Different effects in tactile attention between the thumb and its metacarpus and the palm

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HIGHLIGHTS

► We investigate the mental representation of the thumb, its metacarpus and the palm.
► The thumb and its metacarpus share the same mental representation.
► The representation of the palm differs from that of the thumb and its metacarpus.
► Processing of tactile stimuli starts in the palm and progresses toward the fingers.

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ABSTRACT

The aim of this study is to establish whether the thumb is represented independently of the palm. An exogenous spatial cueing paradigm was used, where participants had to detect a tactile stimulus that could appear on the proximal and distal phalanges or metacarpus of the thumb (thenar area; Experiment 1) and the metacarpus of the thumb or hypothenar area of the palm (Experiment 2) of the left hand. Our results suggest the thumb and its metacarpus share the same mental representation, which is distinct from the representation of the palm.

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1. Introduction

Strikingly little is known about the representational relation between the fingers and palm of the human hand since only a few studies have investigated this issue. Results from spatial tactile cueing paradigms [4] suggest the existence of distinct mental representations of the fingers (digits 3 and 4) and palm. Further evidence comes from the study of spontaneous somatosensory sensations [15,16], where the effects of attention were found to be of different nature in these two parts of the hand, with the factors influencing the frequency of these phenomena over the fingers different from those that changed their frequency over the palm. The research conducted by Haggard et al., [8] is also relevant here since the authors showed that the representation of fingers is somatotopic, whereas the mental representations of the hands are influenced by external spatial localisation. However, the target in this study was the whole hand, not the palm. This points towards the independence of mental representation between fingers and the palm. However, insofar as research focused only on digits 3–4, the results might not generalize to the thumb and, so, its relationship with the palm. There is indeed an ongoing debate on whether the thumb should be considered as sharing the same representation with other fingers or as distinct and independent [10,18]. There is empirical support for both these points of view. For example, studies on finger agnosia support the idea of different mental representations for different fingers [1,2,6,14,12]. Other studies, however, provided evidence supporting the idea that fingers share a common, overlapping representation [21,19].

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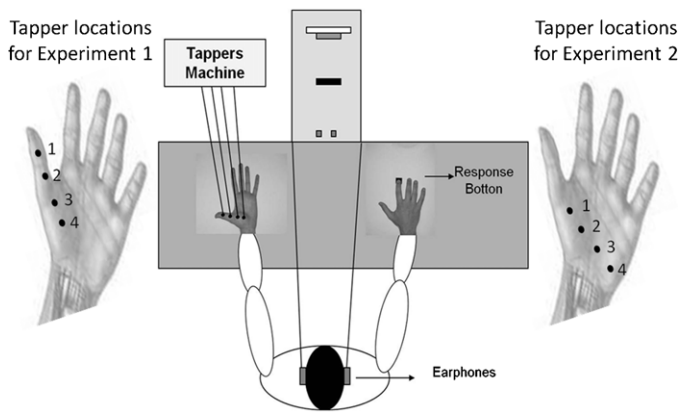
Fig. 1. Tapper locations and schematic drawing of the experimental set-up (Experiments 1 and 2).

Whether or not the thumb shares the same representation as other fingers also raises questions as to its relationship with the palm, since the latter seemingly has a different representation from the fingers. Whereas the metacarpus of all fingers constitutes the base of what is defined as the palm (i.e., a rather uniform and distinct anatomical zone), the metacarpus of the thumb has the additional feature of being more mobile and sometimes considered to be part of the thumb. However, to the best of our knowledge there has been very little research carried out in this area. Our aim in conducting this study was to examine the relationship between the thumb, its metacarpus and the rest of the palm, and to investigate whether or not they share the same mental representation. For this, we looked for similarities and differences in the speed with which tactile stimuli were detected in an attention task. We used a spatial cueing paradigm [4] where subjects had to detect a tactile target delivered at the location of a tactile cue or elsewhere, at varying time intervals from it. The stimuli were delivered through tappers placed on the thumb and the palm. In Experiment 1, the tappers were placed in the distal and proximal phalanx of the thumb, and the thumb metacarpus (thenar area). The logic was that if the thumb metacarpus were represented differently from the rest of the thumb, attention effects in these two areas would be different. In Experiment 2, the tappers were placed in the thumb metacarpus (thenar area) and hypothenar area. If the thumb metacarpus were represented differently from the rest of the palm, different attention effects would be observed between these two areas.

2. Experiment 1

2.1. Methods

Eighteen students of Sport Sciences (eleven men, seven women) from Granada University, Spain, took part in this study. Their mean age was 21.4 ± 4.3 years. All participants reported normal or corrected-to-normal vision and normal tactile perception. They were unaware of the purpose of the Experiment, all received a €5 gift voucher in return for their participation, and all gave their signed informed consent. The study was carried out in accordance with the ethical guidelines of the Experimental Psychology Department of Granada University.

Tactile stimuli were presented with a Tapper Controller. Four tappers were placed on the volar side of the left hand: two on the thumb phalanges (one on the distal and one on the proximal) and two on the thumb metacarpus (thenar area; Fig. 1). A tactile stimulus was delivered by a small metallic rod (2 mm diameter) propelled by a computer which controlled a miniature solenoid with a duration of 5 ms. The skin indentation produced a stimulus well above

the detection threshold. The 4 tappers were placed 2.6 cm apart. Participants were positioned so that they were facing a loudspeaker 40 cm in front of them and responded by pressing a button on the right hand side of the table with the index finger of their right hand. The experiment lasted approximately 40 minutes.

The participants were blindfolded so that they could focus their attention on the tactile sensation. Each trial started with a central "fixation signal" from the central loudspeaker cone (70 dB (A) auditory warning signal). Both tactile cue and target consisted of a 5 ms tap delivered by an identical miniature solenoid. The tactile cue was presented at an interval of between 300 and 500 ms after the auditory warning signal, at one of the four locations. The tactile target occurred randomly and equiprobably either 100 or 1000 ms after the onset of the cue. We ascertained that the cue and target stimuli were processed in a pilot test as two separate sensory events. Participants were told the position of the cue and that of the target were not related and were instructed to ignore the cues. Participants were given 1000 ms from target onset to respond to the targets by pressing the right button with the index finger of their right hand. If they responded before the target appeared or failed to respond within 1000 ms of target onset, an error feedback signal was emitted (1600-Hz tone, 300 ms duration). Between the end of one trial and onset of the next there was a variable interval of 1000–2000 ms. Cues and targets could be presented at each of the four tapper positions equiprobably and randomly.

A total of 32 conditions (2 SOAs; 100 and 1000 ms × 16 cue-target combinations) were presented 12 times each. To reduce the likelihood of participants' anticipating and responding prematurely, we added a subset of trials (96 catch trials) in which no target was presented. Trials were run in blocks, with participants completing 4 blocks of 120 trials, each divided into 4 sub-blocks. Before the experimental trials, participants took part in 36 practice trials, which were excluded from the analyses.

2.2. Data analyses

Response times faster than 150 ms (0.52%) or slower than 850 ms (0.72%) were excluded from the analyses. The mean correct RTs were submitted to an analysis of variance (ANOVA), with SOA (100 ms vs. 1000 ms), Target Area (thumb phalanges vs. thenar area) and Cueing (cue and target at Same Place vs. Different Place; coded as SP and DP, respectively) as within-subject factors. Post hoc comparisons were carried out with the Newman–Keuls test.

2.3. Results

No significant main effects of SOA ($F(1, 17) = 1.50$, $p > .23$, $\eta^2 = .29$) and Target Area ($F(1, 17) = 1.84$, $p > .19$, $\eta^2 = .03$) were obtained. The main effect of Cueing attained significance, $F(1, 17) = 22.8$, $p < .001$, $\eta^2 = .52$, with responses for DP being faster than for SP (321 and 333 ms, respectively). The SOA × Target Area interaction did not reach significance ($F(1, 17) = .03$, $p > .86$, $\eta^2 = .00$) and this was also the case for the Target Area × Cueing interaction ($F(1, 17) = .13$, $p > .72$, $\eta^2 = .00$). The SOA × Cueing interaction was significant, $F(1, 17) = 18.0$, $p < .001$, $\eta^2 = .15$. Post hoc comparisons showed that RT were faster in the DP than the SP condition both at short (329 ms vs. 335 ms, respectively; $p < .044$) and long (313 ms vs. 332 ms; $p < .001$) SOA. Furthermore, a reliable decrease in RT was found at the long SOA compared to the short SOA for DP ($p < .001$) but not for SP ($p > .24$). The SOA × Target Area × Cueing interaction did not reach significance ($F(1, 17) = .004$, $p > .95$, $\eta^2 = .00$).

3. Experiment 2

Experiment 1 provided no evidence on distinct representations for the thumb and its metacarpus. Their morphology and function
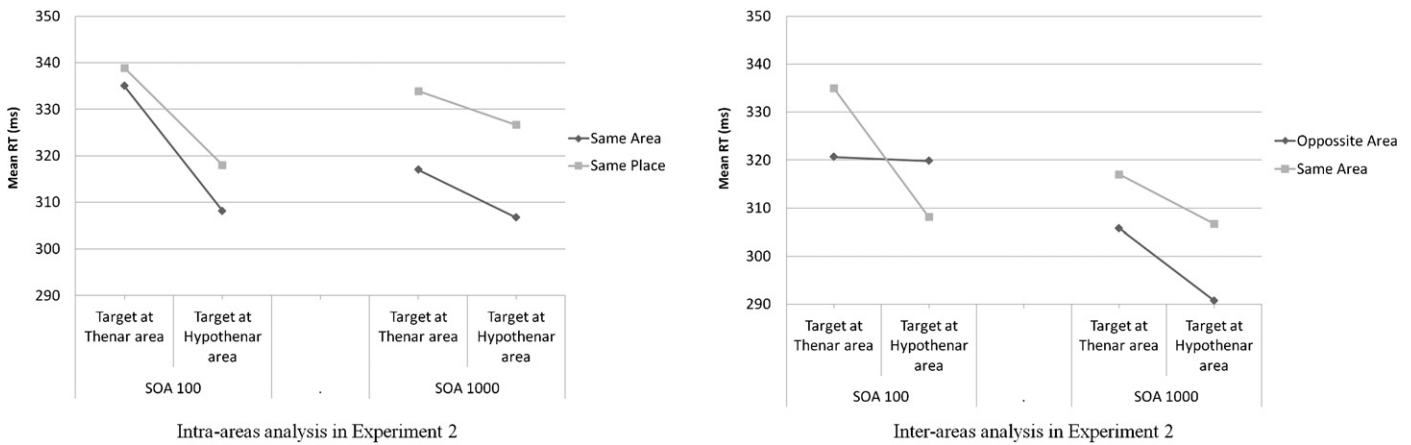
Fig. 2. Intra-Area Cueing effect as a function of SOA in the left panel (Experiment 2). Inter-Area Cueing effect as a function of SOA in the right panel (Experiment 2).

in relation to the other fingers may mean they behave as a single entity, with a single representation. The thumb and its metacarpus perform a wide range of conjoined movements and this particularity may manifest itself in different mental representations. If so, differences would be obtained when comparing the metacarpus of the thumb with another area of the palm. To test this hypothesis, two tappers were placed in the thenar area and two in the hypothenar area.

3.1. Methods

Eighteen participants (nine men, nine women) took part in this study. Their mean age was 22.1 ± 2.32 years, all reported normal or corrected-to-normal vision, and all gave their written informed consent. The procedure and set-up were the same as in Experiment 1, except that the tappers were located at different locations (see Fig. 1).

3.2. Results

Trials with correct responses faster than 150 ms (1.57%) or slower than 850 ms (1.97%) were excluded from the RT analyses. Mean RTs were subjected to a SOA × Target Area × Cueing repeated measures ANOVA. No significant main effect of SOA was obtained ($F(1, 17) = .97$, $p > .33$, $\eta^2 = .09$). The main effect of Target Area was significant (thenar: 327 ms; hypothenar: 314 ms; $F(1, 17) = 27.12$, $p < .001$, $\eta^2 = .25$) as was the main effect of Cueing (SP: 329 ms; DP: 312 ms; $F(1, 17) = 47.4$, $p < .001$, $\eta^2 = 47$). The SOA × Target Area interaction did not reach significance ($F(1, 17) = .83$, $p > .37$, $\eta^2 = .08$), and this was also the case for Target Area × Cueing interaction ($F(1, 17) = .22$, $p > .64$, $\eta^2 = .00$). The SOA × Cueing interaction was significant ($F(1, 17) = 14.89$, $p < .001$, $\eta^2 = 0.15$) since RT were faster in the DP than the SP condition both at short (321 ms vs. 328 ms, respectively; $p < .046$) and long (303 ms vs. 330 ms, respectively; $p < .001$) SOA. Furthermore, a significant decrease of RT was found at the long SOA compared to the short SOA for DP ($p < .001$) but not for SP ($p > .61$). The three-way SOA × Target Area × Cueing interaction was significant ($F(1, 17) = 4.69$, $p < .045$, $\eta^2 = .03$). Post hoc comparisons showed that RT were faster in the DP than the SP condition in short SOA for thenar area ($p < .002$) and marginally significant for hypothenar area ($p < .062$). The same results were found in long SOA for the thenar ($p < .003$) and hypothenar areas ($p < .002$). Furthermore, a faster RT was found in short SOA at the hypothenar area compared to the thenar area for DP ($p < .001$) and marginally significant in SP ($p > .08$). In long SOA the same pattern of data was found for SP ($p < .004$) and marginally significant in DP ($p > .09$).

In order to better investigate the respective contribution of each segment to the effects presented just above, two additional ANOVAs were performed, one on Intra-Area effects, the other on Inter-Area effects. The intra-areas analysis evaluates differences in the areas studied separately, as both cue and target were on the same part of the hand. There are two cueing conditions: Same Area vs. Same Place. Same Area (SA) was coded when the cue and target were presented in the same area being studied (thenar or hypothenar area) but at different locations (e.g. different tappers). Same Place (SP) meant the same tapper provided both the cue and target stimuli as previous analysis. The inter-areas analysis, for its part, evaluates differences across two adjacent areas (e.g. cue and target are on different parts of the hand). There are also two cueing conditions: Same Area (as intra-areas analysis, SA) vs. Opposite Area. Opposite area (OA) was coded when the cue and target were presented at different parts of the hand (thenar or hypothenar area). This kind of analysis is similar to that used previously to study visual hemifield modulation on visual cueing (e.g., 14) [24] and has been proved more efficient in detecting significant differences between different anatomical areas [4] in tactile attention.

In the Intra-Area analysis (see left panel of Fig. 2), no significant main effect of SOA was obtained ($F(1, 17) = .19$, $p > .66$, $\eta^2 = .03$). The main effect of Target Area was significant, $F(1, 17) = 20.4$, $p < .001$, $\eta^2 = .49$, since RTs for targets appearing in the hypothenar area were faster than for those appearing in the thenar area (315 ms vs. 331 ms, respectively). The main effect of Intra-Area cueing was also significant (SP: 329 ms; SA: 317 ms; $F(1, 17) = 24.7$, $p < .001$, $\eta^2 = .30$). The SOA × Target Area interaction was significance ($F(1, 17) = 5.57$, $p < .03$, $\eta^2 = .11$) since RT was faster in hypothenar than thenar area (313 ms vs. 337 ms, respectively, $p < .001$) in short SOA, but no significance in long SOA (317 ms vs. 325 ms, $p > .07$). The Target Area × Cueing interaction did not reach the significance ($F(1, 17) = .42$, $p > .53$, $\eta^2 = .00$). The SOA × Cueing interaction was marginally significant ($F(1, 17) = 4.28$, $p > .054$, $\eta^2 = .00$). Indeed, RT were faster in the SA than the SP condition both at short (322 ms vs. 328 ms, respectively; $p < .001$) and long (312 ms vs. 330 ms, respectively; $p < .001$) SOA. Furthermore, a faster RT was found at the long SOA compared to the short SOA for SA ($p < .002$) but not for SP ($p > .64$). The three-way SOA × Target Area × Cueing interaction was no significant ($F(1, 17) = .09$, $p > .76$, $\eta^2 = .00$).

In the Inter-Area analysis (see right panel of Fig. 2) there was no main effect of SOA ($F(1, 17) = 3.09$, $p > .097$, $\eta^2 = .41$). The main effect of Target Area was significant (thenar: 320 ms; hypothenar: 307 ms; $F(1, 17) = 17.6$, $p < .0006$, $\eta^2 = .28$) as did the main effect of Cueing (OA: 309 ms; SA: 317 ms; $F(1, 17) = 12.45$, $p < .003$, $\eta^2 = .09$).

The SOA × Target Area interaction did not reach significance ($F(1, 17) = .09$, $p > .77$, $\eta^2 = .00$), nor did the Target Area × Cueing interaction ($F(1, 17) = 2.68$, $p > .12$, $\eta^2 = .04$). The SOA × Cueing interaction was significant ($F(1, 17) = 5.54$, $p < .03$, $\eta^2 = .06$) since RT were faster in the OA than the SA condition at long SOA (298 ms vs. 312 ms, respectively; $p < .002$) but not at short SOA (320 ms vs. 322 ms, respectively; $p > .72$). Furthermore, a faster RT was found at the long SOA compared to the short SOA for OA and SA ($p < .001$ and $p < .045$ respectively). The three-way SOA × Target Area × Cueing interaction was significant ($F(1, 17) = 11.6$, $p < .003$, $\eta^2 = .10$). Post hoc comparisons showed that at short SOA for thenar area, faster target detection latencies were obtained when cue was presented in hypothenar area (OA: 321 ms; SA: 335 ms; $p < .046$). In the hypothenar area we obtained the opposite results, that is faster latencies when the cue was presented in hypothenar area (SA: 308 ms; OA: 320 ms; $p < .001$). At long SOA, for the thenar area, faster target detection was observed when the cue was presented in hypothenar area but without reaching significance (OA: 306 ms; SA: 317 ms; $p > .08$). This pattern of result reached significance in the hypothenar area (OA: 291 ms; SA: 307 ms; $p < .001$). Furthermore, a faster RT was found at the hypothenar area compared to the thenar area for SA in short SOA (308 ms vs. 335 ms; $p < .001$), but not for OA (320 ms vs. 321 ms; $p > .85$). In long SOA, faster RT at hypothenar area compared to the thenar area for OA was found (290 ms vs. 305 ms; $p < 0.42$) and SA (306 ms vs. 317 ms; $p < .001$).

4. General discussion

We investigated whether the thumb and palm have different mental representations. We designed two tactile cueing tasks where tappers were placed in the thumb phalanges and thenar area (Experiment 1) and in the thenar and hypothenar area (Experiment 2) so that we could establish whether there were any similarities or differences in the way an event is detected. In both Experiments, the first metacarpus of the thumb (thenar area) was the key area owing to its characteristic features, which distinguish it from the metacarpi of other fingers. In Experiment 1, we obtained similar effects in the thumb and the first metacarpus. Previous research [4] revealed that the latencies for the palm were different from those found in the middle and ring fingers. The combined results of these two studies suggest, therefore, that the relationship the middle and ring fingers have with their metacarpus is not the same as the relationship between the thumb and its metacarpus. This supports the idea that the thumb should be considered as a special finger [10,18]. The relationship between the thumb and its metacarpus, which goes in a different direction than the other fingers, suggests that different fingers may have different mental representation [5,9,10,22] or, at least, that each finger has a different relationship with the palm.

Different results were found when the tappers where placed in the thenar area (i.e., the thumb metacarpus) and the hypothenar area (Experiment 2). First, target detection was slower when both the cue and target were delivered at the thenar area (SA thenar) than when they were delivered at the hypothenar area (SA hypothenar). Second, the time to detect the target was similar when the cue was presented at the hypothenar area and the target at the thenar area (OA thenar) as when the cue was presented in the thenar area and the target at the hypothenar area (OA hypothenar). This is close to what was reported earlier [4] and may reflect differences in regional speed at which attention selects information. It may, therefore, constitute evidence on different mental representations, as well as a hierarchy where the centre of the hand (palm) plays a predominant role. The metacarpus of the thumb is thus represented independently from the palm, and the thumb is likely represented as part of its metacarpus. However, the former conclusion is based on indirect evidence and further investigation is needed.

Combining the results of this study and the previous one [4] reveals that, in short SOA, and whether the cue is delivered to the palm (all the metacarpi except the thumb metacarpus), middle and ring fingers, or thumb (and its metacarpus), detection of the subsequent target is faster when it is delivered in the palm. Regardless of the initial point of stimulation, detection is seemingly faster in the palm. When the cue and target are presented in the fingers or thumb, target detection is slower. This suggests that attentional processing in the fingers (thumb included) is either slower or starts later than in the palm. This is borne out by the fact that when the cue is presented in the palm and the target is delivered in the fingers, and vice versa, detection speed has an intermediate value. Some results from our previous study [4] constitute an additional argument. When the cue was presented at distal locations and the target at more proximal locations, detection of the latter was faster than in the opposite setting. This is a clear hierarchy, which suggests that attentional processing starts in the palm and progresses in time towards the fingers. That this pattern disappears in the long SOA also supports this idea. It is as if the representation of the whole hand were activated gradually, as if priority were given to the centre before spreading outwards towards the extremities. Thus, the representation of the hand is not uniform but, rather, fragmented. Otherwise no such hierarchy would be found. Such a hierarchy has been described previously in the literature [7], suggested that the body scheme is modular and hierarchical.

Differences between the palm and fingers have been described in the literature [4,15,16]. For example, different attention effects were found on spontaneous somatosensory sensations [15,16] arising on these two areas, and the factors influencing the frequency of these phenomena over the fingers differed from those altering their frequency over the palm. Yet, our study runs counter to data relating to the physiology and psychophysics of touch. At peripheral levels, there are more tactile receptors in the fingers than the palm [11], and the cortical representation of the fingers is larger than that of the palm [20], conferring greater tactile sensitivity to the fingers than the palm [11]. So why is it we found detection of stimuli to be faster in the palm, and why is it that attentional processing seemingly starts in the palm and progresses towards the fingers? Probably the number of mechanoreceptors and the extent of the cortical representation of these parts support their relative sensitivity but not the speed with which they process signals. This could be a kind of compromise between sensitivity and speed, such that the more sensitive a segment, the more time it needs to perform processing accurately. The complexity of the peripheral and central nervous system dedicated to the fingers could thus favor precision but not speed, rather like the procrastination suggested in the case of saccadic eye movements [3].

Faster latencies in the DP than in SP condition might reflect an attentional component known as Inhibition of Return (IOR) [13]. Attention is thought to orient away from previously attended locations to promote further exploring. If this were the case, then attention was directed to the location of the cue at first, and then shifted away in a surprisingly short time. Such subtle and quick shifts may explain why it was previously suggested that the tactile modality might be insensitive to the spatial distribution of attention [i.e., 23]. Yet, attentional effects found in Experiment 2 cannot be the consequence of the cue, providing participants a spatial framework within which to interpret the subsequent target [i.e., 17], since the Hypothenar Area remained insensitive to cueing. A spatial framework cannot explain our results, unless if attention were shifted over the representation of the hand [25] and that some parts of the hand had different representations.

5. Conclusions

Our results support that the first metacarpus of the thumb shares the same mental representation as the thumb, which is different from the rest of the palm. Some questions remain and warrant further study. For example, whether the fingers share the same representation.

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