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OBSERVATION

Perceptual Grouping in Haptic Search: The Influence of Proximity, Similarity, and Good Continuation

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We conducted a haptic search experiment to investigate the influence of the Gestalt principles of proximity, similarity, and good continuation. We expected faster search when the distractors could be grouped. We chose edges at different orientations as stimuli because they are processed similarly in the haptic and visual modality. We therefore expected the principles of similarity and good continuation to be operational in haptics as they are in vision. In contrast, because of differences in spatial processing between vision and haptics, we expected differences for the principle of proximity. In haptics, the Gestalt principle of proximity could operate at two distinct levels—somatotopic proximity or spatial proximity—and we assessed both possibilities in our experiments. The results show that the principles of similarity and good continuation indeed operate in this haptic search task. Neither of our proximity manipulations yielded effects, which may suggest that grouping by proximity must take place before an invariant representation of the object has formed.

Keywords: Gestalt principles, perceptual grouping, haptic search, touch, haptics

The Gestalt theory of perceptual organization aims to explain how the visual system organizes the incoming stream of visual information. For example, the Gestalt principle of grouping by proximity states that parts of the visual field that are in relative proximity to each other tend to be grouped into one whole (which could be a pattern, a texture, or an object) whereas the Gestalt principle of grouping by similarity states that parts of the visual field that are similar (e.g., in color or shape) are grouped (e.g., Olson & Attneave, 1970; Schulz & Sanocki, 2003). The Gestalt principle of grouping by good continuation states that that we tend to group lines or curves that follow an established direction. Since the early works on the Gestalt theory of perceptual organization (Koffka, 1922; Wertheimer, 1912, 1923), a considerable amount of research has been conducted on the Gestalt principles, but their exact mechanisms remained unclear (see for an overview Wagemans, Elder, et al., in press; Wagemans, Feldman, et al., in press). An important fundamental question is at which stage of perceptual processing Gestalt principles are operational and whether or not all Gestalt principles are operational at the same level(s) of processing. There are only a few studies that investigated this issue, and the overall conclusion is not entirely clear: Gestalt principles may be operational at multiple levels with either feedforward or feedback connections or both (e.g., Palmer, Brooks, & Nelson, 2003). Investigating the applicability of the Gestalt principles in another sensory modality could shed more light on this issue. Because differences between modalities are mainly present at early stages of perceptual processing, with representations retaining more of the properties and dimensions of the proximal stimuli (the sensory signals), we expect to find differences in the applicability of Gestalt principles when they operate at early stages of perceptual processing. In contrast, if a Gestalt principle mainly operates at high levels of perceptual processing, with representations in which the sensory aspects of the proximal stimuli are already filtered out to achieve more invariant interpretations of the environmental objects, we do not expect to find differences between modalities. In this paper we will investigate whether three Gestalt principles (grouping by proximity, by similarity, and by good continuation) influence haptic search.

The haptic sense, in relation to the Gestalt theory and its grouping principles, is particularly interesting because of its active and multisensory nature. One of the major differences between visual and haptic perceptual processes is the position of the perceptual sensors: In the visual modality the sensors are in a more or less fixed, relative position to each other. In contrast, if we explore an object by touch, we do not only use the sensors in our skin, but we also need to move our hands and fingers to obtain information related to the type of material we are dealing with or the shape characteristics of the object (Lederman & Klatzky, 1987). The knowl-

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edge about the position of our hands and fingers (proprioception) has to be combined with the tactile input on the skin (touch). This process takes time (Overvliet, Azañón, & Soto-Faraco, 2011) and involves distinct areas in the brain (Azañón, Longo, Soto-Faraco, & Haggard, 2010). Because of the clear difference in processing of location between vision and haptics, it is an interesting question whether or not the Gestalt principle of grouping by proximity also applies in haptics. Depending on the stage of haptic processing, the Gestalt principle of proximity could operate at two distinct levels: proximity on the skin (somatotopic proximity; before integration of touch with proprioception) or proximity in space (spatial proximity; after integration of touch with proprioception). If grouping by spatial proximity influences haptic search, it may be operational at a high level. A failure to find grouping by proximity in either of the two cases implies that proximity is likely to influence search at low levels of perceptual processing, way before an invariant representation of the stimulus has been formed.

In addition to differences in how certain perceptual properties are processed in vision compared to haptics, there are other properties that are processed in a similar manner (e.g., orientation). In primary somatosensory cortex there are neurons tuned to particular edge orientations, much like in primary visual cortex (Haggard, 2006; Hyvärinen & Poranen, 1978). Many of these neurons exhibit orientation tuning that is preserved across modes of stimulus exploration (static vs. dynamic) and that is relatively insensitive to other stimulus characteristics, such as amplitude, speed, and whether it is a raised line or a bar (Bensmaia, Denchev, Dammann, Craig, & Hsiao, 2008). In secondary somatosensory cortex there are neurons that code general orientation over the hand and even over two hands (Hsiao, Lane, & Fitzgerald, 2002). All of these studies point toward an analogous neural mechanism for early visual and tactile form processing. Taking this into account, one may expect the Gestalt principle of grouping by similarity, and specifically when similarity is defined by shape or orientation, and the principle of grouping by good continuation, which is by definition dependent on orientation of stimuli, to influence haptic search in a similar way as it does in vision.

To investigate the applicability of these three Gestalt principles in haptics, we conducted a haptic search experiment in which participants had to explore a column of item pairs with both of their index fingers (Figure 1A). One of these item pairs was the target and the other item pairs were distractors. Analogous to visual search (Treisman, 1982), we expect that when distractor pairs can be grouped they can be rejected faster and therefore search times will be shorter as compared with situations in which distractors cannot be grouped. For our experimental manipulation of similarity, we compared distractor pairs that had the same orientation (either horizontal or vertical) with those that had a dissimilar orientation. We tested the Gestalt principle of proximity in two separate conditions. In Experiment 1A, we tested whether the Gestalt principle of proximity applies in spatial coordinates. If so, we predict faster search when distractors are spatially closer to each other compared with when they are further apart. In Experiment 1B, we varied proximity at a lower level in the haptic perceptual hierarchy by varying proximity on a somatotopic level. We asked participants to scan the search displays with either two

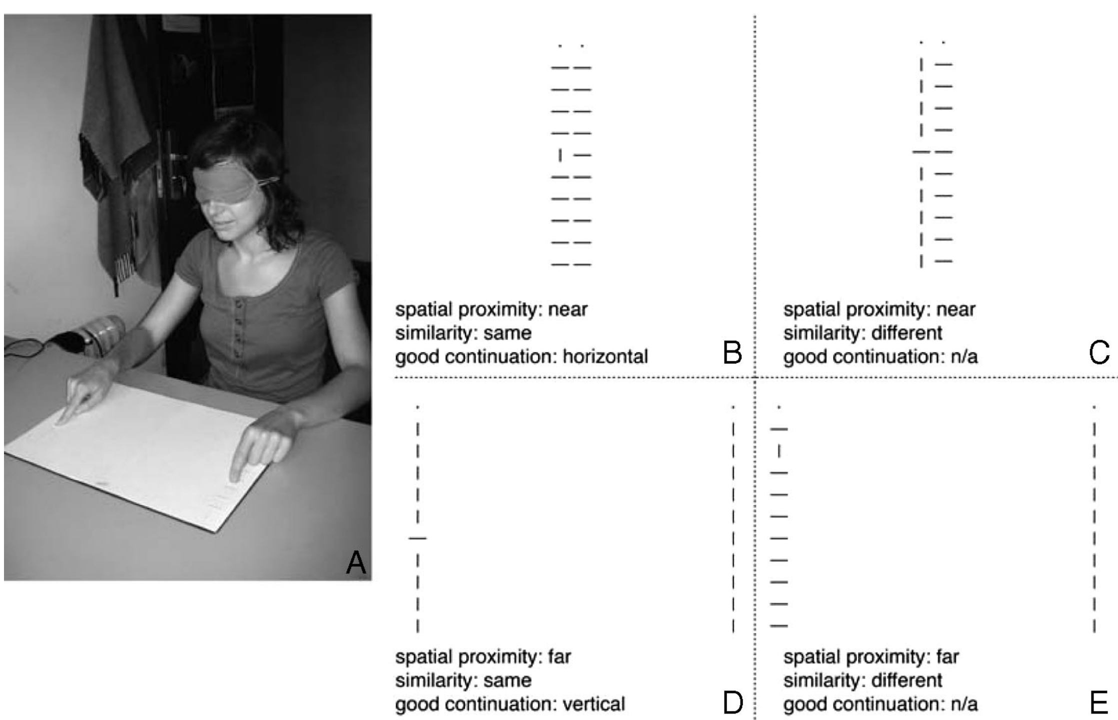

Figure 1. (A) A participant performing the task in Experiment 1A with conditions proximity: far and similarity: dissimilar. (B–E) Examples of stimuli in Experiment 1: (B) spatial proximity: close, similarity: same, good continuation: horizontal; (C) spatial proximity: close, similarity: different; (D) spatial proximity: far, similarity: same, good continuation: vertical; and (E) spatial proximity: far, similarity: different.

fingers close to one other (of the same hand) or with two fingers that are distant (single fingers of both hands). Formulating a hypothesis for this condition is not as straightforward as in the spatial proximity condition because previous research has shown that two fingers of two hands can process separate items faster than two fingers of one hand, but this difference diminishes when a single (grouped) object is touched in both configurations (Overvliet, Mayer, Smeets, & Brenner, 2008; Overvliet, Smeets, & Brenner, 2008, 2010). Taking this into account, if the Gestalt principle of grouping by proximity is applicable in a somatotopic reference frame, we hypothesized that when the distractor pairs can already be grouped based on similarity, search times will be shorter when the somatotopic distance is shorter (using two neighboring fingers of one hand opposed to using two single fingers of both hands). However, when the distractor pairs are dissimilar and cannot be grouped based on similarity, we expect to find an opposite pattern: longer search times when using two neighboring fingers of one hand as compared with two single fingers of both hands.

Method

Participants

Twelve volunteers from the university community were paid for their participation in this study (mean age 24.6, one left-handed, four males). None of the participants reported any abnormalities in their tactile perception. All participants provided written informed consent before participation. The local ethical committee approved the study.

Stimuli and Setup

The stimuli consisted of tangible vertical and horizontal lines with a length of 1.5 cm and a line width of 1.4 mm that protruded approximately 1 mm from the surface of the swell paper (Zychem Ltd., Cheshire, United Kingdom). We placed 10 rows of item pairs that were aligned vertically on each swell paper. The vertical distance between the centers of the item pairs was 2.5 cm. Two starting positions (dots with a diameter of 3 mm) were placed above the item pairs also with a distance of 2.5 cm from the first item. In each trial, a target pair was presented at a random position in one of rows 2–10. The target pair was defined as being different from the distractor pair: If the distractor pairs consisted of two similar items, then the target pair consisted of two dissimilar items and vice versa.

In Experiment 1A we varied similarity, spatial proximity, and good continuation (within the similar trials). We measured 80 trials, with 20 repetitions for each proximity–similarity combination. For the similarity manipulation, the distractor pairs were either the same or different in orientation, and within the “same” trials they could exhibit good continuation in either a vertical (between distractor pairs) or a horizontal direction (within distractors pairs). For the spatial proximity manipulation, we placed the centers of the items either 2.5 cm (close) or 36 cm (far) apart. All trials of all conditions were presented in a randomized fashion. Examples of one of the stimuli in each condition are shown in Figure 1.

In Experiment 1B we varied somatotopic proximity, and again similarity and good continuation within the similar trials. Somatotopic proximity was manipulated by asking the participants to scan the rows of item pairs with their index and middle finger of the same hand (proximity near) or by using their index finger of one hand and the middle finger of another hand (proximity far). The use of the left and right hand was randomized. The number of trials and other manipulations were the same as in Experiment 1A.

Procedure

The participants were seated behind a table and blindfolded. A few practice trials preceded the actual experiment. At the start of each trial the experimenter placed the tips of both index fingers at the two starting positions at the top of the two columns (see Figure 1). A starting signal indicated that the participant had to start the trial. The task for the participant was to simultaneously move their fingers down the column of item pairs and press a foot pedal as soon as they found the target pair. The scanning time was then recorded by the computer and saved along with the target position and the experimental condition. The experimenter always watched how the participant performed the task to make sure that both fingers were on the same row. If not, the trial was repeated at the end of the experiment.

Analysis

Because of the randomized position of the target pair over the trials, search time for each individual trial depended on the number of item pairs that had been scanned. Moreover, in each trial a fixed amount of time was spent to start moving and to respond to the target. To be able to compare the search times of the different trials within each condition, we standardized the exploration time by fitting a regression line through the data and compared the slopes of the different conditions. To determine the constant start and response time, we first linearly regressed the data of all four conditions. We took this intercept as the fixed intercept in the separate regressions of the four different conditions. The slopes of these regressions represent the speed of scanning. Before doing the regression, we removed the outliers because they can have a large influence on the regression parameters. We defined outliers as trials that had a search time that was larger or smaller than the mean ± 2 *SD* for each subset of trials with the same target position within each experimental condition (4.4% of the trials). Erroneous trials were also discarded, which constituted less than 2% in any of the conditions reported in this paper.

Results

The mean slopes of the regression lines for all conditions are shown in Figure 2. We performed a repeated measures ANOVA with the factors spatial proximity (near vs. far) and similarity (different, similar horizontal, similar vertical) on the average search slopes for both proximity conditions. We specified orthogonal a priori (Helmert) contrasts for the similarity factor. Contrast 1 compared the mean of the two similar conditions (horizontal and vertical) with the different condition (to test the similarity manipulation). Contrast 2 compared the horizontal with the vertical similar conditions (to test the good continuation manipulation). For Experiment 1A, we found a significant main effect for similarity ($F(2, 22) = 46.11$, $p < .001$, $\eta_p^2 = .81$) but not for proximity and no interaction. Moreover, we found a significant effect in both

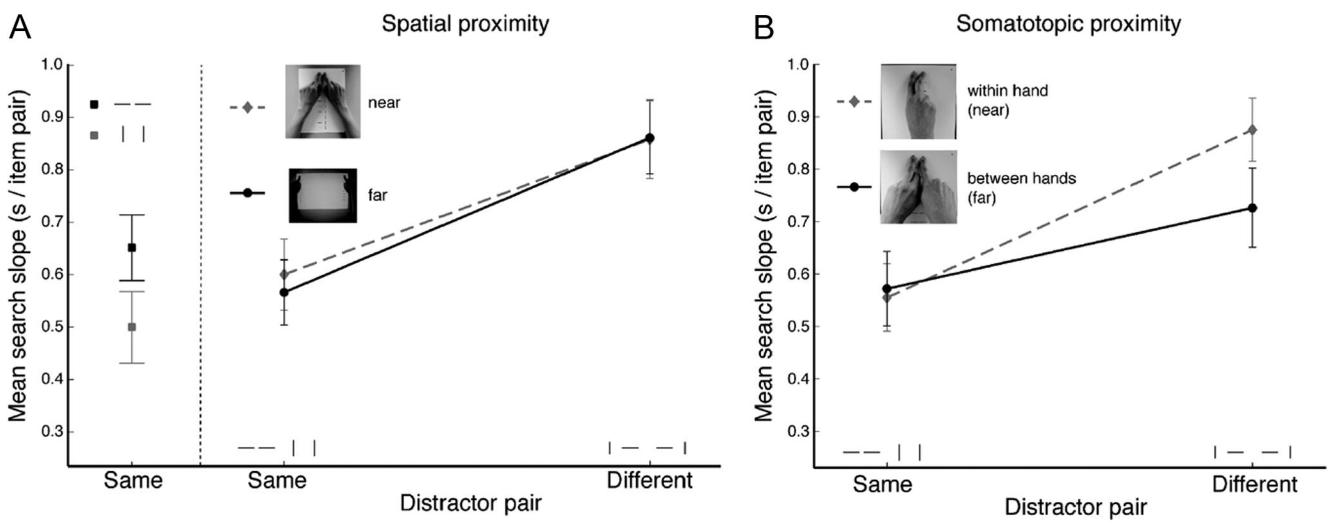

Figure 2. The mean slopes of the regression lines for spatial proximity condition (A) and somatotopic proximity condition (B). Error bars indicate the standard errors of the mean over participants. The inset in panel A shows the good continuation manipulation. The pictures in the legend show the proximity manipulation.

contrasts ($F(1, 11) = 61.77$, $p < .001$, $\eta_p^2 = .85$ and $F(1, 11) = 21.02$, $p < .001$, $\eta_p^2 = .66$) for similarity and good continuation, respectively.

For Experiment 1B we tested whether somatotopic proximity and similarity influenced the search slopes. We found a main effect for similarity ($F(2, 22) = 45.23$, $p < .001$, $\eta_p^2 = .80$), proximity ($F(1, 11) = 6.29$, $p < .05$, $\eta_p^2 = .36$), and an interaction between these two ($F(1, 11) = 6.53$, $p < .01$, $\eta_p^2 = .37$). We again found an effect for the similarity contrast ($F(1, 11) = 131.32$, $p < .001$, $\eta_p^2 = .92$). These effects show that when the items pairs are dissimilar search is slower when the items are somatotopically closer as compared with when they are further apart.

The mean intercepts of Experiment 1A (1.09 ± .31 s) and 1B (.84 ± .29 s) are not significantly different ($t_{df = 11} = .82$, $p = .43$), which indicates that participants did not adopt different strategies in Experiment 1A and 1B.

Discussion

We investigated whether the Gestalt principles of similarity, good continuation, and proximity are operational in haptics. The results showed clear effects for the similarity manipulation, indicating that this Gestalt principle indeed operates in the haptic modality. The finding that good continuation in the vertical direction yields faster search in Experiment 1 indicates that grouping takes place not only within a distractor pair but (also) across distractor pairs. We manipulated proximity in two ways: proximity defined by spatial distance and proximity defined by somatotopic distance. We hypothesized that if the Gestalt principle of grouping by proximity would apply on a spatial level, we should have found faster search when the distractor pairs were physically closer (Experiment 1A). For the somatotopic proximity manipulation we hypothesized that if the items were similar we should find faster search for somatotopic closer distractor pairs (explored with two fingers of one hand) as compared with pairs that were separated over two hands (Experiment 1B). We did not find support for either of the two hypotheses, and therefore we conclude that the Gestalt principle of grouping by proximity does not apply to haptic search. An alternative explanation could be that the Gestalt principle of grouping by temporal structure (common fate) may have come into play because the distractors "come and go" in pairs when the fingers move over them from one pair to the next. This effect would be present in all conditions, but it could be quite strong, in fact perhaps dominating the proximity manipulation.

Because underlying neural mechanisms of visual and haptic processing of edge orientation show several similarities, the result that we found an effect for these two Gestalt manipulations is informative. It corresponds to the findings by Chang, Nesbitt, and Wilkins (2007a, 2007b), who showed in a visuo-haptic comparison that grouping takes place in a similar fashion in vision and haptics when the grouping displays are comparable. However, this may have been due to the use of visual mediation of the haptic input (Lederman, Klatzky, Chataway, & Summers, 1990). Our study shows grouping by similarity and good continuation in a pure haptic paradigm. Different from Chang et al., we did not find an effect for our spatial proximity manipulation. In contrast, we found perceptual slowing when the distractor pairs were somatotopically near, suggesting interference in processing of haptic input on neighboring fingers. This finding replicates previous studies (Overvliet, Smeets, & Brenner, 2007; Overvliet et al., 2010). An alternative explanation of the effect for similarity lies in the task itself. Although the instruction was to find the odd pair within a column of item pairs, participants may have adopted a strategy in which they were looking for an odd item in one of two columns. This could have slowed down performance in the dissimilar trials, where two types of items have to be monitored.

In sum, the results of both of our proximity manipulations show that grouping by proximity does not take place in haptic search and therefore visual perceptual grouping by proximity must take place before an invariant representation of the object has formed.

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