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Short paper

The Oblique Effect in the Perception of the Direction Between Two Points of Vibration on the Back

Myrthe A. Plaisier and Astrid M.L. Kappers

***Abstract*—Vibrations on the back of a person can convey information about direction through sequentially switching on two vibration motors. For perception of direction the oblique effect can occur, meaning that perception of cardinal directions is more precise than perception of oblique directions. We investigated the role of the positioning of the vibrations with respect to the spine. In the first condition all vibration motors were placed in a circle around the spine ('Circle' condition) and direction was conveyed by switching on vibration motors on opposite sides of the circle. In the second condition the vibrations were placed in two semi-circles of which the centers were on the left and right sides of the back ('Semi-circle' condition). We found that participants showed larger deviations as well as a larger spread for oblique directions than for cardinal directions in both conditions. This indicates that the oblique effect occurred. Therefore, the oblique effect can occur irregardless of the positioning of the vibration motors with respect to the spine. Both deviations and spread were larger in the 'Semi-circle' condition than in the 'Circle' condition suggesting an advantage for centering motors around the spine, although this might have been influenced by the distance between vibrations.**

Index Terms—Vibrotactile, haptic perception, direction.

I. Introduction

Due to an increase in the use of tactile feedback implemented in for instance vibration vests, the need for understanding vibrotactile perception on the torso has become more urgent. With increased interest in wearables, vests have become especially relevant. Often vibration is used to provide cues that are useful for navigation and obstacle avoidance. However, vibrotactile feedback can also be used to trace shapes. It has been shown that geometric shapes or letters that are traced with vibration can be recognized by participants e.g. [1]–[5]. Perception of navigational cues or traced shapes, however, will be affected by perceptual anisotropies of the body part where the tactile cues are presented. Directions may be perceived in a systematically biased way and shapes might feel deformed. Known perceptual biases may be anticipated and corrected for in the design of a device or wearable.

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It is well-known that tactile acuity of the different body parts varies, meaning that smaller distances can be distinguished, for instance, on the hand than on the calf [6]. However, there exist also anisotropies in perceived distances depending on the orientation in which a distance is presented. Distances along the length of a body part are generally perceived to be smaller than across the width of a body part [7]–[11]. It has been suggested that this is due to asymmetries in the receptive fields of the underlying neuronal representation [8]. These studies are usually done using pressure stimuli, not vibrotactile stimulation. Most of these studies did not focus on the torso. Interestingly, there is one study that reports the absence of this anisotropy in perceived distance for the belly [12].

The available studies on vibrotactile perception on the torso do report on several instances of anisotropies. Localisation of vibration, for instance, has been reported to be more precise near the spine and navel than at other positions around the torso [13], [14]. Directly on the spine sensitivity is, however, reduced [15]. Additionally, localisation of vibrations with respect to one another was found to be more accurate in the horizontal direction than in the vertical direction [15]. In a recent study, we have investigated the perceived distance between two vibrations [16]. We found that distances were perceived as being larger in the vertical direction than in the horizontal direction. Also distances were perceived as larger when two vibrations were on opposite sides of the spine compared to when they were not. Finally, distances felt smallest when vibrations were presented simultaneously rather than sequentially and when vibrations were presented simultaneously participants rated distances of 4 cm to feel very similar to distances as large as 12 cm.

Besides perceived distance, also perceived orientation can exhibit systematic biases. Haptic perception of orientation has been mostly studied using parallelity tasks [17], [18]. Usually a bar has to be rotated to match the orientation of another bar, i.e. make the two bars parallel. For such tasks it is known that two types of oblique effects can occur. The first type of oblique effect is difference in precision of the perception of cardinal and oblique angles. Precision of the perception of cardinal angles has been found to be larger than for oblique angles. This is determined by comparing the inter-trial spread of the perceived direction for cardinal and oblique angles. The second type of oblique effect is difference in accuracy of the perceived direction. Cardinal angles have been found to be perceived with a higher accuracy than oblique angles. This is determined by comparing the absolute deviation between the presented direction and the perceived direction between both types of angles. Both types of oblique effect can occur independently. Oblique effects were originally found in vision, but are also known to occur in haptic perception [19] and also occur for blind participants [20]. While haptic perception of orientation has been mostly studied by matching the orientation of two bars, it is also possible to match the orientation of a bar to the perceived direction between two vibrations, that is, the direction of the line between a first and a second vibration.

In a recent study we found that the perceived direction between two vibrations is subject to systematic biases [21]. We found that cardinal directions were perceived more accurately and with higher precision than oblique directions. This means that both types of oblique effect occurred. These results are very comparable to results found for haptic parallelity tasks even though the task was quite different. This suggests that the oblique effect is a general effect in haptic perception occurring in various situations. In the same study we also found that oblique directions were perceived to be biased towards the horizontal direction. This can lead to traced shapes feeling compressed in the vertical direction. In the current study we investigated the perception of direction on the back further. Specifically, we investigated the perceived direction between two subsequent vibrations depending on the positioning of the vibrations on the back.

In our previous study on the perceived direction between two points of vibration we always presented a vibration at the center point of a circle located on the spine before presenting a vibration at a certain direction on a circle around it. As the center point was located on the spine, the spine may have functioned as an anchor point [22]. Often anchor points are joints and localisation of stimuli is better near such an anchor point such as the wrist or elbow [23]. It has been argued that the spine also functions as an anchor point given that localisation is more accurate near the spine than on other locations on the back and due to its location at the body mid-line [13], [15]. This might, for instance, be the reason that perceived distances were larger when vibration points were presented on opposite sides of the spine [16]. In the current study we investigated whether the occurrence of the oblique effects depends on the placement of the vibration motors with respect to the spine. More specifically, we set out to determine whether oblique effects also occur when the first of the two vibrations is not located on the spine like was the case in our previous study [21]. Furthermore, we tested whether the oblique effects also occur when the line connecting two subsequent vibrations is not centered on the spine.

We included two conditions. In one condition a set of vibration motors were placed on a circle that was centred around the spine similar to our previous study [21]. This time, however, we did not provide a vibration in the center of the circle. A direction was conveyed by sequentially switching on vibration motors on opposite sides of the circle (Fig. 1A). So this condition avoided vibrations on the spine. If the oblique effects occur for this condition this indicates that these effects do not depend on one vibration being located at an anchor point while comparing the location of the second vibration to this anchor point. We will refer to this as the 'Circle' condition. In a second condition we did not center the circle around the spine, because even if we didn't provide a vibration at the center of the circle, the spine might still be used as an anchor point relative to which the direction between the two points on the circle is perceived. This is because the line connecting the two vibrations is in the 'Cirlce' condition always centered on the spine. To this end we positioned the motors in two semi-circles with the center points on the far left and right sides of the back (Fig. 1B). This condition will be referred to as 'Semi-circle' condition. We also tested whether the oblique effects occur for this condition. If we find oblique effects in both conditions this indicates that the occurrence of the oblique effects is largely independent of the positioning of the vibrations with respect to the spine. Additionally, we tested whether performance differed between the two conditions in terms of accuracy and precision of the perceived directions.

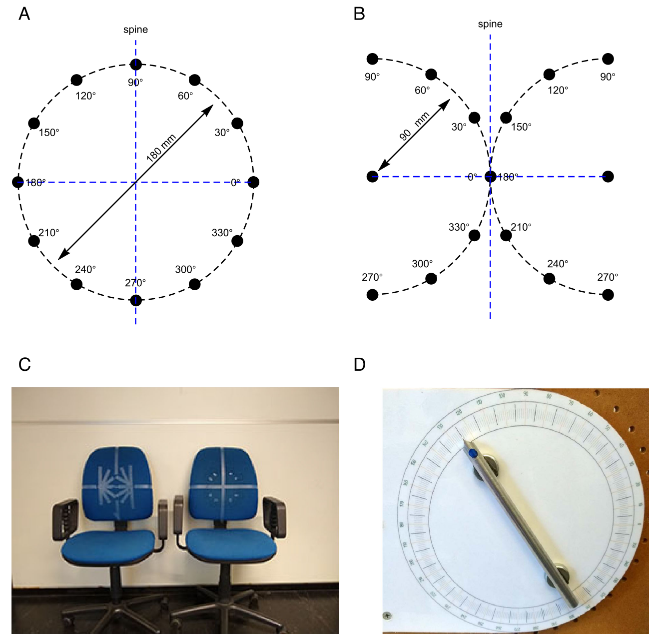

Fig. 1. A) Lay-out of the vibration motors in the 'Circle' condition. B) Lay-out of the vibration motors in the 'Semi-circle' condition. C) Picture of the chairs that were used to attach the vibration motors to. The markings show the positioning of the vibration motors on the backrest. The center of the circle and semi-circles was positioned about 25 cm above the seat of the chair. D) Arrow that participants rotated to indicate the perceived direction between the two sequential vibrations. The blue dot was positioned at the end with the arrow head. The arrow head could also be felt.

II. Method

A. Participants

Twelve participants (2 were self-reported left-handed and the others right-handed, age range 21 – 25 years) participated in this study. All participants were students of Eindhoven University of Technology and received financial compensation for their participation. They signed informed consent prior to the start of the experiment and the study was approved by the ethical committee of the Human Technology Interaction section of Eindhoven University of Technology.

B. Setup and Stimuli

The hardware consisted of a micro controller (Arduino mega) and coin-style ERM vibration motors (0834 flat vibration motor via Opencircuit). The vibration motors had a diameter of 8 mm. The motors were fixed to the backrest of an office chair. The motors could be positioned in a circle or in two semi-circles with a radius of 9 cm (Fig. 1A and B). The position of the backrest was kept fixed, so the exact positioning of the motors on the back varied with the height of the participants. The radius of the circle was chosen such that the motors were in contact with the back also for the participants with the narrowest back. The motors were positioned well below the shoulder blades for all participants (Fig. 1C). The positioning of the vibration motors was kept the same for all participants, because most applications that incorporate vibration motors in a chair, and often in wearables too, the positioning of the motors is not changed or scaled for differently sized users. It is also not obvious how a scaling should be implemented as it is not known how it influences perception. For the sake of applicability of the results we therefore chose the keep to backrest the same for all participants.

Participants were seated on the office chair with their back centred on the back-rest. On the table directly in front of them was an arrow that could be rotated in the frontoparallel plane (Fig. 1D). The arrow was within easy reach and roughly at eye height. Participants wore blurring goggles to prevent them from reading the degrees on the protractor around the arrow. It was important that participants were aware which direction the arrow head was pointing. They could feel the arrow head, but due to the blurring goggles they couldn't clearly see the arrow head. Therefore, the arrow head was emphasised with a blue dot. To dampen the sounds of the vibration motors the participants wore noise-canceling head phones playing white noise.

In the 'Circle' condition the direction of 0° was represented by the most leftward motor switching on first followed by the most rightward motor switching on. This represents a line pointing from left to right and the participants rotated the arrow to match the direction of this line. In the 'Semi-circle condition the direction of 0° was represented by the motor in the left semi-circle switching on followed by the most rightward motor on this semi-circle. For 0° this second motor was positioned on the spine. Note also that in the 'Semi-circle' condition the first motor switching on was always the motor in the center of either the left or the right semi-circle. In the 'Circle' condition there was no motor present in the center of the circle.

C. Experimental Procedure and Design

All participants performed each of the two conditions. The order in which the conditions were performed was counter-balanced across participants. The conditions were performed in separate experimental sessions of 45 minutes with at least 2 hours between the sessions, but mostly they were performed on different days. Prior to the start of a session they performed a block of practice trials to become familiar with the task. During a practice block each direction was presented once in random order. These practice trials were also used to make sure that all vibrations were clearly perceivable for the participant. Participants were not aware of the spatial lay-out of the motors and the motors were obscured from view with a black sheet when they entered the room. Participants were instructed to sit with the spine centered on the backrest and the experimenter made sure that they complied with this instruction prior to the start of the experiment and that they maintained the same position throughout the experiment. The curved shape of the backrest of the chair also helped centering the spine on the center of the backrest. Participants were asked to lean comfortably against the backrest such that they could clearly perceive the vibrations. The curved shape wrapped around the back of the participants so that all vibration motors were pressed against the the back.

During a trial a motor was switched on for 1 s and after a break of 1 s the second motor was switched on for 1 s. After the second motor was switched off the participant was asked to match the perceived direction between the first and the second motor by rotating the arrow. The experimenter read off the setting on the protractor and entered it into the computer before starting the next trial. All directions (12 for the 'Circle' condition and 14 for the 'Semi-circle condition) were presented in random order within a block; all participants received 12 such blocks. Participants were not aware of these blocks of trials as there were no breaks in between blocks. The procedure and the directions that were presented were the same for both conditions. Note, however, that in the 'Semi-circle' condition 90° and 270° were presented twice as often as in the 'Circle' condition because they were presented on the left and on the right sides of the back. The position of the arrow was not changed between the end of a trial and the start of the next trial. Since the presented directions were randomized this resulted in random variation of the distance over which the arrow needed to be rotated across trials.

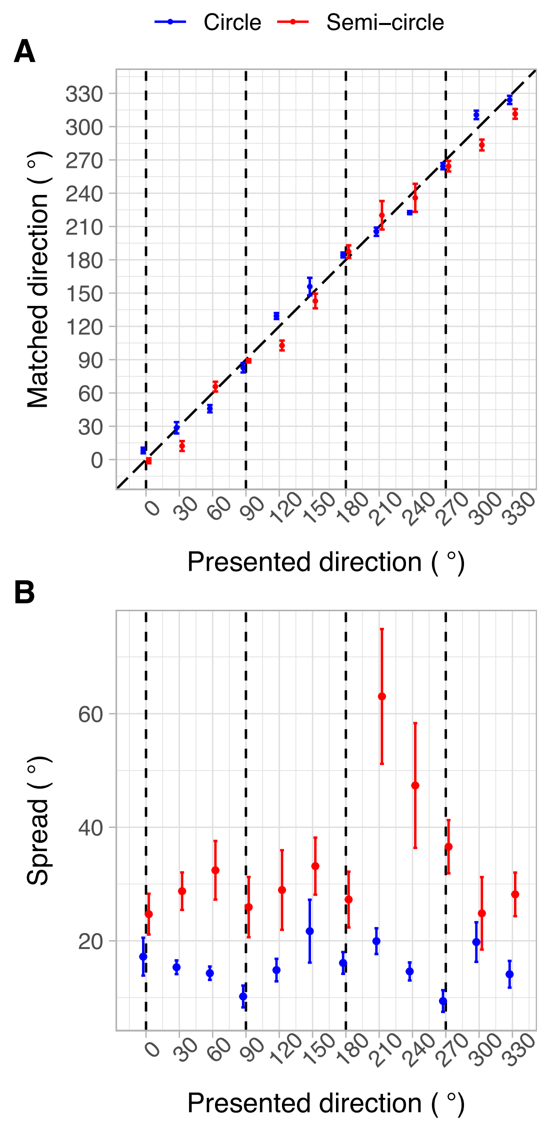

Fig. 2. Results as a function of the presented direction for both conditions. A) The responded direction averaged over participants. B) The spread (standard deviation) averaged over participants. The vertical dashed lines indicate the cardinal directions and the error bars indicate standard error of the mean. A small offset was introduced in the horizontal position to prevent overlap between the points.

III. Results

Due to technical difficulties sometimes the second motor did not switch on. Trials where this happened were excluded (less than 2% of all trials). Fig. 2A shows the matched directions as a function of the presented direction averaged over participants. It can be seen that for both conditions the data follows the unity line indicating that participants were able to perform the task. It can also be seen that some under- and over-estimations occurred. A graphical representation of the resulting deformation is shown in Fig. 3. It can be seen that there was a tendency for matched directions in the oblique case to be biased towards the horizontal in the 'Circle' condition. The cardinal directions were also somewhat deformed, with the matched vertical directions being tilted to the left or right and especially in the 'Semi-

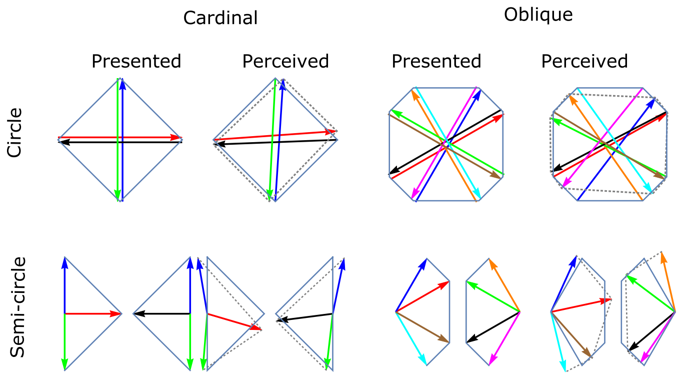

Fig. 3. Graphical representation of the presented and matched directions averaged over all participants for each direction. This is shown separately for the two conditions and cardinal/oblique directions. The solid grey lines indicate the veridical directions and the dashed grey lines indicate the perceived directions. The arrows pointing from the first vibration to the second vibration in the 'Circle' condition are shown for the presented case with a slight offset because otherwise the arrows would overlap.

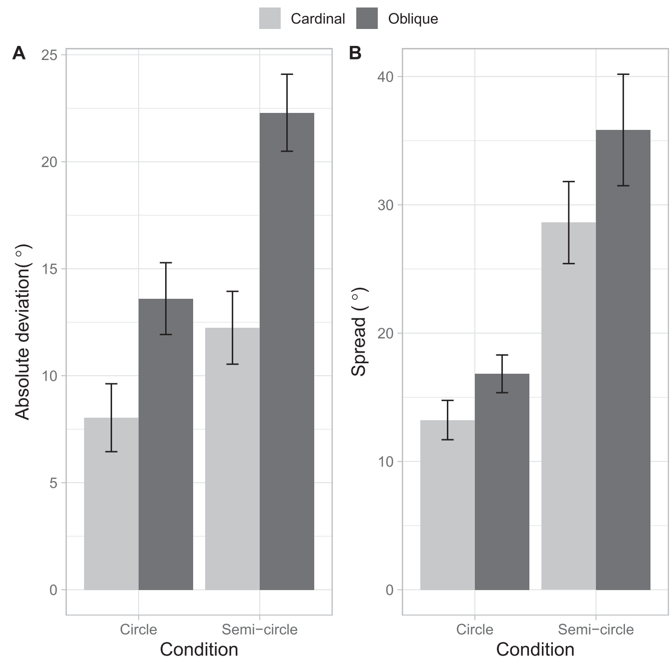

Fig. 4. Results averaged over cardinal and oblique directions. A) The absolute value of the deviation taken just before collapsing over cardinal and oblique directions for both conditions averaged over participants. B) The spread (standard deviation) averaged over participants. The error bars indicate the standard error of the mean.

circle' condition the matched horizontal directions were tilted downwards. Deformations appear to be smaller for the cardinal directions than for the oblique directions. This can also be seen in Fig. 2A in which responses appear to be closest to the unity line for cardinal directions (indicated with the blue vertical dashed lines). We used the spread as a measure of the precision of the matched direction shown in 2B. Here we calculated the standard deviation of the individual participants' responses for each direction and in each condition. These were then averaged over participants and the standard error was calculated. It can be seen that the standard deviation was systematically larger for the 'Semi-circle' condition than the 'Circle' condition.

To investigate a possible 'oblique effect' and whether there was an effect of condition, the data were aggregated over all directions for cardinal and oblique directions separately. We did this for the absolute deviation and the spread. We took the absolute deviation just before collapsing over all oblique and cardinal directions because the signed deviation might average out across the different directions. Fig. 4A shows the absolute deviation for both conditions and cardinal and oblique directions. The same is shown for the spread in Fig. 4B. Here the spread refers to the individual participant's standard deviation calculated per direction and condition. These values were subsequently averaged over all directions. It can be seen that the absolute deviation as well as the spread were larger for the 'Semi-circle' condition than the 'Circle' condition. Both the absolute deviation and spread were also larger for oblique directions than cardinal directions. To analyse possible effects we performed a 2x2 (Condition x Cardinal/Oblique) repeated measures ANOVA on the absolute deviations and on the spread. For the absolute deviation this analysis showed a main effect of Condition ($F(11,1) = 16.7, p = 0.002$) as well as for Cardinal/Oblique ($F(11,1) = 24.5, p = 0.0004$), but no interaction effect ($F(11,1) = 3.36, p = 0.09$). For the spread the ANOVA showed a main effect of Condition ($F(11,1) = 34.2, p = 0.0001$) and of Cardinal/Oblique ($F(11,1) = 7.1, p = 0.02$), while no interaction effect was found ($F(1,11) = 1.13, p = 0.3$).

IV. Conclusion

Our results show that two types of oblique effect occurred in both conditions. First, for the 'Circle' condition as well as for the 'Semi-circle' condition we found that the absolute deviations were smaller, i.e. the accuracy higher, for cardinal angles than for oblique angles. Second, we found for both conditions that the inter-trial spread was smaller, i.e. the precision higher, for cardinal angles than oblique angle. In a previous study in which we positioned the vibration motors in a circle around the spine with a vibration motor in the center on the spine, we also found that both types of oblique effect occurred [21]. That previous study was similar to the 'Circle' condition except that in the 'Circle' condition we didn't present a vibration on the spine in the center of the circle. The fact that oblique effects occurred in both cases shows that it was not necessary to present one of the two vibrations on an anchor point, in this case the spine, for these effect to occur. It could be that the fact that the line connecting two subsequent vibrations being centered on the spine could still lead to the spine to act as an anchor point and enabling oblique effects to occur. However, in the 'Semi-circle' condition the lines connecting the vibrations were not centered on the spine and also in this case both types of oblique effect occurred. This indicates that the oblique effects occur largely independent of the positioning of the vibrations with respect to a possible anchor point such as the spine.

Besides testing whether oblique effects occurred in both conditions, we also compared performance between both conditions. We found that there was a clear difference in the performance between the 'Circle' and 'Semi-circle' conditions. The absolute deviations were smaller in the 'Circle' condition than in the 'Semi-circle' condition. Furthermore, the spread was smaller in the 'Circle' condition than in the 'Semi-circle condition. There are several explanations possible for this difference. It could be due to the differences in the distance between the two points of vibration in the two conditions (18 cm in 'Circle' condition and 9 cm in the 'Semi-circle' condition). Vibrations that are located further apart might be easier to locate and therefore lead to higher precision and increased accuracy of the matched directions. This is related to the two-point threshold as it becomes difficult to distinguish the two vibrations when the distance between them is close to the two-point threshold. The two-point discrimination threshold for vibrotactile stimuli does depend on several factors such as the type of vibration motors [24], but also decreases with longer inter-stimulus onset asynchronicity (SOA) [25]. In a study that resembled our set-up most closely a two-point threshold of about 5.3 cm at an SOA of 0 ms and 2.8 cm at an SOA of 200 ms was found [25]. In the current study the onset asychronicity of the two vibrations was 1 s and in both conditions the distances were significantly larger than either of these values for the two-point threshold. Furthermore, in our previous study we used a circle centered around the spine with a center vibration and the distance between the two vibrations was 11 cm [21]. In that case we found a spread of $10.8 \pm 1.27(SEM)$ for cardinal directions and $16.8 \pm 1.30(SEM)$ for oblique directions. This is comparable to the spread in the 'Circle' condition (Cardinal: $13.2 \pm 1.53(SEM)$, Oblique: 16.8 ± 1.47 (SEM)) found in the current study where the distance between two vibrations was much larger (18 cm). This shows that the distance between the two vibrations between these two cases did not influence the perceptual performance much. In the 'Semi-circle' condition the distance between subsequent vibrations was smaller (9 cm), but still significantly larger than the two-point threshold. The absolute deviations for cardinal directions ($M = 9.4, SD = 6.2$) and oblique directions ($M = 20.2, SD = 5.5$) found in our previous study [21] are in between the absolute deviations that we found for the 'Circle' and 'Semi-circle' conditions of the current study.[1] were further apart in the 'Circle' condition of the current study than in our previous study made it easier to perform the task and thus task performance was influenced by the distance between subsequent vibrations. However, the positioning of the vibrations motors likely also has played a role as participants indicated that they found the 'Semi-circle' condition rather confusing.

An important difference between the two conditions is that in almost all directions presented in the 'Circle' condition the two subsequent vibrations were presented on opposite sides of the spine except for the vertical directions (90° and 270°) when both motors were located on the spine. In the 'Semi-circle' condition the subsequent vibrations were presented on the same side of the spine except for the horizontal direction (0° and 180°) for which one of the motors was located on the spine. In a previous study on distance perception, we have found that distances between vibrations on opposite sides of the spine feel larger than on the same side of the spine [16]. This could be due to the cortical separation between the left and right sides of the back. Possibly, this makes it easier to locate the two stimuli. Similarly, cortical separation might make it also easier to estimate the direction between two vibrations when they are on opposite sides of the spine such as in the 'Circle' condition or when one vibration is located at the spine like in our previous study on vibrotactile perception of orientation [21]. It could also be that the fact that distances between two vibrations are perceived to be larger when the vibrations are on opposite sides of the spine made it also easier to estimate the direction between two vibrations. When a vibration occurs directly on the spine bone conduction can occur which might influence perception. In our experiments bone conduction was very limited since only few trials included vibrations directly on the spine.

Apart from the oblique effect for absolute deviation we did not find clear systematic biases for the signed deviations. While biases occurred for the different directions, they were not clearly systematic. From visual inspection of Fig. 3 it seems that perception of oblique directions was biased towards the horizontal direction for the 'Circle' condition. This did not seem to be the case in the 'Semi-circle' condition. Biases in perceived directions will lead to deformations when a shape is being traced. Biases in perceived direction are not the only possible source of deformations in perceived shape. For instance, it has been shown that localisation of vibration is better in the horizontal direction than in the vertical direction [15]. Interestingly, we found in an earlier study that distances in the vertical direction felt longer than in the horizontal direction [16]. This is opposite to other studies finding that distances across the body width are perceived to be longer than along the body width for pressure stimuli [8]–[11]. However, a recent study using pressure stimulation to present distances on the back replicated our finding that distances presented in the vertical direction felt longer than in the horizontal direction when presented near the spine [26]. When distances were presented at the shoulder blade, however, they found the opposite effect. This shows that distance perception is inhomogeneous across the back. Our current study shows that perception of direction also tends to be inhomogeneous across the back, but not in a clearly systematic way.

The perception of direction has a clear relevance to navigation. Often vibratory belts are used in the context of navigation and the position of the vibration on the waist indicates, for instance, walking direction. The vibrations positioned in a circle on the back, like in the current study, could potentially be used in a similar way. However, these results are not only relevant for providing information about direction. As mentioned in the introduction, vibration can be used to trace shapes. Our results show that shapes will feel potentially compressed in the vertical direction. While tracing shapes on the back might remind most of us of a childhood game, it is also used as a way of communication by persons with a combination of vision and hearing loss. This is known as Social Haptic Communication (SHC) and is mostly used in the European Nordic countries. It was developed by Palmer and Lahtinen in the early nineties [27], [28]. Since then the number of countries in which a version of SHC has been introduced is increasing. Often it is used to give situational information such as the lay-out of a room, whether there is applause, or about emotions. We have recently shown that vibration patterns can be used to emulate SHC [29]. Experienced SHC users were able to link the vibration patterns to the intended sign, or haptice. Vibration could provide an opportunity to enable SHC over large distances, to send messages to multiple users at the same time or to even automate it. Therefore, it is important to advance understanding of how shapes that are traced using vibration are perceived.

[1] The values mentioned here are taken from the text of [21], the values shown in Fig. 5A of that paper are incorrect.

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