



Perceptual grouping determines haptic contextual modulation



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ABSTRACT

Since the early phenomenological demonstrations of Gestalt principles, one of the major challenges of Gestalt psychology has been to quantify these principles. Here, we show that contextual modulation, i.e. the influence of context on target perception, can be used as a tool to quantify perceptual grouping in the haptic domain, similar to the visual domain. We investigated the influence of target–flanker grouping on performance in haptic vernier offset discrimination. We hypothesized that when, despite the apparent differences between vision and haptics, similar grouping principles are operational, a similar pattern of flanker interference would be observed in the haptic as in the visual domain. Participants discriminated the offset of a haptic vernier. The vernier was flanked by different flanker configurations: no flankers, single flanking lines, 10 flanking lines, rectangles and single perpendicular lines, varying the degree to which the vernier grouped with the flankers. Additionally, we used two different flanker widths (same width as and narrower than the target), again to vary target–flanker grouping. Our results show a clear effect of flankers: performance was much better when the vernier was presented alone compared to when it was presented with flankers. In the majority of flanker configurations, grouping between the target and the flankers determined the strength of interference, similar to the visual domain. However, in the same width rectangular flanker condition we found aberrant results. We discuss the results of our study in light of similarities and differences between vision and haptics and the interaction between different grouping principles. We conclude that in haptics, similar organization principles apply as in visual perception and argue that grouping and Gestalt are key organization principles not only of vision, but of the perceptual system in general.

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1. Introduction

In order to efficiently process information from the environment, the perceptual system has to organize the perceptual input across space and time. For example, the perceptual system determines what parts of a visual scene belong together (grouping), and what is figure and ground (figure–ground organization). The nature of perceptual organization is at the very heart of Gestalt psychology (Koffka, 1922; Wertheimer, 1912, 1923). One of the major challenges of Gestalt psychology is the quantification of its principles. Here, we use contextual modulation as a tool to quantify perceptual grouping in the haptic sensory modality.

Perception of an object is known to strongly depend on its (spatial and temporal) context. For example, finding a friend in a busy train station is much more of an effort than in an uncluttered environment. Context effects also occur with very simple stimuli. For

example, in vision, vernier offset discrimination strongly deteriorates, when the vernier is flanked by lines (Fig. 1A; e.g., Westheimer, Shimamura, & McKee, 1976). In audition, both melodic and rhythmic context affect recognition of embedded tones (Jones, Boltz, & Kidd, 1982). Hence, in these – and other – modalities, the perceptual system integrates information over both space and time.

In visual perception, the effect of context is usually explained by local interactions between target and context. For example, the deteriorating influence of flankers on target discrimination has been explained by lateral inhibition (e.g., Solomon & et al., 2004; Westheimer & Hauske, 1975), and spatial pooling (e.g., Badcock & Westheimer, 1985; Wilkinson, Wilson, & Ellemberg, 1997). However, a growing number of studies investigating context effects in visual perception show that the local context of a target is not a good predictor of performance. Rather, the entire (global) stimulus configuration has to be taken into account to predict performance (e.g. Livne & Sagi, 2007; Malania, Herzog, & Westheimer, 2007; Manassi, Sayim, & Herzog, 2012; Sayim, Westheimer, & Herzog, 2008, 2010). In particular, we showed that vernier

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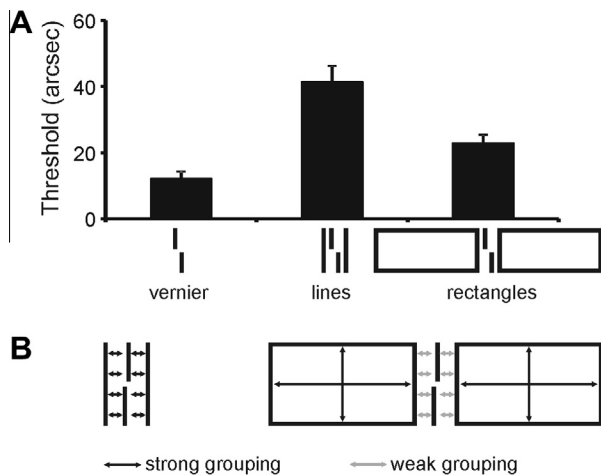


Fig. 1. (A) Contextual modulation of vernier thresholds in the visual domain. When a vernier is flanked by lines, performance deteriorates. When the lines are part of rectangles, i.e., grouped in a good Gestalt, performance improves compared to the lines alone (adapted from Sayim, Westheimer, & Herzog, 2010). (B) Grouping between a vernier and flanking lines is strong. Grouping between flanking lines and the vernier is reduced when the lines are part of rectangles. Grouping between the parts of the rectangles is strong.

discrimination is determined by the grouping of the target with the flankers by various grouping cues, such as size (Malania, Herzog, & Westheimer, 2007; Manassi, Sayim, & Herzog, 2012), color, contrast polarity, and depth (Sayim, Westheimer, & Herzog, 2008), good Gestalt (Sayim, Westheimer, & Herzog, 2010), and regularity (Manassi, Sayim, & Herzog, 2012). For example, single lines flanking a vernier target strongly deteriorated performance. Integrating these (local) lines into (global) rectangles, i.e., grouping the lines into a shape, improved discrimination (Fig. 1A; Sayim, Westheimer, & Herzog, 2010). We proposed that when the lines were parts of rectangles, they ungrouped from the vernier target, reducing interference by the flanking lines (for illustration, see Fig. 1B). Such influence of target–flanker grouping on performance shows that purely local mechanisms cannot explain these context effects (see also, Manassi, Sayim, & Herzog, 2013).

An important question is whether grouping mechanisms are specific to vision or a characteristic of the perceptual system in general. Grouping effects, for example, have also been shown in other modalities, such as auditory (Bregman & Campbell, 1971) and haptic perception (Chang, Nesbitt, & Wilkins, 2007a, 2007b; Frings & Spence, 2013; Gallace & Spence, 2011). For example, we recently found that grouping by proximity influenced the speed of haptic enumeration (Overvliet & Plaisier, in press; Verlaers, Wagemans, & Overvliet, 2015) and the accuracy in haptic contour detection (Overvliet, Krampe, & Wagemans, 2013). Similarly, good continuation and similarity improved haptic search performance (Overvliet, Krampe, & Wagemans, 2012; Van Aarsen & Overvliet, in preparation). These results suggest that similar principles as in the visual modality applied to the haptic modality. However, all these studies could be explained by local grouping, without the need to integrate spatio-temporal information of the whole stimulus display. The question thus remains whether grouping effects that cannot be explained by local similarity occur in haptics, for example, when global features favor different ways of grouping than local features.

The haptic system derives sensory information via two different input channels, touch (on the skin) and proprioception (location of the limbs relative to each other and in space). The touch input stems from the mechanoreceptors and thermo receptors embedded in the skin. The proprioceptive input is derived from

mechanoreceptors and muscle spindles that are embedded in the muscles, tendons and joints. In order to, for example, determine the location of an object or its edges, we need to interact with the object to integrate proprioceptive with tactile information (Lederman & Klatzky, 2009). This integration process takes about 250 ms (Overvliet, Azañon, & Soto-Faraco, 2011) and requires several separate brain areas (Azañon et al., 2010). Because of the active and multisensory nature of the haptic sense, its relation to the Gestalt theory and grouping principles is particularly interesting. The number (10 fingerpads vs. 2 retinas) and positions (relatively flexible vs. fixed) of the haptic and visual sensors and the size of the perceptual field (small vs. large) is one of the major differences between visual and haptic perceptual processes. Visual perception allows parallel processing, while in the haptic modality, we need to move our hands and fingers in order to extract the shape of an object (Lederman & Klatzky, 1987) or to obtain information about spatial relations between objects; this is a serial process.

In the current study, we investigate the influence of different contextual configurations on the perception of a haptic target stimulus (Fig. 2). Participants were presented with haptic verniers consisting of two short lines with an offset between the two (similar to the visual domain; Fig. 1). Participants indicated the offset direction of the vernier. The vernier was either presented alone or flanked by line configurations. First, we investigated whether the basic effect of close-by flankers in the visual modality, i.e. a deterioration of performance by the flankers, also occurred in haptics. Next, we were interested whether grouping of flankers had a similar effect on haptic vernier discrimination. We hypothesize that, if the stimulus as a whole is taken into account, similar flanker effects will be found as in the visual counterpart: flankers that ungroup from the target will interfere less with vernier discrimination compared to flankers that group with the target. On the other hand, if only local information is used, the global flanker configuration would not be crucial and we will find similar deterioration of vernier discrimination with flankers that are locally similar.

We found that grouping and the global configuration of target and flankers determined haptic vernier offset discrimination, similar to the visual domain. Interestingly, flanking rectangles only reduced interference compared to single lines when they were narrower than the target, and not when they were of the same width as the target. We suggest that different weightings of grouping cues in the haptic and visual domain may underlie this finding. As proposed earlier (Sayim, Westheimer, & Herzog, 2010), our results show that contextual modulation can be used as a tool to quantify Gestalt laws – at least in the visual and haptic domain. Differences and similarities of vision and haptics reveal in how far (specific) grouping principles are features of the perceptual system in general.

2. Method

2.1. Participants

Nineteen volunteers from the university community were paid for their participation in this study (mean age 21.7 ± 2.5 years, 18 right-handed, 12 females). We measured both tactile sensitivity (mean score $4.66 \pm .41$; maximum score is 5) and moving and static 2-point discrimination (mean score $2.21 \pm .42$ mm and $2.79 \pm .63$ mm, respectively) by using the Touch-Test[®] Sensory Evaluators and the Touch-Test[®] Two-Point Discriminator (North Coast Medical, Inc., USA). None of the participants had a score below “normal” as indicated by the Touch-Test[®] manufacturer. The study was conducted in line with the ethical principles regarding research with human participants as specified in The Code of

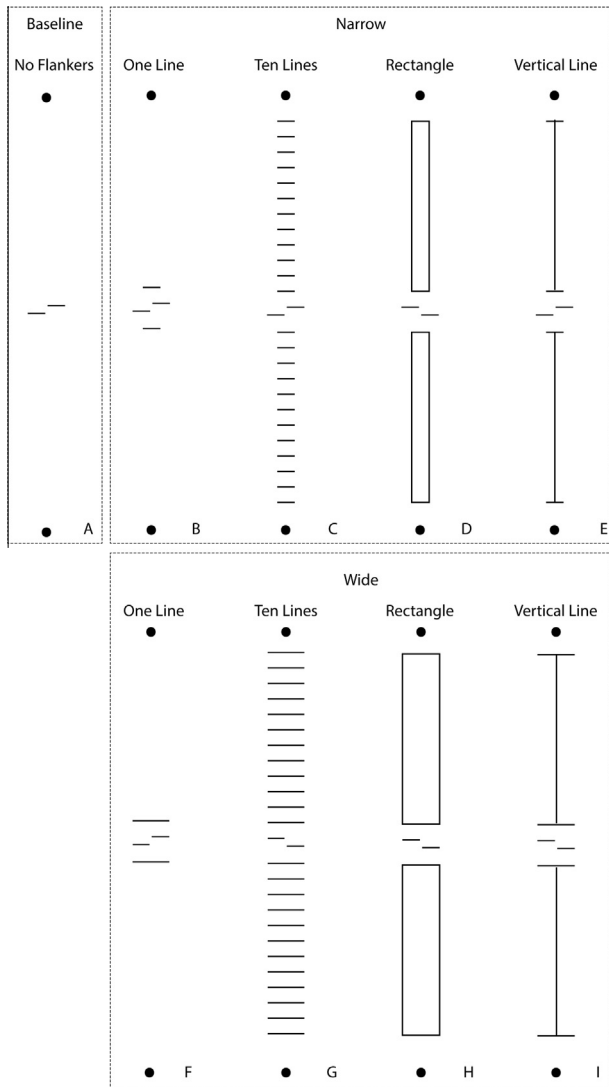


Fig. 2. Stimuli used in the experiment. (A) Baseline, vernier only, (B–E) narrow flanker conditions. (B) One line, (C) 10 lines (D) rectangles (E) perpendicular lines (F–I) Wide flanker conditions. (F) one line (G) 10 lines, (H) rectangles (I) perpendicular lines.

Ethics of the World Medical Association (Declaration of Helsinki). The study was approved by the Medical Ethical Committee of the University Hospital Gasthuisberg (Leuven). Participants gave written informed consent before starting the experiment. The screening and ethical considerations of the participants were similar to an earlier study by the first author (Overvliet, Krampe, & Wagemans, 2013).

2.2. Stimuli and apparatus

The stimuli consisted of a tactile vernier, which was placed horizontally in the middle of a 12 cm long strip of ZY[®]-TEX2 Swell Paper (Zychem Ltd., Cheshire, England). The lines of the vernier protruded about 1 mm from the surface of the swell paper and were 4.0, 4.5 or 5.0 mm long (depending on finger width of the participant), had a line width of 0.35 (1 point) mm and were separated by 2 mm. For the different flanker conditions we placed flankers around the vernier as shown in Fig. 2. The flankers were either as wide as, or narrower than the vernier (see below). In order to keep the narrow-wide manipulation constant over participants with different finger sizes, we scaled the stimuli in their

width according to finger width of the participant. As a result we used three sizes of stimuli, small (for finger widths smaller than 15 mm), medium (for finger widths of 15–16 mm, and large (for finger widths larger than 16 mm). The narrow flankers (Fig. 2B–E) had a width of 4.0, 4.5 or 5.0 mm and the wide flankers (Fig. 2F–I) a width of 8.3, 9.4 or 10.5 mm (for small, medium and large respectively). In order to keep the total distance that the finger had to move constant (100 mm) over the different conditions, start and end points with a diameter of ~2 mm were placed at both ends of the stimulus.

In total, we created 9 different conditions: no flankers, 1 line, 10 lines, rectangles and perpendicular lines, each flanker type “wide” and “narrow”. The vernier offset direction was counterbalanced, i.e., half of the trials required “left” and the other half “right” responses. The resulting 18 different trial types were repeated 10 times each, resulting in 180 trials. All trials were delivered completely randomized to the participants. Because of the large number of trials and possible adaptation effects, the experiment was conducted in two sessions of approximately 60 min each.

2.3. Procedure

At the beginning of the session the experimenter measured participants’ tactile acuity and sensitivity (as described in Section 2.1) and asked them to read and sign the informed consent form. The experimenter then seated the participants in the experimental set-up (Fig. 3) and blindfolded them. In each trial the experimenter put the index finger of the dominant hand of the participant on the starting position. The task for the participant was to move their finger to the end of the stimulus and indicate which one of the vernier lines was above the other, i.e., farther away from the participant’s location on the horizontal plane. They did so by pressing food pedals (left pedal for left on top, right pedal for right on top). Participants first practiced ten trials before they started the experiment. They started moving their finger across the stimulus when a starting beep sounded, and were supposed to stop when they reached the end position. Participants were not allowed to move sideways or backwards. Responses were recorded by the computer along with the stimulus information. No feedback was given during the course of the experiment. The experiment was divided in two separate blocks of 90 trials. The blocks were identical in terms of the number and types of trials, but were randomized differently. In between the two blocks there was a break of a minimum of 5 min. In total the session took about 1 h.

3. Results

3.1. Exploration times

In order to be able to compare the error rates of the different experimental conditions to each other, we first verified whether the exploration times were similar across conditions. Mean exploration time was 4.26 ± 1.64 s per trial. We first tested whether the individual flanker conditions were significantly different from baseline (no flankers) by running 8 paired samples *t*-tests with Bonferroni correction (test alpha 0.0063). Ten-lines, box and perpendicular flankers differed (both wide and narrow) from baseline (all $t > 3.35$, all $p < .004$). A repeated measures ANOVA on the exploration times in the eight different flanker conditions revealed a main effect of flanker type ($F(3,54) = 10.87$, $p < .001$, $\eta_p^2 = .38$) flanker width ($F(1,18) = 13.43$, $p < .01$, $\eta_p^2 = .43$) and an interaction ($F(3,54) = 5.67$, $p < .01$, $\eta_p^2 = .24$). Post hoc *t*-tests only revealed differences between ten-lines-narrow and ten-lines-wide, one-line-wide and ten-lines-wide, ten-lines-wide and box-wide,

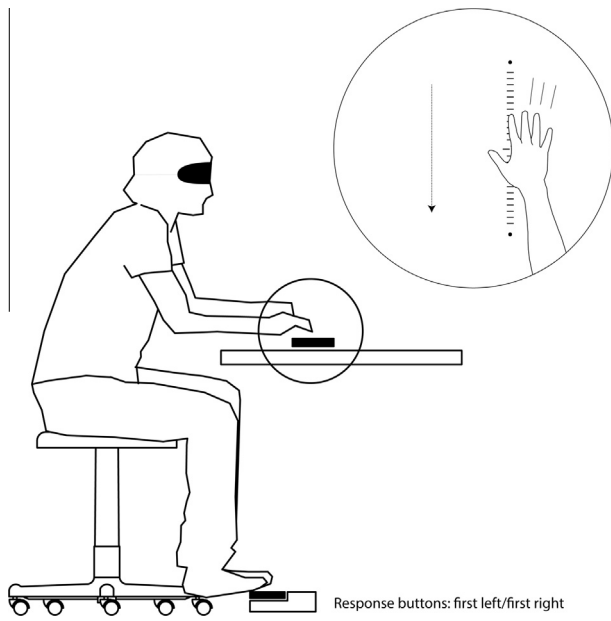


Fig. 3. Experimental setup. In the inset the orientation of the stimulus and the movement direction of the finger pad are shown.

and ten-lines-wide and perpendicular-wide (all $t > 3.36$, all $p < .003$).

These results can be explained purely by the proportion of tactile input (number and distance of raised lines vs. empty swell paper) that had to be explored in each condition. Hence, these differences cannot explain the differences in error rates we report below. Moreover, no speed-accuracy trade-off was found, the overall correlation between exploration time and error rate was negligible (Pearson $r = -0.014$).

3.2. Proportion of errors

The overall mean proportion of errors was $.35 \pm .19$, the mean error rates for each flanker condition are shown in Fig. 4. We first tested whether the individual flanker conditions were significantly different from baseline (no flankers) by running 8 paired samples t -tests with Bonferroni correction (test alpha 0.0063). We found that baseline significantly differed from one-line-narrow, perpendicular-narrow, one-line-wide, ten-lines-wide, rectangle-wide and perpendicular-wide (all $t_{df=18} > 3.09$, all $p < .006$).

Next we tested the effects of the flanker types by running a repeated measures ANOVA with factors flanker type (one line, ten lines, rectangles and perpendicular) and flanker width (narrow and wide). We found a main effect of flanker type ($F(3, 54) = 3.90$, $p < .05$, $\eta_p^2 = .18$), flanker width ($F(1, 18) = 7.78$, $p < .05$, $\eta_p^2 = .30$), and an interaction ($F(3, 54) = 4.08$, $p < .05$, $\eta_p^2 = .19$).

Post-hoc paired samples t -tests revealed differences between ten-lines-narrow and ten-lines-wide, one-line-narrow and ten-lines-narrow, and one-line-narrow and rectangles-narrow (all $t_{df=18} > 3.41$, all $p < .003$, Bonferroni corrected alpha level of .0031).

4. General discussion

Since the early Gestalt psychologists (e.g. Koffka, 1922; Wertheimer, 1912, 1923) countless studies have shown that perceptual grouping is a key principle of visual perception (for a recent review see Wagemans et al., 2012, 2012). For example, it was shown that grouping determines contextual modulation of basic

spatial vision (Sayim, Westheimer, & Herzog, 2010). In several studies with various visual stimuli, such as verniers (Malania, Herzog, & Westheimer, 2007; Sayim, Westheimer, & Herzog, 2008), Gabors (Saarela et al., 2009), and letters (Banks & White, 1984), it was shown that when target and flankers grouped, performance was good, when they did not group (or grouped less), performance was poor. In order to investigate whether contextual modulation can be used as a tool to quantify Gestalt principles in the haptic modality, we tested in the current study whether perceptual grouping modulates haptic vernier discrimination similar to the visual domain. In our experiment, we presented a haptic vernier target flanked by line configurations narrower than, or of the same width as the vernier. We found that single flanking lines strongly deteriorated performance compared to unflanked verniers, showing that flankers interfered with vernier discrimination. Hence, the target was not perceived independently of the flankers. This is a classical context effect. When adding further flanking lines to the single lines condition in the narrow condition, performance improved. Note that the single lines directly above and below the vernier were the same in both conditions. Therefore, purely local interactions between the target and the single flankers cannot explain these results. We suggest that, similar to visual perception, in the condition with 10 narrow flankers, the flankers grouped with each other and ungrouped from the vernier. Performance was also better in the narrow rectangles condition compared to the single flanker condition. Again, we suggest that the advantage was due to the ungrouping of vernier and flankers – participants could access the vernier with less interference from the flankers when they were grouped into rectangles. In contrast, in the single flankers condition, the vernier and the flankers formed a single group, decreasing access to the vernier.

In the wide condition, we replicated the basic flanker effect. When the vernier was presented in isolation, performance was better compared to when it was flanked by single lines. In the 10 flanking lines condition, performance did not improve compared to the single flanking lines condition. This was expected under the grouping assumption as increasing the numbers of flanking lines of the same size does not decrease grouping with the target (Malania, Herzog, & Westheimer, 2007; Manassi, Sayim, & Herzog, 2012). When presenting same width rectangles, performance did also not improve. This was not expected under the visual grouping explanation. In visual perception, also rectangles of the same size as the target improved performance compared to single flanking lines (Manassi, Sayim, & Herzog, 2012; Sayim, Westheimer, & Herzog, 2010). Before discussing the unexpected lack of improvement with wide (equal width) rectangles, we now consider two alternative explanations to the grouping account – first, improved target *anticipation*, and second, improved target *localization*.

The target *anticipation* explanation assumes that participants' estimate of the spatio-temporal occurrence of the target was better when their mechanoreceptors were stimulated by a pattern along the motion path of the finger. The pattern would serve as a helpful (additional) indicator of the distance between the starting point and the target. The repetitive, equally spaced pattern in the 10 flankers condition would prepare participants for the upcoming target and help to focus attention to the correct moment, i.e. when the finger passed the target. Hence, the superior performance in the 10 flankers condition would be due to a more precise allocation of attention. In the single flankers condition, by contrast, mechanoreceptor stimulation between the starting point and the first flanker, which was immediately followed by the target, came only from a flat, homogenous surface not yielding any information in addition to the execution of the motor behavior itself (i.e., “knowing” the magnitude of the arm movement), and the time it took to reach the target. While the scanning speed was too fast

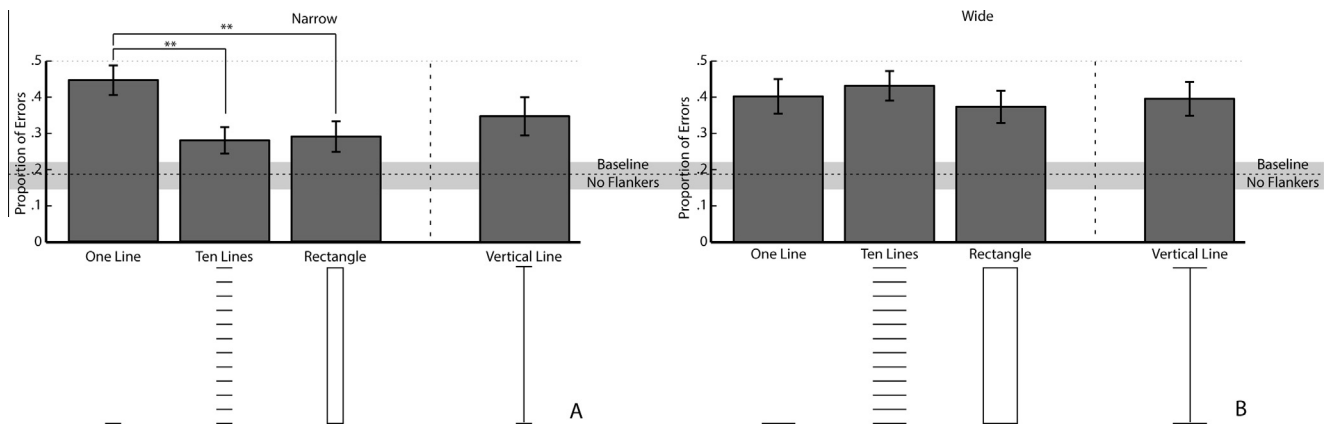


Fig. 4. Results. Bars show the mean error rates over participants for the different flanker conditions in the narrow (A) and in the wide condition (B). Below each bar an example of the flankers is shown. Error bars are the standard errors of the mean over the participants. The horizontal dotted line is the mean error rate in the baseline (no flankers) condition, the gray area represents the standard error of the mean.

to count the number of flanking lines and use this information to anticipate the target, an explanation based on anticipation assumes that distance(-until-target) estimates are more precise with lines compared to without lines. However, assuming that it is the regular pattern of indents (which yields additional information) does neither explain the advantage in the narrow rectangles condition, nor the lack of an advantage in the condition with 10 flankers of the same width as the vernier. First, the side lines of the rectangle do not yield additional information compared to the flat surface in the single flanking lines condition, similar to the control condition (perpendicular line). However, performance improved. Second, the 10-same-width-flankers condition yielded the same information as the 10-narrow-flankers condition because the spacing between the flankers was the same, and the same number of flankers was presented. However, performance did not improve. For these reasons, we reject target anticipation as an explanation for our results.

The second explanation assumes that target *localization* was easier in the conditions, which yielded superior performance. In the two wide single flanking lines condition, the space between start position and target was empty. Hence, deviations to the left or to the right, and therefore missing the (centre of the) target, seem more likely in the single flanking lines conditions compared to the rectangle and 10 lines conditions. Moreover, task demands could have been higher in the single lines conditions because participants might have needed additional resources to make sure not to miss the target in these conditions. However, as the anticipation explanation, this explanation fails to account for our results. First, participants did not miss the target on any trial after the training phase – this part of the task was fairly simple. Second, failure of localization does not account for the lack of an improvement in the 10 wide lines, and the wide rectangles condition. The narrow perpendicular line condition which serves as a “tactile guide” to the target position equally well as the 10 lines and rectangles conditions, yielded a trend for better performance compared to the single lines condition, however, this difference did not reach significance. Finally, the localization explanation does not account for the basic flanker effect, i.e., the deterioration of performance when adding single flanking lines to the vernier, as there is no guide to the target location in any of the two conditions (narrow and wide).

Why did we not fully replicate the results found in the visual domain? Besides the different modalities, there are several differences between the visual and haptic experiments. In contrast to studies in vision where target and flankers were presented simultaneously (Malania, Herzog, & Westheimer, 2007; Manassi, Sayim,

& Herzog, 2012; Sayim, Westheimer, & Herzog, 2010), here, participants scanned the stimulus sequentially. Flankers that preceded the target, i.e. were located above the target on the stimulus sheets, were – in loose analogy to experiments in vision – “forward masks” and flankers that followed the target, i.e. were located below the target, were “backward masks”. Note that we did neither investigate the individual contributions of the forward and backward masks, nor did we vary temporal aspects of stimulus exploration here. From experiments in vision, we know that contextual effects are highly sensitive in regard to temporal stimulus characteristics (e.g., Greenwood, Sayim, & Cavanagh, 2014; Huckauf & Heller, 2004). For example, in backward masking, we found similar grouping and ungrouping effects as with simultaneous presentation (Solomon & et al., 2004). However, when – similar to the present experiment – wide (same-width) rectangles flanked the vernier, no advantage was found compared to single flanking lines. Only stimulus onset asynchronies (SOAs), i.e. temporal gaps between target and flanker onsets, longer than about 60 ms yielded a trend for an advantage of wide rectangles compared to single flanking lines; short SOAs did not. It seems that in the visual domain, ungrouping by good Gestalt takes more time than ungrouping by other features. However, in the present experiment, we did find ungrouping by good Gestalt: narrow rectangles improved performance compared to narrow single flankers. Hence, temporal aspects were not key for ungrouping (or the lack of ungrouping) by good Gestalt in the present study.

A second explanation for the differences in the wide rectangle condition between vision and haptics could be that different grouping principles are weighted differently in the two domains. In the stimuli we used, different grouping principles are at work simultaneously. These principles, such as proximity or good Gestalt, can either contribute to or counteract target-flanker grouping. For example, the single flankers can be grouped with the target by proximity. We expected that in the rectangles condition, grouping between the target and the flankers by proximity would be overruled by within-flanker grouping based on good Gestalt, i.e. grouping of the single flanking lines with the (three other lines of the resulting) rectangles. In the same-width condition, besides grouping by proximity, the single flankers also grouped by similarity, in this case size similarity as they are of the same width as the vernier. In the narrow flankers condition, in contrast, the flankers do not group with the target by size similarity because they are narrower than the target. We suggest that the combination of these three grouping principles could explain our results. In the narrow rectangles condition, the vernier

ungroups from the target by good Gestalt and by dissimilarity in size. In the same width rectangles condition, ungrouping only occurs because of good Gestalt and not by similarity in size. The combination of the two grouping cues makes the target stand out sufficiently to observe the improvement we found. In contrast to the visual domain, ungrouping by good Gestalt alone was not sufficient in this experiment.

Also in the single- and ten-lines conditions, size differences between the target and the flankers alone did not determine performance. No differences were observed between the single-narrow and single-wide flanker conditions, even though, weaker target-flanker grouping would be expected when the flanking lines were narrower than the target (grouping by size similarity; however, each *element* of the vernier was similar in size to the narrow single line flankers). We only found a difference between the narrow and wide conditions when the number of flanking lines was increased. Size alone was not sufficient. While there was no additional grouping cue as in the rectangles condition, grouping of the two flanking lines directly neighboring the target with additional lines was necessary, similar to visual perception (Malania, Herzog, & Westheimer, 2007; Manassi, Sayim, & Herzog, 2012). Our results show that the combination of different grouping factors yields stronger ungrouping than a single grouping factor, highlighting one of the major challenges in the quantification of Gestalt principles, namely, how different grouping factors interact. In future studies, parametric variation of the different grouping factors will give a precise account of their interactions. Revealing similarities and differences of grouping factor interactions between different modalities will help to better understand how to perceptual system integrates information, and the role of grouping and good Gestalt in perceptual systems.

A third aspect that could explain our deviating results in the wide rectangle condition in the haptic modality is the difference between vision and haptics in exploring the stimulus. While in vision the whole stimulus is seen at once, in haptics the stimulus has to be explored serially with the finger (see also temporal characteristics above). When moving the finger pad down the stimulus without any guidance, the finger could move slightly to the left or the right, which will cause drifting off one of the sides of the rectangle in the wide, but not in the narrow condition. If one of the sides is (occasionally) missing, participants' perception of a flanking rectangle could be compromised. This is less likely to be the case in the narrow rectangle condition.

Overall, the strong similarities between visual and haptic perception indicate that grouping and perceptual organization operate at a level beyond particular senses, reflecting the structure and processing mechanisms of the perceptual system in general. However, our results also suggest that visual grouping and haptic grouping do not always coincide. The differences between haptics and vision reveal distinctive features of the two perceptual systems. We propose that using contextual modulation as a tool to quantify Gestalt laws of perceptual organization is not only useful in the visual domain (Sayim, Westheimer, & Herzog, 2010) but equally applies in haptics, and presumably other domains.

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