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RESEARCH NOTE

Serial search for fingers of the same hand but not for fingers of different hands

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Abstract In most haptic search tasks, tactile stimuli are presented to the fingers of both hands. In such tasks, the search pattern for some object features, such as the shape of raised line symbols, has been found to be serial. The question is whether this search is serial over all fingers irrespective of the hand, or whether it is serial over the fingers of each hand and parallel over the two hands. To investigate this issue, we determined the speed of static haptic search when two items are presented to two fingers of the same hand and when two items are presented to two fingers of different hands. We compared the results with predictions for parallel and serial search based on the results of a previous study using the same items and a similar task. The results indicate that two fingers of the same hand process information in a serial manner, while two fingers of two different hands process information in parallel. Thus, considering the individual fingers as independent units in haptic search may not be justified, because the hand that they belong to matters.

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Introduction

In most haptic search tasks, tactile stimuli are presented to the fingers of both hands. In such tasks, the search pattern for some object features, like the shape of raised line symbols, is found to be serial (Klatzky and Lederman 1995; Lederman et al. 1988; Lederman and Klatzky 1997; Overvliet et al. 2007b, 2008; Purdy et al. 2004), meaning that the more items are presented the longer it takes to find the target. However, in the previous studies it was assumed that the hand that the finger is attached to is irrelevant, because search time was evaluated in terms of the number of fingers but not to which hand they belong. Is this assumption justified? There is some evidence that search is serial across fingers (Overvliet et al. 2007a) but parallel across hands (Overvliet et al. 2008). This evidence is from studies involving active search, and the two mentioned studies used very different methods, so we here examine this issue more directly. We determined whether the speed of a static haptic search task depends on whether the two items are presented to two fingers of the same hand, or to two fingers of different hands. We compared the results with predictions for parallel and serial search based on the results of a previous study using the same items and a similar task.

Method

Eight participants (6 males, all right handed; age range 23–48 years) had to indicate under which finger they felt the target. The experiment consisted of four blocks of 40 trials each. During each block a single pair of fingers was used:

both index fingers, both middle fingers, index and middle finger of the left hand, index and middle finger of the right hand. The blocks were presented in a counterbalanced order. In 75% of the trials of each block there was one target (cross) and one distracter (circle). The position of the target varied at random between the two possible positions. In the remaining 25% of the trials there was no target (i.e. there were two distracters).

The setup consisted of two force sensors, which were designed to have a piece of ZY-TEX2® Swell paper (Zychem Ltd., Cheshire, UK) attached to them. The items were crosses (target) and circles (distractors) with a line width of 1.4 mm, which protruded about 1 mm from the surface of the swell paper. Each sensor could be positioned separately to accommodate different hand and finger sizes. With the force sensors we could measure whether a finger was touching the item with a sample rate of 60 Hz. A curtain was placed between the participant and the apparatus to prevent the participant from seeing the display. The setup as seen from the viewpoint of the experimenter is shown in the photographs of Fig. 1.

The task was to either indicate the location of the target or indicate that there was no target present. Participants were instructed to do so as fast and accurately as possible. Participants started a trial (after an auditory signal indicated that they may do so) by lowering the two fingers simultaneously onto the display elements. As soon as they found the target, they had to lift the finger under which they felt the target. If they thought there was no target, they had to lift both their fingers. Search time was defined as the time that elapsed from the moment that the first finger touched an element until the moment that the first finger was lifted. We discarded search times lower than 100 ms.

Results and discussion

The participants were very accurate; they did not make any errors. We determined the median search times for each participant and condition. We distinguish between trials with (present) and without (absent) a target, and between trials in which both items were presented to fingers of the same hand and ones in which they were presented to fingers of different hands. The results are shown in Fig. 1. When both items were presented to the same hand, we found average search times of 1,050 ± 283 and 1,082 ± 363 ms (means and standard deviations across participants) for target present and target absent trials, respectively. When they were presented to different hands we found average search times of 802 ± 252 ms (target present) and 936 ± 273 ms (target absent). A repeated measures ANOVA with these two factors (same or

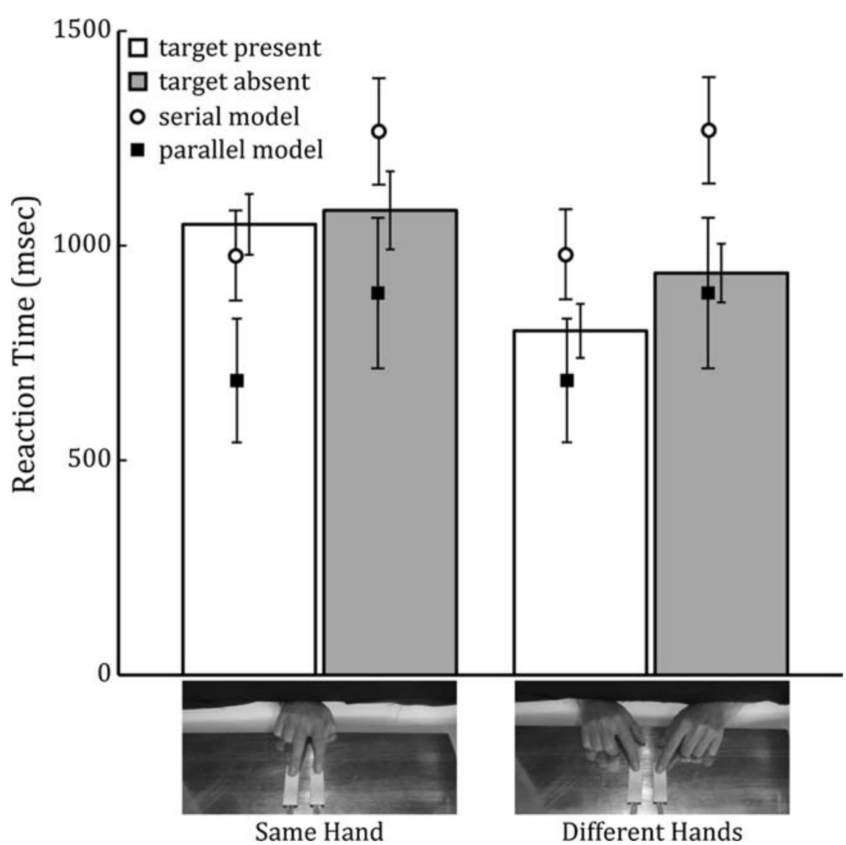

Fig. 1 Mean search times when the target was present (*white bars*) and absent (*gray bars*) with standard errors. *Symbols* show search times predicted by the serial (*open circles*) and parallel (*filled squares*) models of Overvliet et al. (2007b) with standard deviations

different hand; target present or absent) revealed a significant main effect for the number of hands involved ($F_{1,7} = 8.29$; $P < 0.05$) but not for target presence (and no significant interaction).

To determine whether the results can be explained by the search models of the Overvliet et al. (2007b) study,[1] we calculated what search times those models would predict. We did so for both the serial and the parallel search model, using the values that we found for the same items in that study: 686 ms for the intercept $(t_1; \bar{t})$, 290 ms/item for the slope (s) and an average standard deviation (σ) of 291 ms. In Fig. 1, these predictions are shown as circles for the parallel search model and as squares for the serial search model. The standard deviations of the predicted values were calculated using the standard deviations of the model fits in the 2007 study.

In order to determine whether the predicted values are consistent with our current data, we performed t tests for each of the four conditions to check whether the predicted values differ significantly from the mean data. We did not find significant differences between the predicted values for the parallel model and the data of the different hands condition (target present, $t_7 = 1.36$, $P = 0.22$; target absent, $t_7 = 0.49$, $P = 0.64$). We neither found significant differences between the predicted values for the serial model and the data of the same hand condition (target present, $t_7 = 0.901$, $P = 0.40$; target absent, $t_7 = 1.51$, $P = 0.18$). However, the serial and parallel model are rejected on basis of these analysis for the opposite data set, because in most conditions the predicted values are either significantly or marginally significantly different from the data (parallel, same hand condition: target present: $t_7 = 4.46$, $P < 0.01$, target absent: $t_7 = 1.57$, $P = 0.16$; serial, different hands condition: target present: : $t_7 = -2.06$, $P = 0.08$, target absent: $t_7 = -3.49$, $P < 0.01$).

The results demonstrate that considering the individual fingers as independent units in haptic search may not be justified. The serial model best predicts the results of the “same hand” condition in the current experiment, while the parallel model best predicts the results of the “different hand” conditions. This indicates that information is likely to be processed in parallel across two fingers of different hands, and serially across two fingers belonging to the same hand.

One might wonder why serial search patterns have been found in previous search tasks in which two hands were involved, such as our previous study (Overvliet et al. 2007b). This can easily be explained; the conditions that were compared differed in the number of *pairs* of fingers that were used (e.g. the ring fingers of both hands were either both used or both not used). We can therefore readily interpret the results of that experiment in terms of search being parallel between the hands and serial within the hands. The conditions in the experiments only differed in the number of fingers within each hand, so the serial model fit the effects of the manipulation. We predict on the basis of the current data that the slope of the search function would have been higher if we had studied the effect of adding digits of a single hand.

The conclusion that search is parallel across hands despite being serial within a hand of course only holds for features that are processed serially. Many features can be processed in parallel irrespective of which digits are used, such as roughness, temperature (Lederman and Klatzky 1997) and the presence of contours (Overvliet et al. 2007b). We have no reason to expect any difference between search times within and between hands for such properties. Thus, the finding by Purdy et al. (2004, p. 36) that “displays presented to one hand were no more difficult than displays presented to two hands” is consistent with the present results, because Purdy et al. examined search for targets differing in roughness, a property that is processed in parallel across all digits.

An objection to our interpretation of the data might be that a large difference in response time between the fingers might explain some of the differences that we found. For the target present conditions, differences in processing time between the digits cannot cause a systematic difference between search times for the same and different hands. In serial search digits are considered sequentially. In parallel search the response time within a trial is determined by a single finger. Averaging across fingers and hands will therefore remove any differences between the digits. However, for the target absent condition, according to the parallel model, the response time depends non-linearly on the response times of all digits used (Overvliet et al. 2007b). The effects on the averages can be up to half the difference between the individual digits’ response times. We therefore compared the search times for both index fingers (800 ± 224 ms; mean and standard deviation across participants) with the search times for both middle fingers (876 ± 295 ms), and we compared the search times for the non-dominant hand (1,077 ± 342 ms) with the search times of the dominant hand (1,018 ± 214 ms).

[1] The equations for the serial and parallel search models are as follows (for details about how these equations are derived see Overvliet et al. (2007b):

Serial search: $RT(n) = t_1 + (n-1)s$ (target present), $RT(n) = t_1 + (n-1)2s$ (target absent).

Parallel search: $RT(n) = \bar{t}$ (target present), $RT(n) = \bar{t} + \sigma\sqrt{2} \cdot erf^{-1}[-1 + 2\sqrt[n]{0.5}]$ (target absent).

In these equations n is the number of items, s is the slope of the search function, and t_1 is the average time it takes to decide whether an item is the target or not when there is only one item in the display (for parallel search the equivalent value t is the average time that it takes to find the target when it is present).

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Neither of the differences was significant ($t = 1.26$, $P = 0.25$ and $t = 0.51$, $P = 0.63$, respectively). This lack of a difference is in accordance with earlier results (Overvliet et al. 2007b). More importantly, the difference in response time between the fingers could only account for a difference between the conditions in the target absent trials of up to 38 ms, which is much smaller than the 146 ms difference that we found. Moreover, such a difference between response times of individual digits can never explain a difference for the target present trials, where the largest difference is found.

These findings nicely complement the results from active haptic search. In active search, using two hands to find a certain shape among a large array of shapes is much faster than using only one hand (Overvliet et al. 2008), while search with one hand does not benefit from using more digits (Overvliet et al. 2007a) unless the digits work together to recognize a single item (Overvliet et al. 2008). The present study shows that these differences in search efficiency can be explained by a sensory mechanism rather than arising from limitations imposed by the fact that the hand has to be moved from one item to the other.

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