p^2 = .23, (obtained on the same task with British participants; Le Cornu Knight, Longo & Bremner, 2014), *a* = .01 and power at .99, indicated that a sample size, n = 18, would be required in order to test the main effect of Body Part within the Croatian sample. The larger sample size used here was gathered in order to capture any variance due to the variable levels of additional language exposure. 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 their experience of and proficiency in foreign languages throughout their lives (further details below). With the exception of one non-responder, all of the participants reported learning at school either English (n = 28) or German (n = 8), which also uses 'hand' and 'arm' as in English. The duration of additional language education ranged between 4-15 years (average = 8.16, *sd* = 2.78). Table 1 indicates the participants' subjective ratings of their current level of additional language expertise.

=== INSERT TABLE 1 APPROX. HERE ===

	Linguistic distinction: 'hand'/'arm'						Linguistic unity: 'ruka'	
	English	German	Italian	Spanish	French	Portuguese	Slovenian	Russian
None	3	18	30	33	34	36	27	34
Beginner	10	12	6	2	3	0	6	1.5
Intermediate	14	6	1	1	0	1	3	1.5
Expert	10	1	0	1	0	0	1	0

Table 1. The number of participants who self-identified as speaking additional languages according to four levels (none spoken, beginner, intermediate, expert). Languages within the table are separated by those which provide a strict linguistic distinction between hand and arm, and those that have linguistic unity in the term ruka (or similar). One participant indicated both beginner and intermediate level for Russian and so a score of 0.5 was given for each category.

In colour perception, effects of an additional language are dependent upon recent experience, and the availability of its terminology in semantic memory (Athanasopoulos, 2009; Athanasopoulos, Dering, Wiggett, Kuipers, & Thierry, 2010; Thierry, Athanasopoulos, Wiggett, Dering, & Kuipers, 2009). Hence, we also asked the participants which additional languages they had spoken regularly over the past five years and to what level. All of the participants reported English as their most proficient additional language in this timeframe, which was therefore selected for the purpose of further analysis. A variable representing recent additional language experience (L2R) was created, in which: no response was scored 0 (None; n = 9); Beginner (n = 7) was scored 1; Intermediate (n = 11) was scored 2; and Expert (n = 10) was 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).

Written informed consent was obtained from all of the participants. The experimental procedures were approved by the Research Ethics Committees of: the

Department of Psychology, Goldsmiths, University of London; and the Department of Psychology, University of Zagreb; and the Croatian Ministry of Science, Education and Sports.

2.2. Materials and procedure

Data collection took place in Zagreb, Croatia, where all of the participants lived and worked. Recruitment, informed consent and all tasks were conducted in Croatian with the assistance of a native Croatian-speaking research assistant. Participants were greeted in a quiet room situated in their place of work by the principal researcher (English-speaking) and a native Croatian research assistant. 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. Participants were presented with the tactile distance estimation task prior to the two body-specific language tasks, so as not to prime them with English labels. All procedures were undertaken in the Croatian language, with instructions given both written and verbally.

2.2.1. Brief language interview

Five questions probed participants' additional language experience across a range of contexts and timeframes. The first question contained a table of additional languages commonly spoken in Croatia, in which participants were asked to indicate which additional languages they currently spoke and to what level (Beginner, Intermediate or Expert). Three open response boxes allowed participants to indicate any languages that were not presented in the table. If an additional language was not spoken it was indicated that the participant should leave the table blank. Question 2 asked which additional languages had been learnt in school, and for how many years. Question 3 asked whether the participants had taken any language courses since leaving school.

Question 4 asked which additional languages were spoken regularly in the past 5 years and to what level. Question 5 asked whether any other language had been spoken regularly in their life, in what contexts (e.g. work, home) and for how many years.

2.2.2. 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 attempting to ensure that the two points of each pair touched the skin simultaneously, producing similar pressure between stimuli as well as across trials. Each presentation lasted approximately one second, with an inter-stimulus interval 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 (R Core Team, 2013). 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, and forearm. 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.

=== INSERT FIGURE 1 APPROX HERE ===

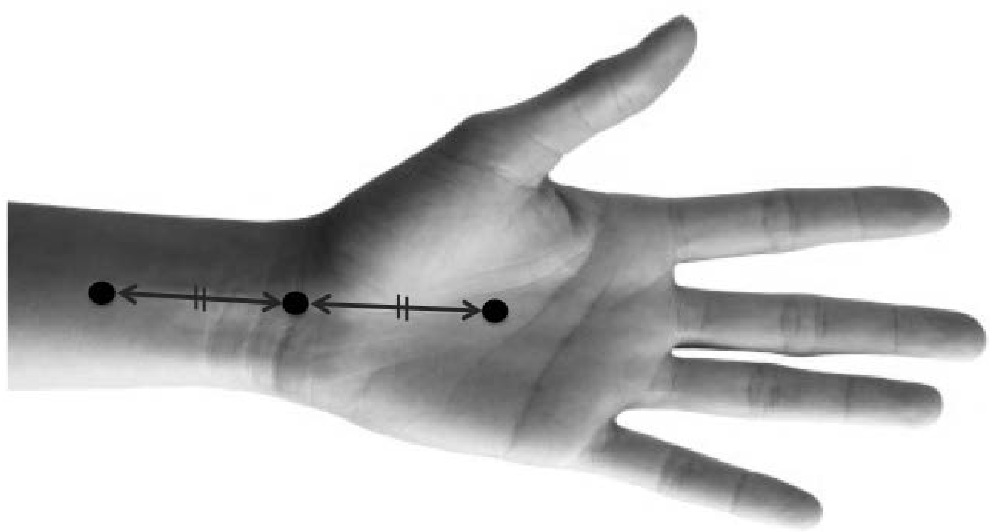

Figure 1. The presentation points at the forearm, wrist and hand are represented as black circles. The arrows between the presentation points are of equal lengths.

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 containing three pages, each with an outline of a gender-neutral human body and the name of a body part written centrally in capitals at the top. The cover of the booklet contained the following instructions, which were also given verbally by the research assistant: "*In this task you will be presented with images of the human body with a body part written at the top of the sheet. Please colour in the body part indicated at the top. Please colour in all, and only, the body part named on the page clearly indicating the boundary. Do not move onto the next picture until you have finished the one you are colouring. Do not go back to the previous picture once you have started on the next*." All of the participants were presented with the word "*RUKA*" to begin in order to avoid priming responses to this question with the English delineation. The words "*ARM*" and "*HAND*" followed, the order of which were counterbalanced between participants. The participants were instructed to pass on any page if they did not understand the word 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 '*HAND*', and '*ARM*', yielded a score out of 2 for each participant ("wrist boundary colouring score"; WBCS). A score of 2 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, in order to probe body-related language production, 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 of interest, 'arm', 'wrist' and 'hand', 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. Tactile perception

Figure 2a illustrates the cumulative Gaussian functions fitted to the data for each Body Part condition for the Croatian sample. 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 FIGURE 2 APPROX HERE ===

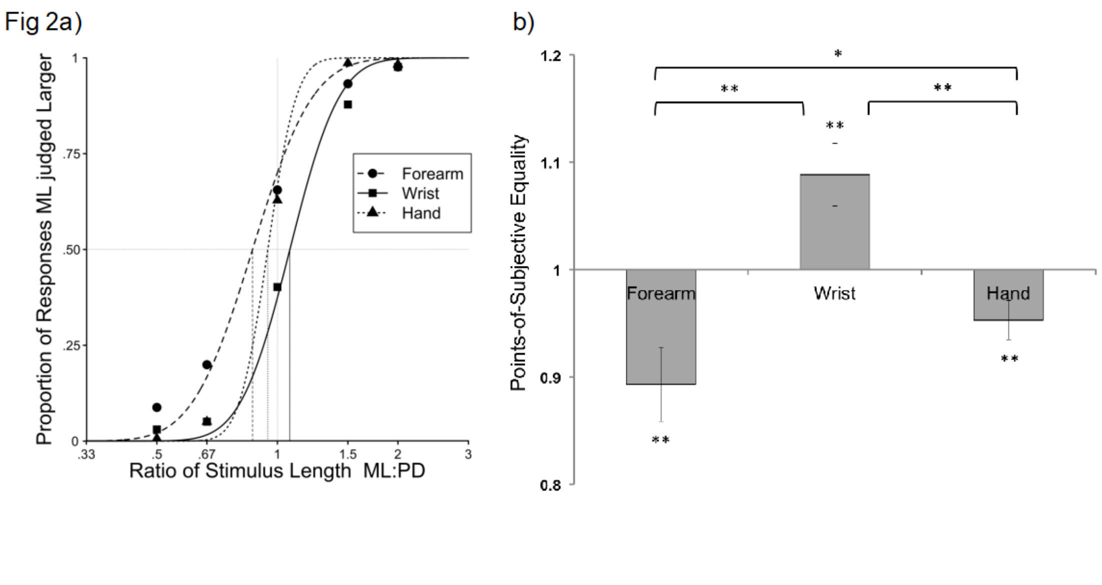

Figure 2a. Cumulative gaussian functions displaying the proportion of mediolateral (ML) distances judged to be larger are plotted as a function of the stimulus ratio (mediolateral:proximodistal, ML:PD) for the Forearm, Wrist and Hand. Stimulus ratios are plotted on the x-axis so that the point 1 represents where the PSE would be veridical, i.e. the ratio of ML and PD response is accurate. The PSE is the point at which the function crosses the y-axis at .50, and is demarcated by the vertical lines extending down from the centre of each of the three curves. 2b. Average raw PSEs for Forearm, Wrist and Hand conditions. Error bars represent the standard error of the mean. The asterisks illustrate PSEs that are significantly different from 1, or from each other, where the null hypothesis has a $p < .01$ (**) and $p < .05$ (*).

3.1.1. Points-of-Subjective Equality (PSE)

Points-of-Subjective Equality (PSEs) were derived from all three body part conditions (Fig 2b). 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: $M = -.06$ ($sd = .11$), t (36) = 3.40, $p = .002$, $d = 1.13$; Hand: $M = -.02$ ($sd = .05$), t (36) = 2.80, $p = .008$, $d = .93$], whereas the Wrist condition revealed a significant proximodistally-biased anisotropy [$M = .03$ ($sd = .07$), 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, $p < .001$, $\eta_p^2 = .29$. 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 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 perceived tactile distance over the wrist boundary.

3.1.2. Interquartile Range (IQR)

Mean IQR scores for the Forearm, Wrist and Hand were .16 (*sd* = .13), .13 (*sd* = .14), and .08 (*sd* = .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).

3.2. 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 3. summarises common responses for these three terms. For the term "ruka" (Fig. 3a), responses were largely consistent indicating that it is a well-established linguistic category that encompasses the entire upper limb. Colouring responses to the terms “hand” and “arm” varied. For “hand” (Fig. 3b), 19 participants coloured the fingertips to the wrist boundary; for “arm" (Fig. 3c) 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 3 APPROX HERE ===

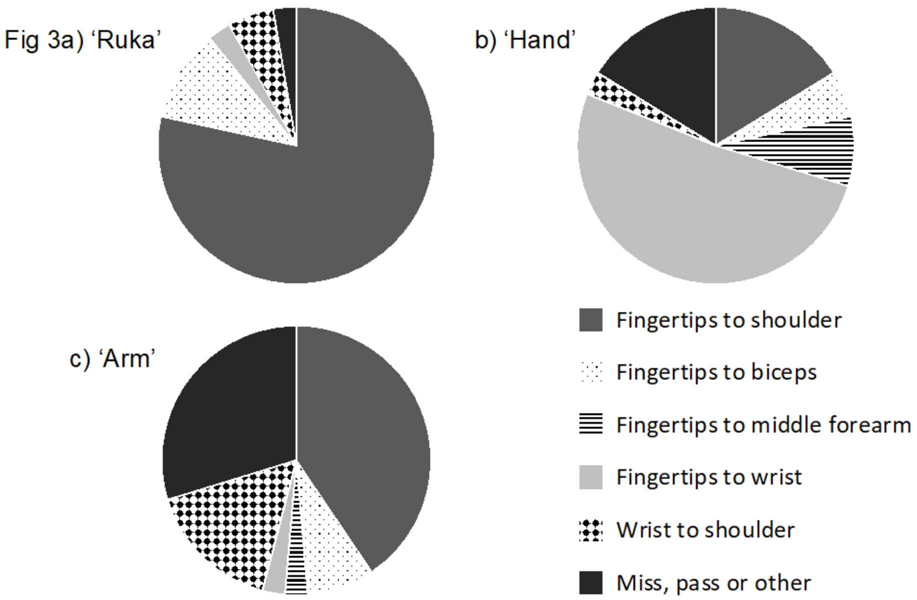

Figure 3. Proportion of common colouring responses on the Body Part Colouring task for each term; a) ‘Ruka’, b) ‘Hand’, c) ‘Arm’. The final tab, ‘Miss, pass or other’ includes responses that were considered misses (no region of the labelled body part was coloured), passes (participants declined to answer), and other (uncommon responses, n < 2, on the relevant body part).

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 additional language experience (L2R; responses to question 4, *brief language interview*), 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 of these 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, $p < .001$.

3.3. The role of language in tactile perceptual distortions

Finally, in order to determine whether the participants' degree of language experience and linguistic environment made a significant contribution to the perceptual elongation of distance over the wrist, our Croatian sample were compared to a sub-sample of previously tested native English-speaking adults (n = 14) (Le Cornu Knight et al., 2014). In order to probe the influence of additional language expertise on tactile distance perception, we separated the participants from our Croatian sample into two groups based on each participant's self-report about their additional language competency in the *brief language interview* (see methods). We considered that both current competency level and recent regular use of an additional language could play a role, and so we split the participants into two groups on the basis of their responses to questions about: i) their current second language competency (question 1) and, ii) their regular second language use across the past 5 years (question 4). All of the participants reported being most proficient with English, as well as speaking it most regularly in the past 5 years compared with all other additional languages, so this language was used to form the basis of separating the groups. Twenty-one participants reported an intermediate or expert level of English competency/use both currently and across the last 5 years. These participants were placed in the L2 High group (n = 21) which reported an average of 9.17 years of either English or German language schooling (*sd* = 2.87; range = 4-15 years). The remaining sixteen participants reported being at beginner level or below in English currently, and/or over the last 5 years. These participants were placed in the L2 Low group (n = 16) which reported a mean of 6.40 years of English or German language schooling (*sd* = 1.68; range = 4-8 years). Two Mann-Whitney U non-parametric tests confirmed that these groups differed in the expected direction in their knowledge of English body part terminology (NEPSY: $U = 22.00$, $p < .001$) but not on their English-like conceptual segmentation (WBCS: $U = 88.5$, $p = .089$).

Figure 4 displays PSE comparisons between Language groups at each Body Part site. A 3 x 3 mixed ANOVA (Body Part x Language groups: UK, L2 High, L2 Low) was performed on log-transformed PSEs, with a Huynh-Feldt correction applied[1]. We observed main effects of Body Part, F (1.81, 86.74) = 13.10, $p < .001$, $\eta_p^2 = .21$, and Language group, F (2, 48) = 3.45, $p = .040$, $\eta_p^2 = .13$, with no significant interaction effect ($F = 1.27$, $p = .289$, $\eta_p^2 = .05$). T-tests confirmed that PSEs at the wrist were significantly more biased towards the proximodistal axis than those at the arm, and

[1] Because the L2 Low group included three participants who reported an intermediate level of English competency either currently or over the last 5 years, we repeated the analysis excluding these participants (L2 High, n=21; L2 Low, n=13). This yielded the same pattern of findings, with no differences between the L2 Low and L2 High groups.

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 ($t = 1.81$, $p = .08$). Testing the main effect of Language groups, bonferroni-corrected multiple comparisons on overall PSEs responses revealed a significant difference between the L2 High and UK speakers (*mean difference* = .048, $p = .046$): L2 High responses were significantly less mediolaterally biased than the UK sample. No further differences were observed (*ps* > .135).[2]

=== INSERT FIGURE 4 APPROX HERE ===

Fig 4)

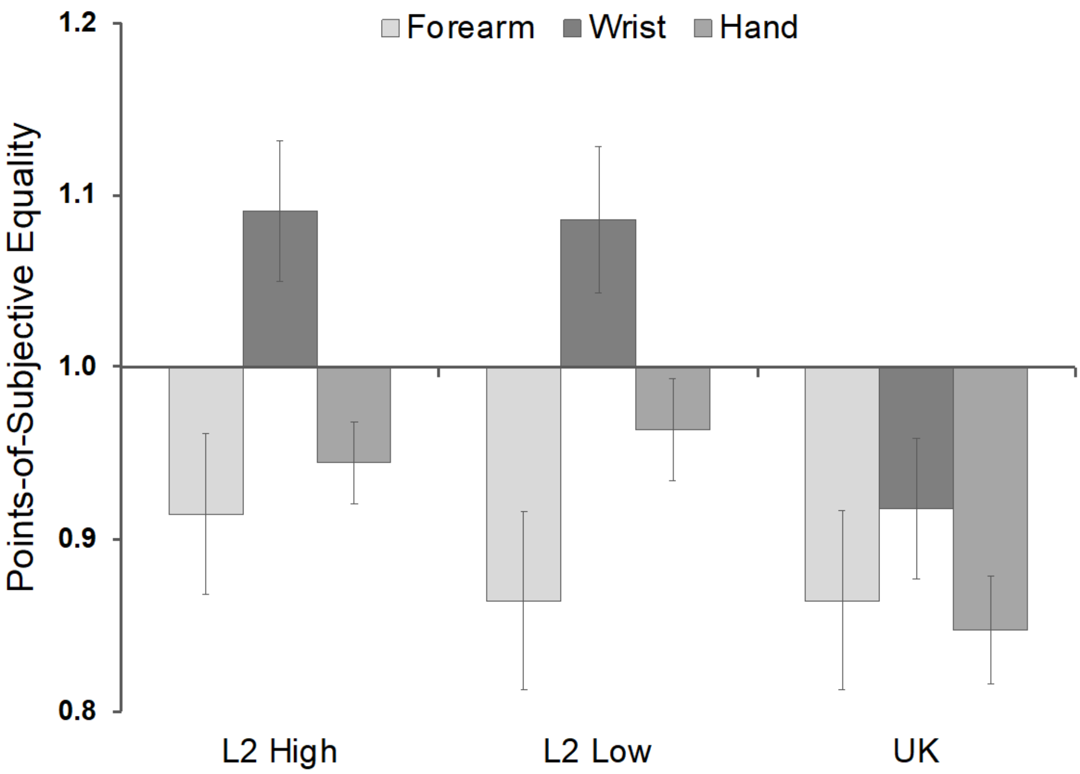

Figure 4. Comparisons of raw PSE across three Language groups: two native Croatian-speaking groups (L2 Low and L2 High) and one native English-speaking group (UK). The graph

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[2] Whilst we had no reason to expect differences in IQRs between UK and Croatian speaking participants, we checked this via a further 3 x 3 mixed ANOVA (Body Part x Language group) performed on IQR scores which revealed a significant main effect of Body Part, F (2, 90) = 10.31, $p < .001$, $\eta_p^2 = .19$, confirming previous findings. Wilcoxon sign ranked tests revealed that IQRs at the hand were significantly smaller than those at the wrist and forearm ($Z = 3.61$, $p = .001$; and $Z = 4.65$, $p < .001$ respectively). No further effects were significant (all *Fs* < 1.47, *ps* > .24).

presents raw PSE data, prior to log-transformation, collected on the Forearm, Wrist and Hand sites, for each group. Mean values are presented so that the point 1 on the y-axis represents where the PSE would be veridical, i.e. there is no proximodistally or mediolaterally biased anisotropy of perceived tactile distance. Error bars represent the standard error of the mean.

4. Discussion

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 tactile distance over the wrist boundary relative to distances presented within one body part category. Whilst the effect of body part boundaries on tactile spatial perception has been demonstrated in adults (de Vignemont et al., 2009; Le Cornu Knight, Longo & Bremner, 2014), and children (from 5 years of age; Le Cornu Knight, Cowie & Bremner, 2016) from a linguistic environment that differentiates the hand and arm, this is the first time the effect has been observed in a linguistic environment which does not generally draw such a distinction at that boundary.

In this study, we measured anisotropies of perceived distance between two tactile points presented in both the mediolateral and proximodistal axes across the forearm, wrist and hand. In Croatian participants, perceived tactile distance on the forearm and hand was biased towards the mediolateral axis, such that stimuli presented across the body part were felt as larger than equivalent stimuli presented along it. This finding is consistent with reports of a mediolateral bias on the dorsal and palmar surfaces of the forearm/hand in English-speaking adults (Longo & Haggard, 2010), across 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 mediolateral axis because the amount of skin for which a neuron is excited is more confined in this axis as compared to the proximodistal one, allowing for more fine-grained discrimination of tactile location.

In line with findings of an exaggerated perception of the distance between tactile points which straddle the wrist (de Vignemont et al., 2009; Le Cornu Knight et al., 2017), recent findings demonstrate that the mediolateral bias in perceived tactile distance on the body is reduced specifically at the wrist in an adult UK sample (Le Cornu Knight et al., 2014). Interestingly, the Croatian adults tested in this experiment not only showed a reduction in this mediolateral bias at the wrist compared to the hand and arm, they in fact showed a proximodistal anisotropy, such that equivalent distances were perceived to be greater in the proximodistal axis at this site. As we shall discuss below the proximodistal anisotropy may reflect an overall reduction in the mediolateral tactile bias across all body parts in Croatian participants compared to UK samples. The finding of a proximodistal elongation of perceived distance over the wrist boundary, represents robust support for the idea that body part boundaries play an important structuring role in spatial representations of the body (De Vignemont, Tsakiris, & Haggard, 2006). We propose that the overall pattern of biases across the body parts might represent 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. So whilst there is an overall bias to perceive tactile distance presented mediolaterally across the limb as larger, the category boundary effect at the wrist boundary overrides this.

With this experiment, we set out to explore the potential structural role of language on the category boundary effect at the wrist, by making use of lingustic differences between Croatian and English in the noun-term delineation of the upper limb. 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”. The tendency for Croatian participants to conceptualise the arm and hand as one unit was confirmed in participants’ responses on the body part colouring task. For the term ‘ruka’, 29 of 37 participants coloured from fingertip-to-shoulder, and a further four participants coloured fingertip-to-bicep. This is comparable to Majid and van Staden’s (2015) 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. Nineteen of the 37 Croatian participants used an English-like conceptualisation of the term ‘hand’ colouring fingertips-to-wrist, whilst only seven coloured ‘arm’ to the wrist boundary. This could reflect inexperience with the English language or perhaps a less consolidated conceptualisation of the term ‘arm’. Indeed, even within cultures that do make a linguistic distinction between hand and arm, there exists variation in whether the term arm is inclusive (Dutch) or exclusive (Japanese) of the hand (Majid & van Staden, 2015).

Importantly, despite clear indications of the different conceptualisations of the forearm/hand in Croatian and English, the Croatian participants showed a similar pattern of perceptual elongation of distance at the wrist relative to the hand and arm. In order to probe further for a potential role of language experience on tactile spatial perception, we divided our Croatian sample into two subgroups of inexperienced and proficient English-speakers; L2 Low and L2 High groups. Comparing data from these groups and that collected previously from a UK sample (Le Cornu Knight, Longo & Bremner, 2014) yielded no group-wise differences in the pattern of distance perception according to body part. Thus, under our current experimental paradigm, we find no support for the proposal that linguistic categories play a role in structuring tactile spatial body representations (de Vignemont et al., 2009), as they do in other perceptual domains (e.g., in colour categorisation; Athanasopoulos, 2009; Kay & Kempton, 1984; Roberson, et al., 2005).

Whilst we do not find support for a role of body part noun terms in the structuring tactile experience of the body, we are also unable to rule out such an influence. We cannot rule out the possibility that tactile structuring at the wrist is mediated by minimal or early exposure to an additional language which makes a linguistic distinction between hand and arm. Indeed, second language knowledge has been shown to implicitly interfere with first language categorisation tasks (for review see Bylund & Athanasopoulos, 2014). Here, we were not able to find a sample of Croatian people who had no experience with an additional language the makes a linguistic distinction between hand and arm. Furthermore, a medical term for the wrist boundary does exist in Croatian ("ručni zglob", roughly translated as 'manual joint'), knowledge of which we did not query within our current Croatian sample. Given current levels of international cultural exchange of English, accessing a sample of Croatian adults with no additional language experience would be practically very difficult. Future studies might examine the presence of the effect comparing an earlier developmental population, for whom medical and additional language experience would be minimal.

Given that we have found no evidence that the structuring of tactile space according to body parts is driven by body part noun experience, we can ask what other processes might lead to the structuring role of body parts in tactile spatial perception. 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 body part boundaries and therefore may contribute to a differentiation of categories (Biederman, 1987; Brown, 1976). The differing functional roles of body parts may also play a part in their categorisation (Morrison & Tversky, 2005; Reed, McGoldrick, Shackelford & Fidopiastis, 2004): the hand being a tool for grasping and manipulating, whilst the arm is primarily involved in extending reach. The modulation of tactile distance across the boundary may not be top-down at all, 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). In line with neuroscientific investigations of other conceptual representations (Kiefer & Pulvermuller, 2012), it also seems likely that information from a combination of these sources may be engaged in concert to contribute to the category boundary effect on tactile distance perception observed here. Future investigation might develop neuroscientific techniques to understand the processes occurring throughout the brain that contribute to body representations that bias such tactile perceptual judgements.

Lastly, we will comment on the differences in tactile perception which we observed between the Croatian participants examined in the current study and data reported previously from a UK sample (Le Cornu Knight et al., 2014). Although we observed the same pattern of tactile spatial anisotropies across body part sites between the samples, there is some indication that Croatian participants (specifically those in the L2 High group) showed reduced mediolateral biases across body part sites compared to the UK participants. As far as we know this is the first documentation of cross-cultural differences in tactile spatial perception of the body. Nonetheless, it is fairly unclear why such a difference might arise. One possibility is that physical differences in body size / shape might play a role. On average Croatians are 5cm taller than their UK counterparts: Croatian men and women stand at 180.4 cm and 166.5 cm respectively, as compared to 175.3 cm and 161.9 cm in the UK (Jureša, Musil & Kujundžić Tiljak, 2012; Moody, 2013). One factor then which might possibly explain the observed differences in tactile anisotropy is thus the length of the participants' arms: having longer limbs might lead to a general extention of tactile perception in the proximodistal axis. In the current study we might speculate that our participants had longer arms/hands than those of the participants in the previously reported UK sample (Le Cornu Knight et al., 2014; unfortunately we have no data with which to confirm or deny this), and that the lesser mediolateral bias in perceived distance in the Croatian sample is explained by participants' arm length. There are a couple of reasons however to cast doubt on this explanation. Firstly, there is no clear reason to think that greater limb length should lead to greater as opposed to a smaller perception of tactile distance on the limb (although see Cardinali, Brozzoli, Urquizar, Salemme, Roy, & Farnè, 2011). Secondly, this explanation does not sit entirely easily with current biological explanations of tactile distance perception. As mentioned above, Longo and Haggard (2010) have argued that the mediolateral bias in tactile distance perception reflects the oval shape of somatosensory receptive fields, which tend to be elongated in the proximodistal axis (Alloway et al., 1989; DiCarlo et al., 1998), leading to relatively higher acuity and greater perceived distance in the mediolateral axis. Longo and

Haggard's (2010) account would thus require that receptive fields were less elongated in the current Croatian sample, something which is not naturally predicted by Croatians being taller or having longer limbs. Future research might consider clarifying this possibility by examining relations between various bodily biometrics and tactile perceptual judgements both within and between cultures.

5. Conclusion

Here we set out to examine the influence of language on the category boundary effect of tactile perception. We found convincing evidence that tactile distances presented over the wrist are perceptually elongated relative to those presented within the hand or arm in a Croatian sample, in a manner consistent with that observed in a UK sample. 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). The fact that this effect is present in spite of cultural differences in the way the Croatian language delineates the upper limb suggests that the structuring of such a body representation does not have its base in language categorisation.

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