An advantage for horizontal motion direction discrimination

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Abstract

Discrimination performance is better for cardinal motion directions than for oblique ones, a phenomenon known as the oblique effect. In a first experiment of this paper, we tested the oblique effect for coarse motion direction discrimination and compared performance for the two cardinal and two diagonal motion directions.

Our results provide evidence for the oblique effect for coarse motion direction discrimination. Interestingly, the oblique effect was larger between horizontal and diagonal than between vertical and diagonal motion directions. In a second experiment, we assessed fine motion direction discrimination for horizontal and vertical motion. It has been suggested that differences in performance strongly depend on motion coherence. Therefore, we tested performance at predetermined motion coherences of 30%, 40%, 50%, 60% and 70%. Unsurprisingly, performance overall increased with increasing motion coherence and angular deviations between control and test stimulus. More importantly, however, we found an advantage for horizontal over vertical fine motion direction discrimination. Noteworthy is the large variability in performance across experimental conditions in both experiments, which highlights the importance of considering individual difference when assessing perceptual phenomena within large groups of naïve participants.

Keywords: motion direction discrimination, motion perception, oblique effect, horizontal motion

1. Introduction

Motion perception is an important visual ability that helps us to navigate through the environment, to recognise self and object motion, and that aids social interactions. Previous studies suggest that our visual system has adapted to the visual environment such that it shows a preference for stimuli that are more common or more relevant. For example, it has been shown that we are better at processing upright compared to inverted faces (Sekuler, Gaspar, Gold, & Bennett, 2004; Tanaka & Farah, 1993) and point-light walkers (Blake & Shiffrar, 2007; Pavlova, 2012; Pilz, Bennett, & Sekuler, 2010). In addition, different species, including monkeys and humans show a preference for looming compared to receding stimuli, which is thought to reflect their relevance to survival (Edwards & Badcock, 1993; Franconeri & Simons, 2003; Maier, Neuhoff, Logothetis, & Ghazanfar, 2004; Pilz, Vuong, Bülthoff, & Thornton, 2011; Schiff, Banka, & de Bordes Galdi, 1986).

A preference for relevant and common visual stimuli seems to extend to the most fundamental mechanisms of visual perception. For example, the perception of orientation in a variety of perceptual tasks is better for cardinal than for diagonal orientations (Appelle, 1972; Essock, 1980; Heeley, Buchanan-Smith, Cromwell, & Wright, 1997; Orban, Vandenbussche, & Vogels, 1984). This so-called oblique effect is thought to originate from a prevalence of cardinal contours in our visual environment (Coppola, Purves, McCoy, & Purves, 1998; Girshick, Landy, & Simoncelli, 2011). Previous studies support the hypothesis that orientation perception is based on visual experience (Annis & Frost, 1973; Gwiazda, Brill, Mohindra, & Held, 1978). Annis and Frost (1973), for example, investigated the oblique effect in two populations that grew up in different visual environments – the Cree, a group of First Nations from James Bay, Quebec, and city-raised Canadians. The authors measured visual acuity for discriminating horizontal, vertical, left oblique and right oblique gratings and found an oblique effect for city-raised Canadians but not the Cree. Annis and Frost (1973) explain their results by the differences in occurrence of orientations in the groups' visual environment. Whereas the Cree live in an environment without prominent visual contours, city-raised Canadians are predominantly exposed to cardinal orientations as found in carpentered environments (also see Fang, Bauer, Held, & Gwiazda, 1997; Timney & Muir, 1976). Gwiazda et al., (1978) used a preferential looking paradigm to measure spatial frequency thresholds for vertical and oblique gratings in infants ranging from 7-50 weeks of age. They found that preference thresholds were very similar for vertical and oblique gratings but increased more rapidly with age for vertical gratings. The above-mentioned studies strongly support the hypothesis that the prevalence of certain orientations in our visual environment has an influence on orientation perception. It is also reasonable to assume that neuronal mechanisms are influenced by the incoming visual information. Many previous neurophysiological studies in cats, for example, have found that the orientations within the visual environment affect the orientation of receptive fields of neurons in early visual areas (Barlow, 1975; Blakemore & Cooper, 1970; Hirsch & Spinelli, 1970), and it is assumed that even though some orientation-specific characteristics are present at birth (Hubel & Wiesel, 1963), they can be influenced by visual experience (Mitchell, 1978).

Neuronal preferences based on visual experience have also been observed for motion directions (Cynader, Berman, & Hein, 1975; Daw & Wyatt, 1976), and the oblique effect for motion directions (Dakin, Mareschal, & Bex, 2005; Gros, Blake, & Hiris, 1998) seems to follow similar reasoning as for orientations: the more common a motion direction is in the visual environment the better its discrimination (Dakin et al., 2005). Dakin et al., (2005) analysed the local statistics of natural movies for translational motion. Their finding that raw energy is more broadly distributed around oblique compared to cardinal motion directions supports the hypothesis that the oblique effect in motion direction discrimination is based on occurrences in the visual environment (note that effects for translational motion do not necessarily generalize to other motion types Edwards & Badcock, 1993).

In a recent paper, we extended the results on the oblique effect in motion direction discrimination to differences between the two cardinal motion directions. We assessed motion coherence thresholds for coarse motion direction discrimination in a comparatively large sample of older and younger adults (Pilz, Miller, & Agnew, 2017), and found higher motion coherence thresholds for vertical compared to horizontal motion. These results were unexpected and seemed surprising at first given that they had not been described before. However, previous studies assessing motion direction discrimination primarily tested relatively small samples of high-performing younger adults, which might have made it difficult to detect such subtle differences (Dakin et al., 2005; Gros et al., 1998).

A performance advantage for horizontal compared to vertical motion seems reasonable when taking into account other areas in vision research, for example, relating to attention or eye-movements. Within the attention literature, anisotropies between cardinal directions have long been reported in that attentional deployment is facilitated along the horizontal meridian (Carrasco, Talgar, & Cameron, 2001; Mackeben, 1999; Pilz, Roggeveen, Creighton, Bennett, & Sekuler, 2012). In addition, smooth pursuit is more accurate and stable for horizontally compared to vertically moving targets (Ke et al., 2013; Rottach et al., 1996), and gain as a function of stimulus velocity decreases faster for vertical than horizontal motion (Takahashi, Sakurai, & Kanzaki, 1978; van den Berg & Collewijn, 1988). It is possible that the preferences for information along the horizontal compared to the vertical meridian share common mechanisms that are potentially related to its relevance in our visual environment. In this paper, we investigated differences in coarse and fine motion direction discrimination in large samples of naïve younger participants. In a first experiment, participants were asked to discriminate four coarse motion directions. Vertical (up/down), horizontal (left/right), and two diagonal motion directions (lower right/upper left) and (upper right/lower left). Our results provided evidence for the oblique effect: participants had lower motion coherence thresholds for cardinal compared to diagonal motion directions. The oblique effect was more pronounced between horizontal and diagonal motion directions than between vertical and diagonal. Importantly, we found large individual differences in performance. Motion direction discrimination performance has been shown to improve with increasing motion coherence (Gros et al., 1998), and directional differences strongly depend on individual differences in motion coherence (Pilz et al., 2017). Therefore, in a second experiment, we systematically investigated the effect of coherence on performance for fine motion direction discrimination. Performance for horizontal and vertical fine motion direction discrimination were assessed at predefined levels of motion coherence in a between-subject design. In addition to improved performance with increasing coherence and angular deviation between control and test stimulus, our results showed a significant advantage for horizontal over vertical fine motion direction discrimination.

2. Experiment 1

2. 1 Methods

2.1.1 Participants

Twenty young adults (18-28 years, M = 20.32, SD = 2.2, 8 males) took part in the experiment. All participants were naive as to the purpose of the experiment and had normal or corrected-to-normal vision of 0.8 or above on an Early Treatment Diabetic Retinopathy Study (ETDRS) logarithmic vision chart. All participants were students of the University of Aberdeen and received two credit points for their participation as part of their curriculum. The experiment was approved by the local ethics committee and experiments were conducted in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). All participants gave written informed consent.

2.1.2 Apparatus

Experiments were conducted on an Apple Mac Mini (OS X; Apple, Inc., Cupertino, CA) using the PsychToolbox extensions (Brainard, 1997; Kleiner et al., 2007) for MATLAB (Mathworks, Natick, MA). Stimuli were presented on a 17-inch Viglen VL950T CRT monitor (Viglen Ltd., St. Albans, Hertfordshire, UK) with a refresh rate of 100 Hz (equivalent to 100 frames per second or fps) and a resolution of 1024 x 786 pixels. The apparatus was similar to other experiments used in our lab (Kerr-Gaffney, Hunt, & Pilz, 2016; Miller, Agnew, & Pilz, 2017; Pilz, Miller, & Agnew, 2017).

2.1.3 Stimuli

Stimuli were random-dot kinematograms (RDKs) similar to those described in Pilz et al., (2017) and Miller et al., (2017). RDKs were of a circular aperture of 9.4° visual angle with 100 dots moving at a speed of 5°/s. All dots had a size of 4 pixels and a limited lifetime of 200ms (equivalent to 20 frames). The dots were white and were presented on a black background. The lifetime and position of each dot was randomly allocated at the beginning of each trial. Once the lifetime of a dot elapsed, or the dot moved out of the stimulus region, it was placed at a random position within the aperture, and set to move in the same direction as before. Stimulus duration was set to 400ms while motion coherence thresholds were individually determined for each participant as described below. Participants were instructed to look at a fixation cross which was presented at the centre of the screen at the beginning of each trial.

2.1.4 Procedure

The Procedure was similar to Pilz et al., (2017). Participants were seated 60 cm from the screen and their head position was stabilized using a chin rest. The experiment consisted of four blocks of two steps each, one block each for horizontal (0°), vertical (90°), lower right (315°) and upper right (45°) motion. The order of blocks was counterbalanced across participants.

In the first step, we assessed whether participants were able to perform the task at a stimulus duration of 400ms and 100% motion coherence. Participants were asked to discriminate coarse motion direction on a standard QWERTY keyboard. For horizontal (left/right), upper right (upper right/lower left) and lower right motion (upper left/lower right), participants were asked to press ‘‘X’’ for left and ‘‘M’’ for right. For vertical (up/down) motion, participants were asked to press ‘‘*’’ for up and ‘‘+’’ for down. Participants performed one block of 20 trials. If accuracy was below 75% in the first block of trials, participants were asked to perform another block of 20 trials. All participants were able to perform above 75% correct within a maximum of two blocks of trials.

In the second step, we assessed the coherence level of each participant for horizontal, upper right, lower right and vertical coarse motion direction discrimination using the method of constant stimuli with 7 levels of motion coherence (5%, 10%, 25%, 40%, 55%, 70%, and 85%). The same task was used as described above. Participants completed 15 trials per coherence for each motion direction, and we fit a psychometric function to assess the 82.5% performance threshold for each participant. If a participant had a coherence threshold higher than 100% in one of the motion directions, a value of 100% was recorded. This was the case for one participants for the upper right condition and one participant for the lower right condition. Data from one participant had to be excluded, because the participant only performed the task for the two cardinal motion directions.

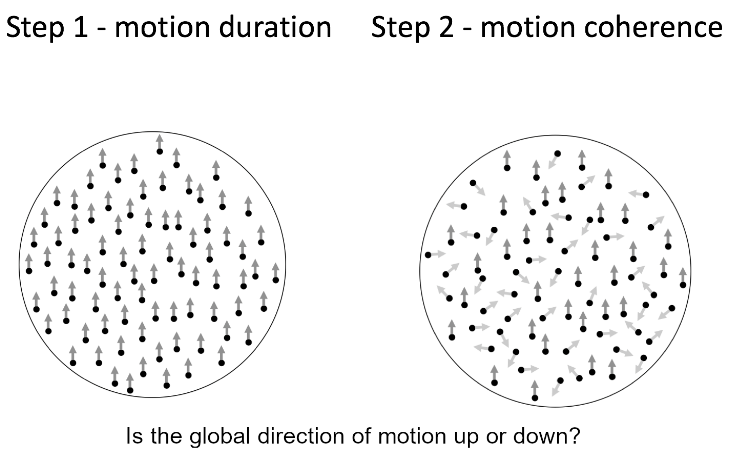

Figure 1. Example of stimuli and trial sequences for the two steps of the experiment for vertical motion. In step 1, coarse motion direction discrimination performance was assessed at a stimulus duration of 400ms and 100% motion coherence. In step 2, stimulus duration was 400ms and coherence thresholds were estimated for each participant individually. Participants had to determine the global direction of motion for one stimulus that appeared on the screen (Figure adapted from Pilz et al., 2017).

2.2 Results

Data were analysed using RStudio (RStudio Team, 2016) and JASP (JASP Team, 2019). Individual motion coherence was assessed by the method of constant stimuli. A within-subject design was adopted to assess thresholds for the two cardinal and the two oblique motion directions (Table 1). A repeated measures ANOVA on the 82.5% thresholds showed a main effect of motion direction, $F(3,54) = 8.126$, $p < 0.01$, $\eta_p^2 = 0.193$. This was supported by a Bayesian repeated measures ANOVA that provided strong evidence for the main effect of motion direction, $BF_{10} = 172.89$. Figures 2 and 3 highlight the large individual differences in performance within and between conditions.

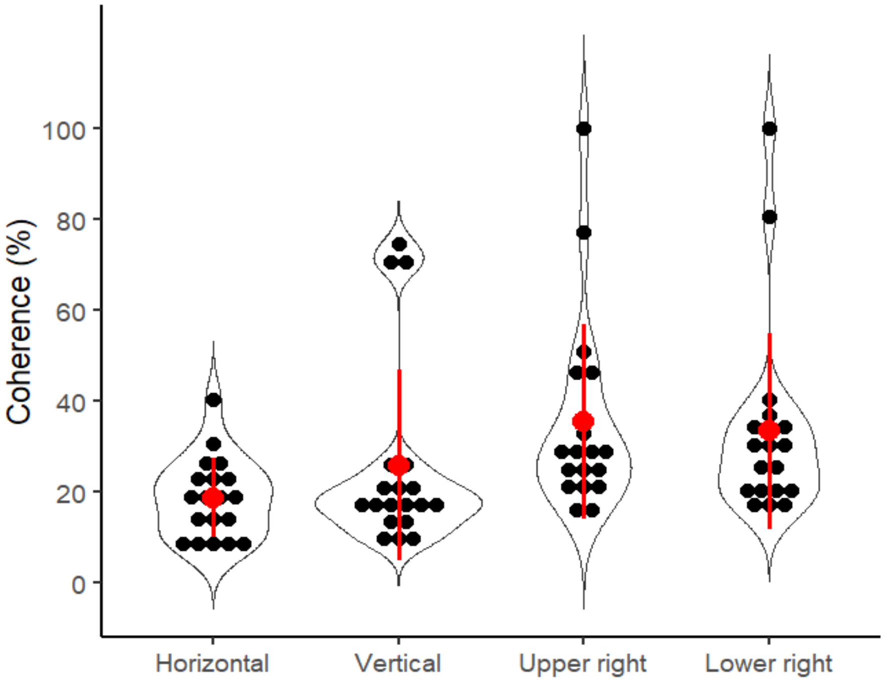

Figure 2. Violin plot of the motion coherence thresholds for horizontal (left/right), upper right (upper right/lower left), lower right (upper left/lower right) and vertical (up/ down) coarse motion direction discrimination with means (red dots) and standard deviations (red bars).

Table 1. Means (M), standard deviations (SD) and 95% bootstrapped confidence intervals (CI) for motion coherence for the four motion directions.

	M	**SD**	**CI**
Horizontal	18.7	8.68	14.91 – 22.53
Vertical	25.9	21.00	16.81 – 35.20
Upper right	35.55	21.47	26.36 – 44.60
Lower right	33.48	21.54	23.55 – 43.12

Post-hoc tests confirmed the oblique effect in that motion coherence was lower for cardinal compared to oblique motion directions (Table 2). There was no significant difference between the two oblique motion directions and between the two cardinal motion directions. Post-hoc tests were not controlled for multiple comparisons. Bayesian statistics indicate that evidence is strongest for the oblique effect being driven by horizontal thresholds, i.e., it is 14.23/47.21 times more likely that there is a difference between horizontal and lower-right/upper right than that there is none whereas it is only 2.72/2.58 times more likely that there is a difference between vertical and lower-right/upper right than that there is none. Only for the comparison between upper-right and lower-right evidence is in favour of the null hypothesis ($BF_{01} = 3.65$).

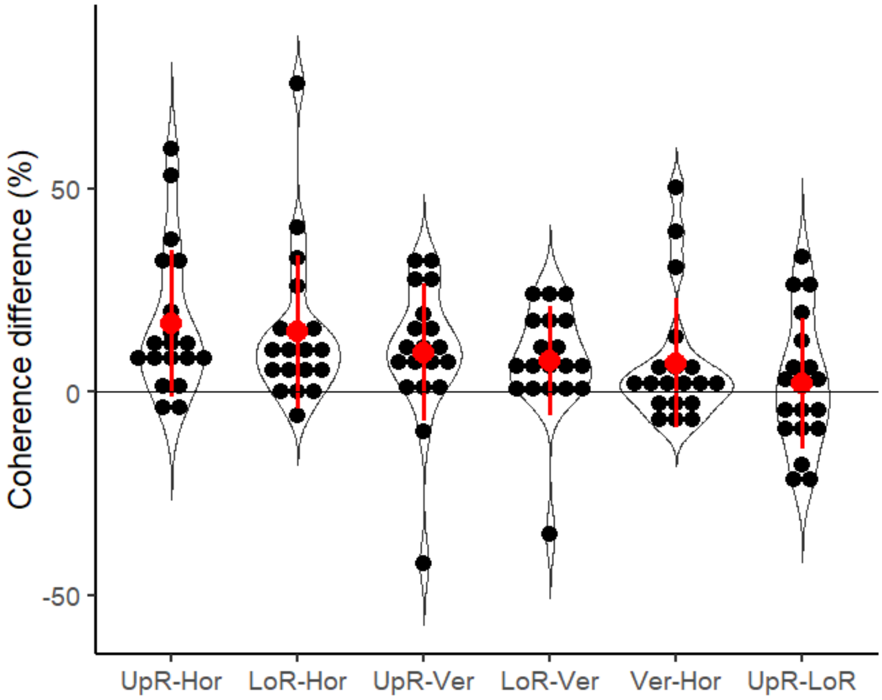

Figure 3. Violin plot of the difference in motion coherence thresholds between conditions (UpR = Upper right, Hor = Horizontal, Ver = Vertical, LoR = Lower right) with means (red dots) and standard deviations (red bars).

Table 2. Multiple comparisons between all conditions presenting t-test results, Bayes factor (BF_{10}) and 95% bootstrapped confidence intervals (CI).

Comparisons	T-test	BF_{10}	CI
Horizontal – upper right	$t(18) = 4.048, p<0.001$	47.21	8.66– 24.76
Horizontal – lower right	$t(18) = 3.423, p= 0.003$	14.23	5.37 – 21.31
Vertical – upper right	$t(18) = 2.506, p=0.022$	2.58	2.38 – 17.31
Vertical – lower right	$t(18) = 2.474, p=0.024$	2.72	1.46 – 13.82
Horizontal – vertical	$t(18) = 1.946, p = 0.067$	1.12	1.23 – 16.41
Lower right – upper right	$t(18) = 0.567, p= 0.578$	0.27	-4.9 – 9.19

2.3 Discussion

In this Experiment, we determined motion coherence thresholds for coarse motion direction discrimination for up/down, left/right, upper left/lower right, and upper right/lower left motion. Our results confirm the oblique effect in motion direction discrimination (Dakin et al., 2005; Gros et al., 1998). Interestingly, the oblique effect was more pronounced for horizontal compared to diagonal motion directions than for vertical compared to diagonal motion directions. In a previous study, we found a significant difference between horizontal and vertical coarse motion direction discrimination (Pilz et al., 2017). The results from this study, however, only provide weak evidence for such a difference. In contrast to the present study, Pilz et al., (2017) only tested vertical and horizontal motion in a larger sample of participants across two age groups, and it is likely that the difference between the cardinal conditions was mostly driven by the group of older participants and the absence of the diagonal conditions. Interestingly, however, Figures 2 and 3 indicate large individual differences within the group of participants that cannot be explained by general performance differences. To further investigate these performance differences, in Experiment 2, we assessed fine motion direction discrimination for cardinal motion directions only. Coarse motion direction discrimination assesses the ability to discriminate between opposite motion directions whereas fine motion direction discrimination refers to the ability to discriminate subtle differences between motion directions. Therefore, results from experiments on fine motion direction discrimination might allow us to draw conclusions with regards to differences in the tuning curves of neurons in primary visual cortex tuned to cardinal and oblique motion directions.

Previous studies assessing fine motion direction discrimination across a variety of different directions are scarce and often, performance is assessed based on a small number of highly trained participants. An initial study by Ball and Sekuler (1986) used a same/different task to investigate fine motion direction discrimination for two cardinal and one oblique direction. Overall, performance was better for the cardinal directions, which is in line with Gros et al., (1998) and Dakin et al., (2005). Fine motion direction discrimination seems to be heavily affected by motion coherence (Pilz et al., 2017; Gros et al., 1998). To assess the effect of motion coherence on fine motion direction discrimination we used predefined levels of 30%, 40%, 50%, 60% and 70% motion coherence in a between-subject design.

3. Experiment 2

3.1 Methods

3.1.1 Participants

Seventy-seven young adults (18-33 years, M = 21.08, 29 males) participated in the experiment. The same criteria as for the above experiment were applied. All participants were students of the University of Aberdeen and received either two credit points for their participation as part of their curriculum or 6£ reimbursement for their time.

3.1.2 Apparatus

The same apparatus was used as described in Experiment 1.

3.1.3 Stimuli

Stimuli were similar to the ones used in the previous experiment with the following differences: the random-dot kinematograms (RDKs) contained 150 dots with a size of 2 pixels, moving at a speed of 6.4/s, and motion coherence was predetermined for all participants at 30%, 40%, 50%, 60% or 70%.

3.1.4 Procedure

In this experiment, we investigated the effect of coherence on fine motion direction discrimination for horizontal and vertical motion. Two RDKs were presented successively, and participants were asked to indicate in which of the two RDKs the dots moved clockwise away from the control direction by pressing *1* if the first interval contained the target motion and *2* if the second interval contained the target motion. In one of the two RDKs, dots moved either horizontally (right, 0°) or vertically (up, 90°). In the other RDK, dots moved diagonally clockwise away from the control direction. The interstimulus-interval was set to 300ms. There were forty trials each for six angular deviations (3°, 6°, 9°, 12°, 24°, and 44°) that were randomly intermixed. Participants were seated 52 cm away from the screen and their head position was stabilized using a chin rest. Each participant performed two experimental blocks of trials, one block for horizontal and one for vertical motion (Figure 4). The order of blocks was counterbalanced across participants. Each block was preceded by a practice. In contrast to Experiment 1, coherence was fixed for all participants. Twelve participants performed the task at 70% coherence, thirteen participants at 60% coherence, eighteen participants each performed the task at 30% and 50% coherence, and sixteen participants performed the task at 40% coherence.

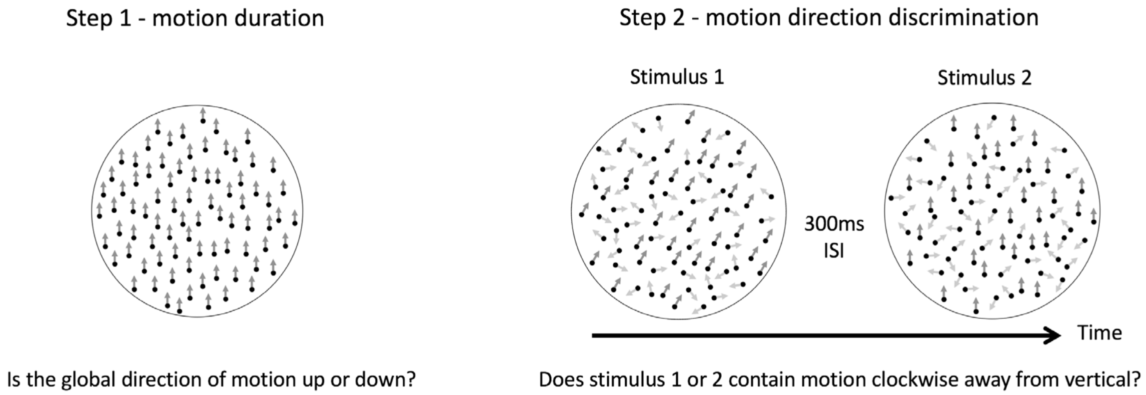

Figure 4. Example of stimuli and trial sequences for both steps of the experiment for vertical motion. In step 1, performance for coarse motion direction discrimination was assessed at a stimulus duration of 400 ms and 100% motion coherence. Participants had to determine the global direction of motion for one stimulus that appeared on the screen. In step 2, participants had to indicate which of two stimuli that appeared sequentially on the screen contained motion clockwise away from target motion (vertical, horizontal)(Figure adapted from Pilz et al., 2017)

The first step was a motion duration task identical to Experiment 1. This step ensured that participants were able to discriminate motion at the given stimulus duration and provided them with some training with regards to the stimulus. The second step was a motion direction discrimination task using a two- alternative forced-choice paradigm. Before each block, participants performed 20 practice trials for the given motion direction with 70% motion coherence and an angular difference of 45° between control and test stimulus. Trial-based feedback was provided only in the first step and the practice of step 2. Participants who performed below 60% accuracy in both conditions across all angular deviations during the main experiment were excluded from the analysis. Overall, seventeen out of seventy-seven participants were excluded from the analysis, resulting in a total sample of 60 participants. More specifically, seven participants were unable to perform the task at 30% coherence, two at 40%, five at 50%, two at 60% and one at 70%, which resulted in samples of eleven participants at 30%, fourteen at 40%, thirteen at 50%, eleven at 60% and eleven at 70% motion coherence.

3.2 Results

Data were analysed using RStudio (RStudio Team, 2016) and JASP (JASP Team, 2019). To assess the whole range of effects across all tested coherence levels, we performed a mixed design 5(coherence) x 2 (direction) x 6(angle) ANOVA on arcsine transformed data (Figure 5). The analysis revealed main effects of motion direction, angle and coherence (Table 3). Interactions were found between motion direction and angle (Figure 6) and angle and coherence. The interaction between direction and coherence (Figure 6), and the three-way interaction between direction, coherence and angle were not significant. In addition to common statistical methods, we also conducted a Bayesian mixed-design ANOVA. Comparing models containing the effect to equivalent models stripped of the effect, we found decisive evidence in favour of the models including the main effect of angle (BF_{10}>100, Table 3) and strong evidence in favour of the model including the main effects of coherence and motion direction (BF_{10}>30). Further, there was decisive evidence in favour of the interaction between motion direction and coherence and strong evidence in favour of the interaction between motion direction and angle. Figure 7 highlights the large variability in performance, in particular with regards to 50% coherence.

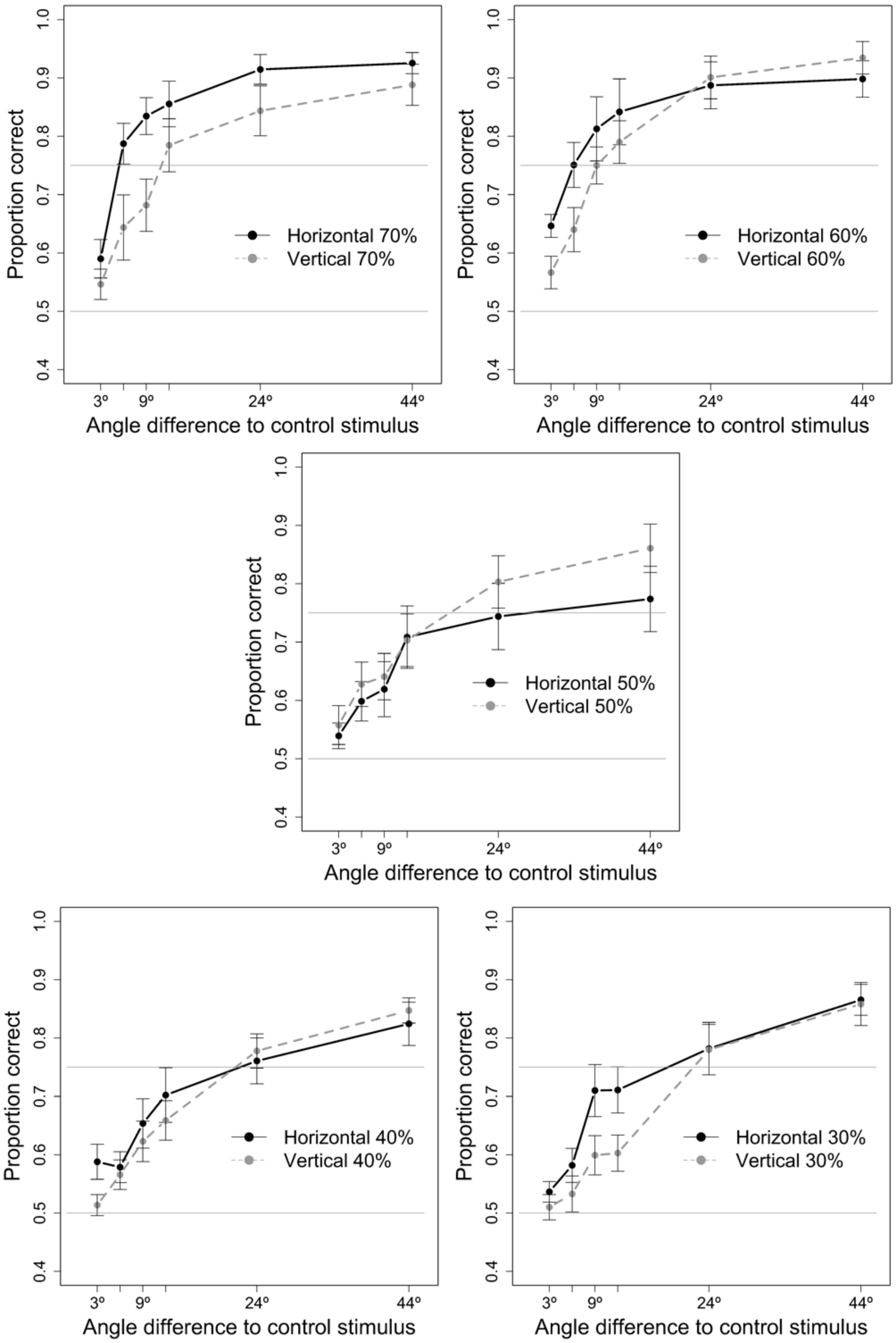

Figure 5: Direction discrimination performance for horizontal (black) and vertical (light grey) for 70% (upper left), 60% (upper right), 50% (middle), 40% (lower left) and 30% (lower right) coherences. Thin light gray lines indicate 0.75 and 0.5 proportion correct to facilitate comparison between plots. Error bars represent standard errors from the mean.

Table 3. Results for a standard mixed-design ANOVA (F-value and p-value), effect sizes (η_p^2) and a Bayesian mixed-design ANOVA ($BF_{inclusion}$).

Effects	F-value	η_p^2	$BF_{inclusion}$
motion direction	$F(1, 55) = 3.8, p = 0.055$	0.065	58.92
coherence	$F(4, 55) = 6.13, p < 0.05$*	0.3	70.84
angle	$F(5, 275) = 168.91, p < 0.001$**	0.75	$1.74 * 10^{91}$
motion direction x angle	$F(5, 275) = 6.187, p < 0.001$**	0.1	2.54
motion direction x coherence	$F(4, 55) = 1.38, p = 0.25$	0.09	161.71
angle x coherence	$F(20, 275) = 1.76, p < 0.05$*	0.11	0.056
motion direction x angle x coherence	$F(20, 275) = 0.84, p = 0.67$	0.06	0.005

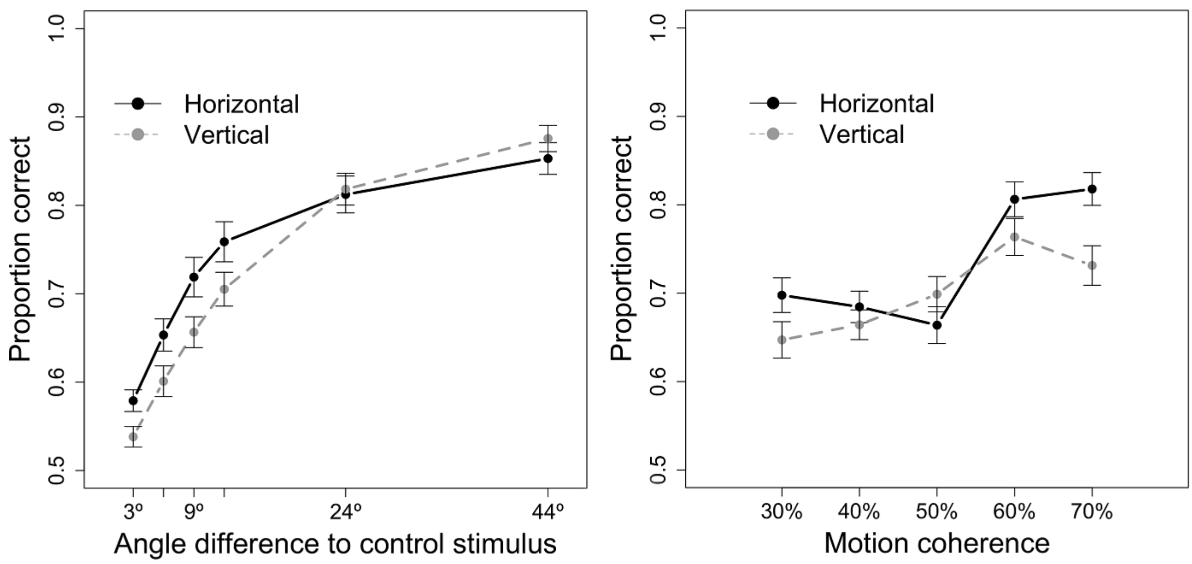

Figure 6. Left: interaction between motion direction and angle. Direction discrimination performance for horizontal (dark grey) and vertical (light grey) motion collapsed across coherences. Differences between motion directions are significant at 3°, 6°, 9° & 12°**.** Right: interaction between coherences and directions. Direction discrimination performance collapsed across angular difference between control and test stimulus. The interaction between coherence and motion direction is not significant.

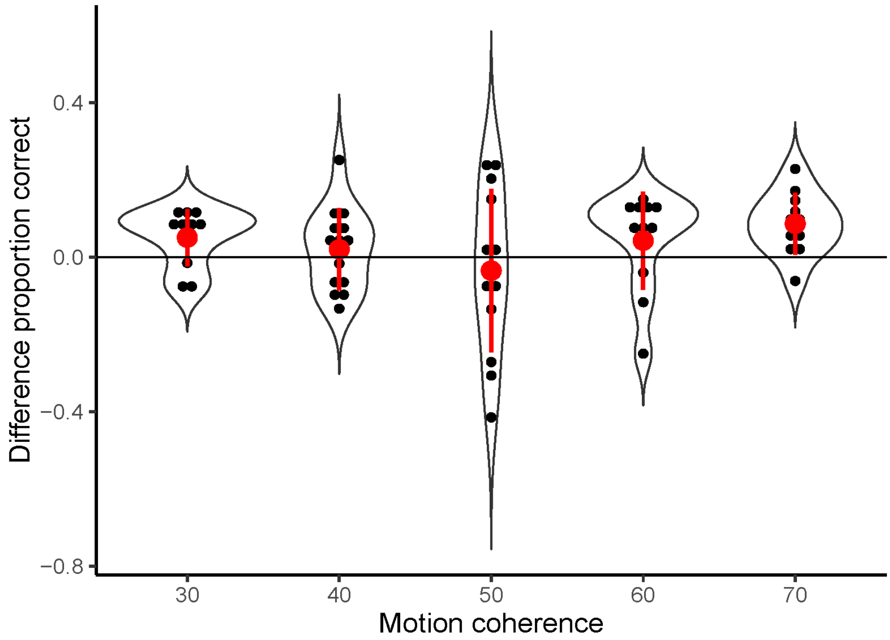

Figure 7: Violin plot highlighting the large variability in performance within and between groups with means (red dots) and standard deviations (red bars). Each dot represents one participant plotted as the difference in performance between horizontal and vertical for all coherences. Dots above the zero line indicate better performance for horizontal and dots below zero indicate better performance for vertical.

3.3 Discussion

In Experiment 2, we tested participants on horizontal and vertical fine motion direction discrimination using predefined motion coherence of 30%, 40%, 50%, 60% and 70%. Participants were better at discriminating motion away from horizontal than away from vertical, an advantage that was most pronounced at small angular deviations between target and test stimulus. These effects are supported by common and Bayesian analyses. Interestingly, Figures 5 and 6 indicate that a horizontal advantage is strongest at 30% and 70% motion coherence whereas there is a large variability in performance at 50%. The interaction between coherence and motion direction was not significant using standard statistical methods. However, using Bayesian statistics, evidence for a model containing the interaction compared to equivalent models stripped of the effect was strong. Individual data plotted in Figure 7 also highlights that most participants show an advantage in performance for horizontal motion for 30% and 70% coherence, whereas there is a large variability in performance for 50%. It is possible that participants have difficulties discriminating target from background motion at 50% coherence, an effect that has been observed in previous studies for contrast (Andersen, Müller, & Martinovic, 2012). However, given the between-subject design, it is also possible that effects are related to between-group differences unrelated to coherence, which needs to be addressed in future studies. To our knowledge, no other study has so far examined the differences in performance between horizontal and vertical motion direction discrimination across coherence levels with a large sample of participants. Gros et al., (1998) assessed performance across different coherence levels and found an increase in performance with an increase in coherence thresholds. However, they did not assess a potential interaction between motion direction and motion coherence.

Overall, the results show an increased performance for horizontal fine motion direction discrimination compared to vertical fine motion direction discrimination, an advantage that seems to depend on motion coherence. We will further discuss this phenomenon in the following section.

4. General Discussion

In two experiments, we investigated performance for coarse and fine motion direction discrimination. In Experiment 1, we assessed individual motion coherence thresholds for horizontal, vertical, upper right and lower right coarse motion direction discrimination. Overall, an oblique effect was found for motion coherence thresholds for coarse motion direction discrimination: performance was better for cardinal motion directions compared to oblique ones. Even though, the oblique effect was more pronounced between horizontal and diagonal motion directions than vertical and diagonal ones, a difference between horizontal and vertical motion direction discrimination, as described in a previous paper (Pilz et al., 2017), was not significant. It is possible that the group of older adults included in the previous paper drove the effect. Experiment 2 investigated possible differences between horizontal and vertical fine motion direction discrimination with predefined motion coherences. Results support a horizontal advantage, which is particularly pronounced at small angular deviations between control and test stimulus and seems to depend on motion coherence. It is possible that previous studies did not report differences between horizontal and vertical motion direction discrimination, because those are generally smaller and more difficult to assess in small high-performing groups of young participants than differences between cardinal and diagonal axes of motion (Andrews & Schluppeck, 2000; Dakin et al., 2005; Gros et al., 1998). The oblique effect in orientation discrimination has been well-studied (Appelle, 1972; Furmanski & Engel, 2000; Heeley et al., 1997; Nasr & Tootell, 2012; Orban et al., 1984), and it is thought that is based on a prevalence of cardinal contours in our visual environment (Annis & Frost, 1973; Coppola et al., 1998; Girshick et al., 2011). It has also been found that more neurons are tuned to cardinal compared to oblique orientations (Li, Peterson, & Freeman, 2003), and early visual areas show increased responses to cardinal orientations (Furmanski & Engel, 2000). Those studies provide a reasonable approach to understanding the neural mechanisms underlying the oblique effect. It is thought that similar mechanisms provide the basis for the oblique effect in both orientation and motion direction discrimination (Dakin et al., 2005). However, as already mentioned above, studies assessing the neural mechanisms related to the oblique effect in motion perception are relatively sparse. In addition to differences between cardinal and oblique orientations, also a performance difference between the two cardinal orientations has been described. Interestingly, however, the so called 'horizontal effect' shows the opposite from the results described in this paper – better performance for oblique and vertical compared to horizontal orientations for high-contrast stimuli presented in noise (Essock, DeFord, Hansen, & Sinai, 2003; Hansen & Essock, 2004; Maloney & Clifford, 2015; Wilson, Loffler, Wilkinson, & Thistlethwaite, 2001). The horizontal effect seems to contradict previous studies on the oblique effect. In particular, an evolutionary explanation of the horizontal effect supports that the visual system suppresses the stimuli that are oriented in the most common meridians in the environment, i.e. horizontal, in order for new and information to become more salient. However, it is argued that both effects are based on similar mechanisms – an overrepresentation of horizontal contours in the visual environment. But whereas performance increases for simple horizontal line or grating stimuli, a mechanism that compensates for the overrepresentation of horizontal contours in our visual environment takes effect when such stimuli are presented in noise (Essock et al., 2003; Hansen & Essock, 2004). The horizontal effect, to our knowledge, has not been described for motion stimuli. Therefore, it is difficult to directly relate our results to this effect. Interestingly, however, most behavioural studies on the horizontal effect use detection rather than discrimination tasks, whereas our results and many other prominent studies on the oblique effect for motion or orientation are based on stimulus discrimination. Therefore, it is also possible that the difference between an impairment or enhancement of horizontal orientations and motion directions is based on the differences between the tasks per se: performance in simple detection tasks are often faster and more accurate than discrimination, for which participants have to compare the stimulus properties to those of an internal representation or another simultaneously presented stimulus (Klein, 2000; Pilz et al., 2012). It is, for example, possible that at early stages of orientation processing, the visual system compensates for the occurrence of more common visual orientations, whereas at later stages, the processing of common orientations is enhanced.

It is difficult to draw more direct conclusions between the horizontal effect in orientation discrimination and our results, and in order to understand whether an enhancement or impairment in processing certain orientations or motion directions reflects specific properties of different stages of processing, future studies are needed.

Important to mention at this point is the large variability in performance across both experiments from this paper. Individual differences in performance are often observed when assessing naïve participants in basic visual tasks such as contrast, colour, motion or orientation perception (Billino & Pilz, 2019; Pilz, Zimmermann, Scholz, & Herzog, 2013; Pilz et al., 2017), and extend to visual attention (Pilz et al., 2012) and the processing of visual illusions (Grzeczkowski, Clarke, Francis, Mast, & Herzog, 2017). Such heterogeneity suggests that visual perception is highly specific and highlights the importance of considering data from individual participants in addition to commonly used statistical methods.

To conclude, our results replicate the oblique effect in coarse motion direction discrimination. More importantly, we find advantages for processing horizontal over vertical motion. Similar to the oblique effect, these results are likely due to a processing hierarchy that is related to the relevance and predominance of certain stimuli in our visual environment. However, future studies are necessary to fully understand the mechanisms underlying the horizontal advantage as described in this study and the large individual differences in performance.

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