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副尺間隔検出における配置の非対称性：刺激方位にわたる一般的事実

人間社会環境研究科　人間社会環境学専攻
A.K.M. レザウル コリム
人間社会研究域人間科学系准教授
小 島 治 幸

Configurational Asymmetry in Vernier Offset Detection : A Generalized Fact across the Stimulus Orientation

A. K. M. Rezaul Karim & Haruyuki Kojima

要旨

我々の先行研究では副尺視力を垂直水平の基本方位において調べた。その結果，副尺視力は，副尺同士の相対的位置，すなわち一方が他方の左にズレているか右にズレているか、あるいはそれらが上または下にズレているかといった２つの副尺の関係性に依存することを示した(Karim & Kojima, 2008)。本研究ではその現象の一般性を斜方位において検討した。実験１では水平より＋45度の方位（時計の針が10時23分の時のような）において，観察者は右側の副尺が下で左側の副尺が上に布置された条件での方が，その逆の条件のときよりも位置ズレ弁別の成績が良かった。実験２では－45度の方位（同７時13分）において副尺視力が測定されたが，右手の副尺が左手の副尺より右手にズレている場合にその逆の場合よりも成績が良かった。この成績の非対称性は両方位において一貫しており、学習によっても消去しなかった。これは視覚システムが対称の布置に選択的な情報処理を行っている可能性を示唆している。

キーワード

布置，非対称性，副尺，ズレ，斜方位

Abstract

Our previous study has demonstrated that in the cardinal orientation, offset detection depends on the relative position of the vernier bars, i.e., how the left and right or upper and lower vernier bars are displaced from each other in space (Karim & Kojima, 2008). The current study examined whether the fact can be generalized to the oblique orientation. Experiment 1 demonstrated that for a pair of vernier bars, one displaced from the other and arranged side-by-side with a large gap at +45° orientation from the horizontal (tilted clockwise such as 10 : 23), observers were, on average, somewhat better at discriminating an offset if the relative position of the lower right-hand bar was to the right of the upper left-hand bar than vice versa. A similar asymmetry was evident in Experiment 2, where observers judged vernier offset for a pair of bars at −45° orientation from the horizontal (such as 7 : 13). In that case, average acuity was significantly better when the relative position of the upper right-hand bar was to the right of the lower left-hand bar than the opposite. The asymmetries in performance were consistent across the two orientations and did not diminish with learning, thus indicating possibly configuration-selective neural processing of the vernier stimulus.

Key Words
Configuration ; asymmetry ; vernier ; offset ; oblique orientation

1. Introduction

Visual perceptual task sometimes requires analysis of the spatial features of a visual scene. Our spatial analytic skill is of great importance because the way we perceive space and position of objects within that space can affect our gross motor skills. For example, good visual acuity is crucial for skilled performance in spatially complex task like surgical procedures. Our performance or mastery of analysis is determined by a number of factors, one of the most dramatic being the stimulus or image orientation (Furmanski & Engel, 2000 ; Mustillo, Francis, Oross, Fox, & Orban, 1988 ; Saarinen & Levi, 1995b ; Skrandies, Jedynak, & Fahle, 2001). In addition, scientists have reported various asymmetries in the way the upper and lower or left and right sides of space are perceived and represented. For example, several studies demonstrated top-left lighting preference in 3D shape perception (Elias & Robinson, 2005 ; Gerardin, de Montalembert, & Mamassian, 2007 ; Mamassian & Goutcher, 2001 ; Sun & Perona, 1998).There is also evidence that such preference can be modified by visual-haptic training (Adams, Graf, & Ernst, 2004). Similarly, Champion and Adams (2007) demonstrated an after training reduced asymmetry between visual search performance with convex and concave distracters, suggesting a modification of the convexity prior. Thus, perceptual asymmetries can be modified by visual experience or learning.

In a recent study, we (Karim & Kojima, 2008) demonstrated that for a pair of horizontal bars arranged side-by-side with a large gap, observers were, on average better at discriminating a vertical offset if the right-hand bar was below the left-hand bar (Fig.1b ; horizontal) than vice versa (Fig.1a ; horizontal).We observed a similar kind of asymmetry when observers judged horizontal offset for a pair of vertically oriented bars one above the other. That is, performance was better when the upper bar was to the right of the lower bar (Fig.1b ; vertical) than the opposite (Fig.1a ; vertical). In consistent with the past studies (Adams et al., 2004 ; Champion & Adams, 2007), we also showed that the asymmetry reduced more or less as a function of training.

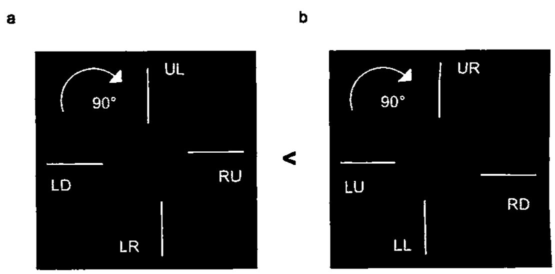

Fig.1. Schematic of the configurational differences in vernier acuity reported in a previous study (Source : Karim & Kojima, 2008). (a) 0° and 90° oriented vernier configurations in which average acuity was worse. (b) 0° and 90° oriented vernier configurations in which average acuity was better.

The demonstration of this surprising fact motivated us to carry out the present study with a two-fold purpose : to see (1) whether the asymmetric response property of the visual system can be generalized to the oblique orientation and (2) whether the response property can be shaped by learning. We conducted two experiments using line vernier stimuli at +45° and −45° orientations respectively and demonstrated that the effect can be generalized to these orientations. We suggest that the configuration preference in vernier offset detection might be a universal property of the cortical neurons at any stimulus orientation. However, unlike the previous study (Karim & Kojima, 2008) we did not see here any diminishing trend of the preference with training, thus indicating a cardinal-oblique difference in response to training and suggesting a necessity of more training at the oblique orientation.

2. Experiment 1: detecting vernier offset at +45° orientation

2.1. Method

2.1.1. Observers

Eight paid undergraduate students of normal or corrected to normal vision participated in this experiment. All observers were naïve to the experimental purpose and did not have any history of psychophysiological or neurological illness.

2.1.2. Stimuli and apparatus

Vernier stimuli, each comprising of two light bars either aligned or misaligned at +45° orientation, were generated using Borland C++ Builder 6. The offset sizes of the misaligned verniers were ±30, ±90, ±150, ±210 and ±270 arcsecs. One of the bars was constant and another one was displaced to the right (−) or left (+). The stimuli were white in color against a black background, with a feature separation of 15 arcmin (Fig.2). The width and length of each bar was 0.5 and 15 arcmins respectively. The luminance of the stimulus and background were measured by a luminance meter (TOPCON BM-3). The Michelson contrast of each stimulus was 0.98 (L_{max}=90.43 cd/m^2; L_{min}=0.81cd/m^2). For displaying the stimuli we used a 55 cm color monitor (Eizo, FlexScan T 962) of 1280x1024 pixels and 85Hz with a high speed graphic card (3 Dlabs Wildcat III 6110). From a viewing distance of 1.82 meters the angular resolution of each pixel was 30 arcsec.

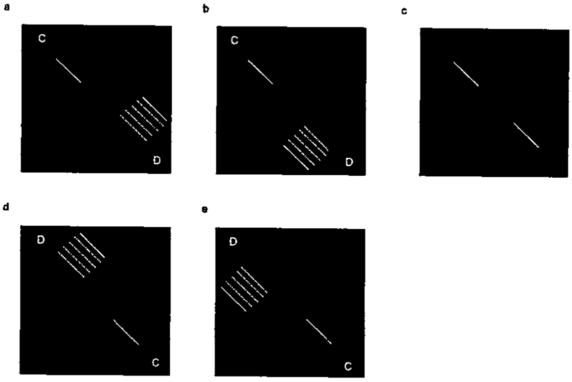

Fig.2. Schematic of the vernier stimuli used in Exp.1. "C" and "D" in the images refer to the Constant and Displaced bars respectively. (a) Stimuli with rightward offset of the lower right-hand bar, (b) Stimuli with leftward offset of the lower right-hand bar, (c) Stimulus with null-offset, (d) Stimuli with rightward offset of the upper left-hand bar, (e) Stimuli with leftward offset of the upper left-hand bar. Vernier separation is defined as the parallel distance between the endpoints of the upper left-hand and lower right-hand bars and vernier offset is defined in arc sec as the perpendicular distance between them. The dotted lines indicate the approximate positions of the displaced bar with different offset sizes.

2.1.3. Procedures

At the beginning, observers took a few practice trials to get some practical knowledge of how to respond with a keyboard. Then they were run in two experimental sessions using the method of constant stimuli. In one session, we presented the 5 possible vernier stimuli of rightward offset (−) and 5 aligned (null-offset) verniers in random order each one repeating 80 times, with stimulus duration of 100 ms and response stimulus interval of 1000 ms, at the centre of the visual field. Similarly, in another session we presented the 5 possible stimuli of leftward offset (+) and the aligned ones. The order of the two sessions was counterbalanced between the training days and between the observers. Observers in a dark room viewed the stimuli binocularly using a chin and forehead rest from a distance said above. Because there was no additional fixation point as to avoid unwanted positional cues available from that point, we asked observers to always attend to the gap between the vernier features while responding. They indicated by a key press (F or J) whether the features were aligned or misaligned, where incorrect responses were followed by an auditory feedback. The two response keys were counterbalanced between the observers.

The experiment was continued for 6 days each day covering 1600 trials in total (800 in each session). A half of the observers were introduced to stimuli with the lower right bar being displaced rightward or leftward (Fig.2a,b) and the remaining half with the upper left bar being displaced in either direction (Fig. 2d,e). From the point of intersection of the two axes (0, 0), the constant bar was always at the same distance across the left-upper and right-lower visual fields. However, observers were not informed of which bar would be constant and which one be displaced (a situation of spatial uncertainty).

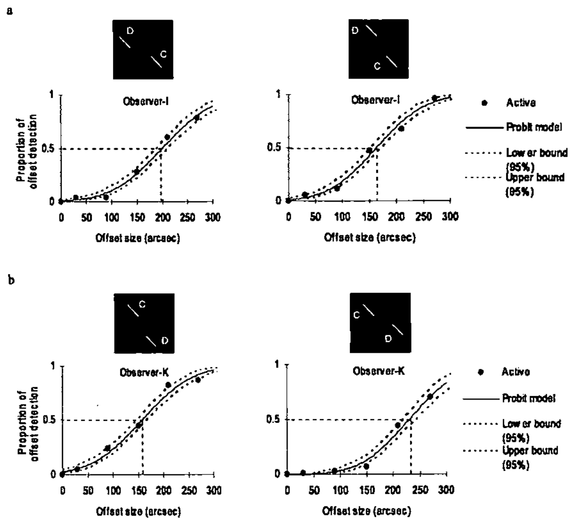

Fig.3. Psychometric functions of two typical observers in a single training day in Exp.1. "C" and "D" in the vernier images refer to the Constant and Displaced bars respectively. (a) Psychometric functions of observer-I for the leftward (left panel) and rightward (right panel) displacements of the upper left-hand bar. (b) Psychometric functions of observer-K for the leftward (left panel) and rightward (right panel) displacements of the lower right-hand bar.

2.1.4. Data processing and statistical analysis

We calculated in each session the proportion of correct offset detection at each offset and the proportion of false detection (i.e., detection of a null-offset vernier as an offset one). The proportions of false detection were used to determine rightward or leftward response biases. The data in the rightward and leftward displacements were separately fitted by probit model (using XLSTAT; Addinosoft USA), with the exclusion of subjective response biases where necessary. According to Yes/No paradigm, thresholds were calculated at 50% correct detection of the vernier misalignment. Fig.3 displays the psychometric functions of two typical observers, one in the upper left bar (a) and another in the lower right bar (b) displacement scenarios, in a single training day.

We analyzed the response bias data in one sample t-test, and threshold data in matched sample t-test (for individual observers) and in repeated measures ANOVA (for group) followed by post-hoc LSD test where appropriate. For repeated measures ANOVA we used the Greenhouse-Geisser correction if a factor had more than two levels. This corrects for possible violation of the sphericity assumption in repeated measures data. For such correction, the parameter ε is estimated as $0 < \varepsilon_{min} \leq \varepsilon \leq 1$, which is used to adjust the degrees of freedom of the F distribution. If $\varepsilon = 1$, no violation of sphericity was detected and the Greenhouse–Geisser correction has no effect. If $\varepsilon < 1$, the resulting test is more conservative than if no correction was applied (de Grave, Franz, & Gegenfurtner, 2006; Greenhouse & Geisser, 1959; Jennings, 1987; Vasey & Thayer, 1987).

2.2. Results and discussion

2.2.1. Response bias

If observers were biased toward a particular vernier configuration against another (i.e., if bias distribution was not uniform in the two configurations), the percentage of error responses to the null-offset vernier would be ultimately higher in the session of that configuration as compared to the session of the counter configuration. So, we purposively used a very simple technique to calculate their relative response biases. First, we calculated in each day the proportions of error responses for each observer in the aligned (null-offset) vernier introduced independently in the two misaligned situations (rightward and leftward). Then we determined rightward or leftward response biases using equation 1. This technique would at least give information if the response bias was uniformly distributed in the two configurations. If it was not uniform, we would exclude the bias on day-by-day basis for individual observers.

$$\text{Response Bias} = (E_r - E_l) \times 100 \qquad (1)$$

Where, E_r and E_l represent in each day the proportions of error responses to the aligned vernier introduced in the rightward and leftward offset sessions respectively. Then for each observer we averaged the response biases over the training days. The average response bias score could, therefore, range between -100 and $+100$, with negative and positive values reflecting leftward and rightward biases respectively. A score approaching zero indicates no response bias.

Fig.4.1 shows mean subjective response biases calculated over all training days (left panels) and mean daily response biases for the two observer groups (right panels). The left panels indicate that response biases were rightward for O3, O4 and O5 (+scores) and leftward for other observers (−scores). When subjected to a series of one sample t-test we found that average response bias scores were significantly different from zero for O2 ($t_{(5)}=-6.217$, $p=.002$) and O6 ($t_{(5)}=-2.572$, $p=.040$) only. So, before fitting psychometric functions for determining offset detection thresholds we excluded on day-by-day basis the response biases for these two observers only.

As shown in the right panels, the mean daily response bias scores for the two observer groups were

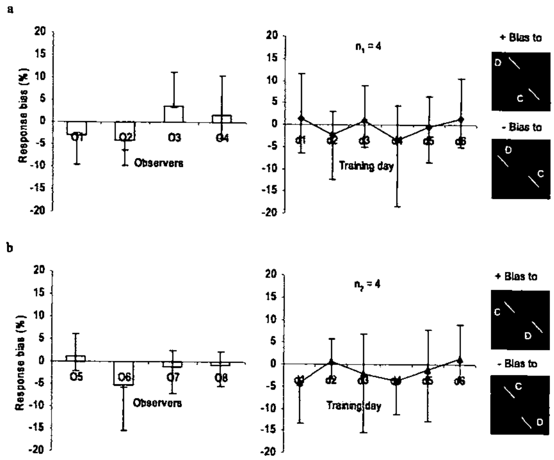

Fig.4.1. Response biases (Mean ± CIs) in Exp.1. (a) Percent biases in the upper left bar displacement; Left panel - subjective biases of 4 observers; Right panel - mean daily biases of the group. (b) Percent biases in the lower right bar displacement; Left panel - subjective biases of other 4 observers; Right panel - mean daily biases of the group. "C" and "D" in the vernier images refer to the Constant and Displaced bars respectively. The positive(+) and negative(-) values indicate biases to rightward and leftward offsets respectively. Error bars reflect 95% confidence intervals (CIs) of the mean differences.

not significantly different from zero both in the upper left (Fig.4.1a ; $t_{(3)}=.466$, $p=.673$ in d1 ; $t_{(3)}=-.992$, $p=.394$ in d2 ; $t_{(3)}=.450$, $p=.684$ in d3 ; $t_{(3)}=-.981$, $p=.399$ in d4 ; $t_{(3)}=-.214$, $p=.844$ in d5 and $t_{(3)}=.555$, $p=.618$ in d6) ; and in the lower right bar (Fig.4.1b ; $t_{(3)}=-2.481$, $p=.089$ in d1 ; $t_{(3)}=.436$, $p=.692$ in d2 ; $t_{(3)}=-.612$, $p=.584$ in d3 ; $t_{(3)}=-3.151$, $p=.051$ in d4; $t_{(3)}=-.387$, $p=.725$ in d5 and $t_{(3)}=.671$, $p=.550$ in d6) displacement scenarios. The right panels also indicate that mean daily response biases (whatever the degree) for the two groups were more or less random across the training days rather than indicating that it reduced with training.

2.2.2. Offset direction, spatial configuration and training effects

Fig.4.2a,b displays daily offset detection thresholds for individual observers and corresponding aggregates of the two groups who experienced stimuli with the upper left and lower right bar displacements respectively. A series of matched sample t-test applied to the individual data demonstrated that two (O1 and O2) of the four observers experiencing the upper left bar displacement (Fig.4.2a) had significantly lower thresholds if the offset was rightward ($t_{(5)}=2.842$, p=.036 for O1 ; $t_{(5)}=8.252$, p=.000 for O2) and two (O6 and O7) of the four observers experiencing the lower right bar displacement (Fig.4.2 b) had significantly lower thresholds if the offset was leftward ($t_{(5)}=-2.686$, p=.044for O6 ; and $t_{(5)}=-3.773$, p=.013 for O7). Other observers of the two groups did not show any asymmetry of this kind. However, the line graphs of aggregated data for the two groups show that average thresholds were lower when the upper left bar was displaced to the right (Fig.4.2a ; right most last panel) and the lower right bar was displaced to the left as compared to the counter-displacements (Fig.4.2b ; right most last panel). Though the differences were non-significant in both the upper left bar ($F_{(1,3)}=3.639$, p=.152) and the lower right bar ($F_{(1,3)}=.825$, p=.431) displacements, the trends were configurationally identical irrespective of which bar was displaced. This led us to plot the grand average by configuration (Fig.4.2d) in addition with plotting by offset direction (Fig.4.2c) taking training as a common factor.

In order to see the effects of different factors first, we analyzed all observers' threshold data in two-way repeated measures ANOVA with offset direction and training as within-subjects factors. The sphericity assumption was violated for training factor and interaction, so the Greenhouse-Geisser correction was applied. It revealed that the main effect of training was significant (Greenhouse-Geisser corrected $F_{(2.244, 15.706)}=4.605$, ε=.449, p=.024) but, not the effect of offset direction ($F_{(1,7)}=.514$, p=.497) and interaction between the two factors (Greenhouse-Geisser corrected $F_{(2.049, 14.342)}=1.261$, ε=.410, p=.314). Then we analyzed the data by the same statistical procedures considering configuration and training as within-subjects factors and found that the main effect of configuration was fairly large ($F_{(1,7)}=4.324$, p=.076) and that of training was significant (Greenhouse-Geisser corrected $F_{(2.244, 15.706)}=4.605$, ε=.449, p=.024) but, not the effect of interaction between the two factors (Greenhouse-Geisser corrected $F_{(2.151, 15.058)}=1.500$, ε=.430, p=.255). A further analysis of the training effect done by post hoc LSD test revealed that mean threshold was significantly lower in the 5th (M=177.939, SE=6.957) than in the 1st (M=203.680, SE=10.431) day of training (p=.028). This improvement was maintained at the 6th (M=177.503, SE=7.226, p=.006) day follow-up.

Finally, we examined configurational differences in the pre- and post-training. We considered 1st day's training as pre-training and 6th (last) day's training as post-training. The pre-training mean threshold difference between the two configurations was more than 4 arcsec (SE=13.98) and the post-training difference was more than 26 arcsec (SE=7.57) (Fig.4.2d). Matched sample t-test revealed that pre-training mean difference was non-significant ($t_{(7)}=.311$, p=.765) but, the post training difference was significant $t_{(7)}=3.504$, p=.010). The post–training higher mean difference was unexpected ; however, it was not significantly different from the pre-training mean difference.

To summarize, we found for two observers significant response biases toward a particular vernier configuration against its counterpart. When excluded their response biases on day-by-day basis before calculating thresholds, we found that the main effect of configuration was nearly significant but, not the effect of offset direction on vernier acuity. That is, irrespective of the upper left and lower right bar displacements average vernier acuity was fairly better when the relative position of the Upper Left bar was to the Right of the Lower Right bar (ULR-LRL con-

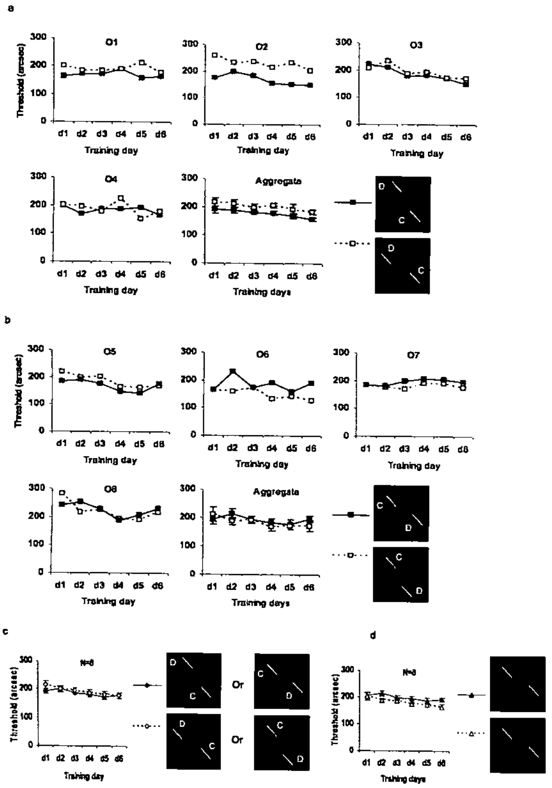

Fig.4.2. Observer performances by offset direction and configuration and training effect in Exp.1. (a) Daily individual thresholds of four observers and their aggregate in the upper left bar displacement. (b) Daily individual thresholds of other four observers and their aggregate in the lower right bar displacement. (c) Offset direction-wise daily mean threshold of all observers irrespective of which bar was displaced. (d) Configuration-wise daily mean threshold of all observers irrespective of which bar was displaced. "C" and "D" in the vernier images refer to the Constant and Displaced bars respectively. The bar's displacement direction is treated here as offset direction. Error bars reflect standard errors (SEs) of the means.

figuration) than when the relative position of the Upper Left bar was to the Left of the Lower Right bar (ULL-LRR configuration) (Fig.4.2d). This effect was significant for 50% of the individual observers (Fig.4.2a,b). Training significantly and consistently improved average vernier threshold without affecting the configurational asymmetry.

3. Experiment 2 : detecting vernier offset at −45° (+135°) orientation

3.1. Method

3.1.1. Observers

Twelve naïve and paid adults of normal or corrected to normal vision participated in this experiment.

3.1.2. Stimuli and apparatus

We used line vernier stimuli, either aligned or misaligned, at −45° orientation (Fig.5). The offset sizes, stimulus contrast, feature separation, feature width and length all were identical as in the first experiment.

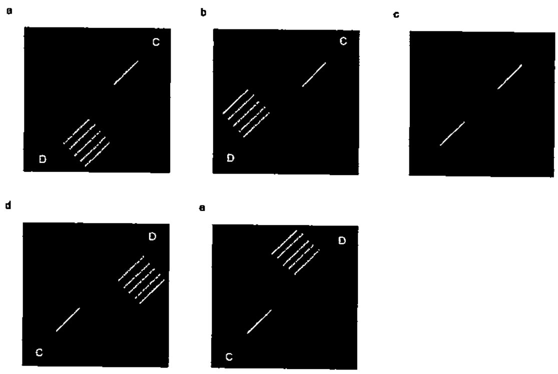

Fig.5. Schematic of the vernier stimuli used in Exp.2. "C" and "D" in the images refer to the Constant and Displaced bars respectively. (a) Stimuli with rightward offset of the lower left-hand bar, (b) Stimuli with leftward offset of the lower left-hand bar, (c) Stimulus with null-offset, (d) Stimuli with rightward offset of the upper right-hand bar, (e) Stimuli with leftward offset of the upper right-hand bar. Vernier separation is defined as the parallel distance between the endpoints of the upper right-hand and lower left-hand bars and vernier offset is defined in arc sec as the perpendicular distance between them. The dotted lines indicate the approximate positions of the displaced bar with different offset sizes.

3.1.3. Procedures

Following identical setup and procedures as in the first experiment, this experiment was run for 12 days.

3.1.4. Data processing and statistical analysis

Like the first experiment, the data were fitted by probit model after excluding the subjective biased responses on day-by-day basis where necessary and thresholds were calculated at 50% correct detection of the vernier misalignment. In order to reduce the effect of presentation order (of the configuration) on any pair of subjective thresholds, we averaged the data in every two successive days of training. Thus for 12 days of training we got 6 pairs of scores for each observer. Then inferential analyses of the data were done following the same statistical tools as in the first experiment. One of the observers (O9) showing higher false detection than correct detection even at larger offsets (i.e., response by guessing) were considered unreliable and hence excluded from our analysis.

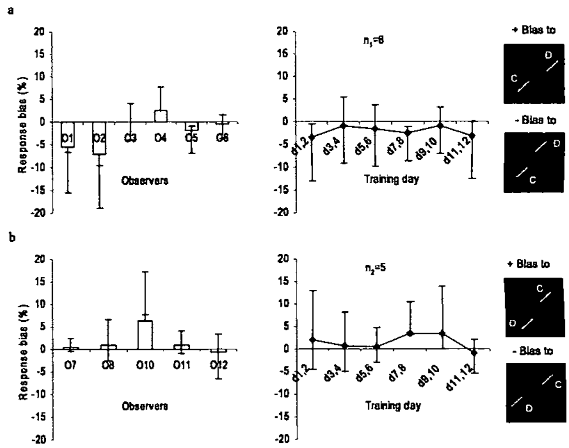

Fig.6.1. Response biases (Mean ± CIs) in Exp.2. (a) Percent biases in the upper right bar displacement; Left panel - subjective biases of 6 observers; Right panel - group mean biases in every two successive days of training. (b) Percent biases in the lower left bar displacement; Left panel - subjective biases of other 5 observers; Right panel - group mean biases in every two successive days of training. "C" and "D" in the vernier images refer to the Constant and Displaced bars respectively. The positive (+) and negative (−) values indicate biases to rightward and leftward offsets respectively. Error bars reflect 95% confidence intervals (CIs) of the mean differences.

3.2. Results and discussion

3.2.1. Response bias

We determined leftward or rightward subjective response biases following the procedures as in the first experiment. Fig.6.1 shows mean subjective response biases calculated over the training days (left panels) and mean response biases for the two observer groups in every two successive days (right panels). The left panels indicate that mean response biases were rightward for O3, O4, O7, O8, O10 and O11 (+scores) and leftward for other observers (−scores). When subjected to a series of one sample t-test we found that average bias scores were significantly different from zero for O 1 ($t_{(11)}=-2.710$, $p=.020$), O2 ($t_{(11)}=-3.395$, $p=.006$) and O10 ($t_{(11)}=2.877$, $p=.015$) only. So, before fitting psychometric functions for calculating offset detection thresholds we excluded on day-by-day basis the response biases for these three observers only.

As shown in the right panels, mean response bias scores calculated in every two successive days for the two observer groups were not significantly different from zero both in the upper right (Fig. 6.1a; $t_{(5)}=-1.358$, $p=.232$ in d1. d2; $t_{(5)}=-.326$, $p=.758$ in d3. d4; $t_{(5)}=-.599$, $p=.575$ in d5. d6; $t_{(5)}=-1.640$, $p=.162$ in d7. d8; $t_{(5)}=-.489$, $p=.645$ in d9. d10 and $t_{(5)}=-1.301$, $p=.250$ in d11. d12) and in the lower left bar (Fig. 6.1b; $t_{(4)}=.660$, $p=.546$ in d1. d2; $t_{(4)}=.324$, $p=.762$ in d3 .d4; $t_{(4)}=.336$, $p=.754$ in d5. d6; $t_{(4)}=2.643$, $p=.057$ in d7. d8; $t_{(4)}=1.379$, $p=.240$ in d9. d10 and $t_{(4)}=-.665$, $p=.543$ in d11. d12) displacement scenarios. The right panels also indicate that mean response biases across the training days (whatever the degree) were constantly leftward when the upper right bar was displaced (Fig. 6.1a) and almost rightward when the lower left bar was displaced (Fig. 6.1b). These refer to the biases to an identical vernier configuration which did not reduce with training.

3.2.2. Offset direction, spatial configuration and training effects

Fig.6.2a,b displays daily offset detection thresholds for individual observers and corresponding aggregates of the two groups who experienced stimuli with the upper right and lower left bar displacements respectively. A series of matched sample t–test applied to the individual data demonstrated that three (O1, O2 and O5) of the six observers experiencing the upper right bar displacement (Fig.6.2a) had significantly lower thresholds if the offset was rightward ($t_{(5)}=5.832$, $p=.002$ for O1 ; $t_{(5)}=6.051$, $p=.002$ for O2 and $t_{(5)}=9.210$, $p=.000$ for O5) and one (O10) of the six observers experiencing the lower left bar displacement (Fig.6.2b) had significantly lower threshold if the offset was leftward ($t_{(5)}=-6.925$, $p=.001$). Though other observers of the two groups did not show any significant difference a few of them showed an asymmetric trend of that kind (e.g., O3, O4 and O11). The line graphs of aggregated data for the two groups show that average thresholds were lower when the upper right bar was displaced to the right (Fig.6.2a ; right most last panel) and the lower left bar was displaced to the left as compared to the counter-displacements (Fig.6.2b ; right most last panel). This asymmetry was significant in the upper right bar displacement ($F_{(1,5)}=10.902$, $p=.021$) and non-significant in the lower left bar displacement ($F_{(1,4)}=1.912$, $p=.239$) scenarios. However, the trends were configurationally identical irrespective of which bar was displaced. This led us to plot the grand average by configuration (Fig.6.2d) in addition with plotting by offset direction (Fig.6.2c) taking training as a common factor.

In order to see the effects of different factors first, we analyzed all observers' threshold data in two-way repeated measures ANOVA with offset direction and training as within-subjects factors. The sphericity assumption was violated for training factor and interaction, so the Greenhouse-Geisser correction was applied. It revealed that the main effect of training was significant (Greenhouse-Geisser corrected $F_{(2.628, 26.278)}=21.862$, $\varepsilon=.526$, $p=.000$) but, not the effect of offset direction ($F_{(1, 10)}=.611$, $p=.453$) and interaction between the two factors (Greenhouse-Geisser corrected $F_{(2.588, 25.879)}=1.244$, $\varepsilon=.518$, $p=.312$). Then we analyzed the data by the same statistical procedures considering configuration and training as within-subjects factors. It was found that the main effects of both configuration and training were significant ($F_{(1, 10)}=10.595$, $p=.009$ for configuration, Greenhouse-Geisser corrected $F_{(2.628, 26.278)}=21.862$, $\varepsilon=.526$, $p=.000$ for training) but, not the interaction effect (Greenhouse-Geisser corrected $F_{(2.740, 27.402)}=1.881$, $\varepsilon=.548$, $p=.160$). A further analysis of the training effect done by post hoc LSD test revealed that the 5 th and 6th day's mean threshold ($M=166.999$, $SE=8.102$) was significantly lower than the 1st and 2nd day's mean threshold ($M=202.065$, $SE=7.295$, $p=.000$). This improvement was maintained, on average, at the 7th and 8th ($M=157.974$, $SE=8.512$, $p=.000$), 9th and 10th ($M=155.247$, $SE=8.590$, $p=.000$) and 11th and 12th ($M=151.246$, $SE=7.425$, $p=.000$) day follow-ups.

Finally, we examined configurational differences in the pre- and post-training. We considered first two days' training as pre-training and last two days' training as post-training. The pre-training average threshold difference between the two configurations was about 36 arcsec, the difference being reduced to 22 arcsec in the post-training (Fig.6.2d). Matched sample t-test revealed that both these mean differences were statistically significant ($t_{(10)}=4.309$, $p=.002$ for pre-training, $t_{(10)}=2.393$, $p=.038$ for post-training).

To summarize, we found for three observers significant response biases toward a particular vernier configuration against its counterpart. When excluded their response biases on day-by-day basis before calculating thresholds, we observed that the main effect of configuration was significant but, not the effect of

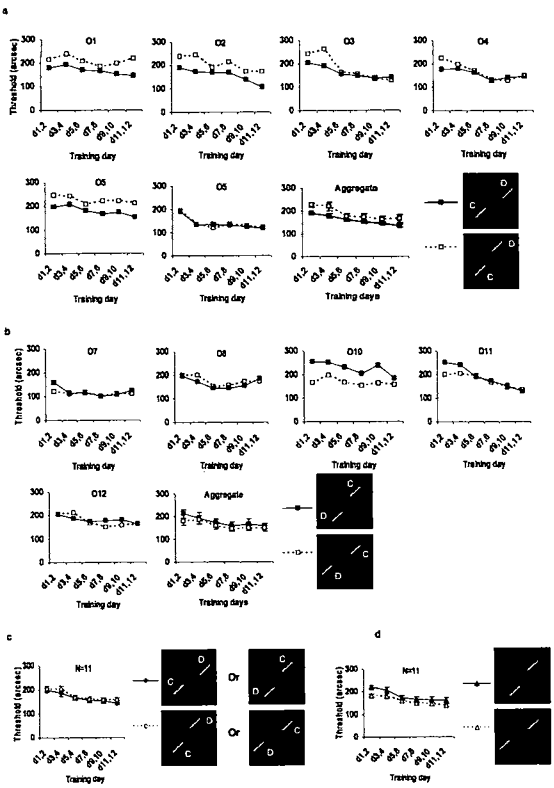

Fig.6.2. Observer performances by offset direction and configuration and training effect in Exp.2. (a) Six observers' individual thresholds averaged in every two successive days and their aggregate in the upper right bar displacement. (b) Other five observers' individual thresholds averaged in every two successive days and their aggregate in the lower left bar displacement. (c) Offset direction-wise mean threshold of all observers in every two successive days irrespective of which bar was displaced. (d) Configuration-wise mean threshold of all observers in every two successive days irrespective of which bar was displaced. "C" and "D" in the vernier images refer to the Constant and Displaced bars respectively. The bar's displacement direction is treated here as offset direction. Error bars reflect standard errors (SEs) of the means.

offset direction on vernier acuity. That is, irrespective of the upper right and lower left bar displacements average vernier acuity was better when the relative position of the Upper Right bar was to the Right of the Lower Left bar (URR-LLL configuration) than when the relative position of the Upper Right bar was to the Left of the Lower Left bar (URL-LLR configuration) (Fig.6.2d). This effect was significant for 36% of the individual observers while a few others showed an asymmetric trend to some degree (Fig. 6.2a,b). Training significantly and consistently improved average vernier threshold without affecting the configurational asymmetry.

4. General discussion

We conducted two line vernier experiments at the oblique orientations demonstrating significant or nearly significant main effect of spatial configuration but, no effect of offset direction on vernier acuity. At individual level, the effect was significant or considerably large roughly for 50% of the observers. The first experiment demonstrated that for a pair of bars arranged side by side with a large gap at +45° orientation, observers were, on average, fairly better at discriminating an offset if the relative position of the upper left-hand bar was to the right of the lower right-hand bar than vice versa regardless of which bar was displaced. That is, with the exclusion of subjective response bias where necessary (Fig.4.1) vernier acuity was better in the ULR-LRL than in the ULL-LRR configuration (Fig.4.2d). The second experiment revealed a similar asymmetry for offset detection at −45° orientation of the vernier bars. That is, performance was significantly better in the URR-LLL than in the URL-LLR configuration (Fig.6.2d) with subjective response bias excluded (Fig.6.1). If the vernier configurations at +45° orientation are compared with the corresponding configurations at −45° orientation we see a consistency of our findings (Fig.7). That is, if configuration ULL-LRR (Fig.7a ; +45°) is rotated 90° clockwise we get configuration URL-LLR (Fig. 7a ; −45°) and similarly, we get configuration URR-LLL (Fig.7b ; −45°) by rotating 90° clockwise the configuration ULR–LRL (Fig.7b ; +45°). The trend is in line with what Karim and Kojima (2008) previously reported using identical stimuli at the cardinal orientation (Fig.1). Thus the results are reasonable and interesting.

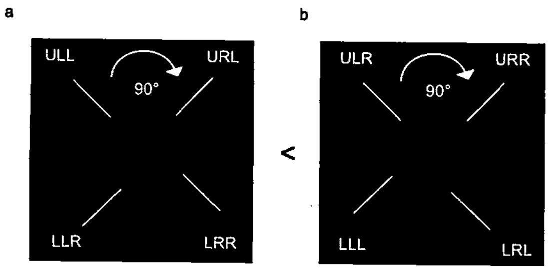

Fig.7. Schematic of the vernier configurations in comparison. (a) + 45° and −45° oriented configurations in which average performance was worse. (b) + 45° and −45° oriented configurations in which average performance was better.

4. 1. Training effect and configurational asymmetry

We successfully demonstrated here the effect of training on vernier offset detection (Fig.4.2c,d ; Fig. 6.2c,d), the results being consistent with the past vernier acuity studies (e.g., Karim & Kojima, 2008 ; Li, & Levi, 2002). The inter-individual differences in learning vernier acuity were striking in our study. In the first experiment, for example, O2, O3 and O5 showed remarkable fall of vernier thresholds in course of training whereas O1 and O7 did not show any improvement (Fig.4.2a,b). The large individual variations were also observed with extended period of training (Fig.6.2a,b ; Exp.2). This is in agreement with the previous similar kind of studies (Karim & Kojima, 2008 ; Fahle & Edelman, 1993 ; McKee & Westheimer, 1978 ; Saarinen & Levi, 1995a). For instance, McKee and Westheimer (1978) reported that after 2000−2500 trials, the range of the individual decrease in vernier thresholds was from 2% to 70%. An important aspect of the present findings is that the average vernier acuity improved with learning but, configurational differences persisted as much as consistently from the beginning to the end of training course in both the experiments (Fig.4.2d ; Fig.6.2d). That is, neural reorganization or plasticity occurred through training without affecting configurational asymmetry. The demonstration of this fact makes an important difference from our previous study in which the asymmetry decreased with at least extended period of training (Karim & Kojima, 2008). This suggests that sensitivity to training is weaker at the oblique orientation than at the cardinal orientation. However, as cortical neurons are plastic (Eichenlaum, 2002 ; Kandel, Schwartz & Jessell, 2001) we cannot rule out the possibility that the asymmetry would be refined or modified by learning even at the oblique orientation. So, for decreasing the asymmetry at this orientation perhaps much more training is necessary.

4. 2. Why is this sort of asymmetry?

As we have shown, the asymmetry cannot be explained by subjective response bias. The possibility of eye movements is also unlikely as the stimulus duration was very brief (100 ms) in our study. Nevertheless, if there had been any eye movements it might not have any role in vernier acuities (Kessy, 1960), because vernier lines have internal orientation information, and may therefore be less susceptible to orientational or angular noise created by head tilt or eye torsion (Waugh & Levi, 1993). Then, why is this sort of asymmetry?

The reason cannot be explained directly by any corresponding asymmetry of neural populations in the visual cortex. However, as in our previous study (Karim & Kojima, 2008) we suspect that cortical neurons might have preference for a particular vernier configuration against another. Because most aspects of spatial vision (e.g., grating acuity, vernier acuity) are quite immature in the human neonate (Skoczenski & Norcia, 1999) and neural organization of the human visual system may be influenced by its early visual input (Freeman, Mitchell & Millodot, 1972 ; Freeman & Thibos, 1973 ; Mitchell, Freeman, Millodot & Haegerstrom, 1973), the preference might have developed as a result of learning at early development. We have some good reason to think the origin of the asymmetry from such experience dependent factor. For example, if the asymmetry would have originated from experience independent factor all individual observers should show the asymmetry. This was not the case in our study, rather ; we found roughly 50% of the observers showing significantly or considerably better performances in a particular vernier configuration (Fig.4.2a,b ; Fig.6.2a,b). While two observers (O5 in Exp.1and O8 in Exp.2) showed an opposite trend, several others did not show any asymmetry at all. This is possible because the experiential worlds are not necessarily equal for all individuals.

Finally, as the higher level mechanism is important to extract the relevant signal for relative position of the vernier features we suggest that the locus of control for the said configurational asymmetry might be more in the higher than in the lower visual cortex. It would not be surprising should there be an involvement of a far visual area, the inferior temporal cortex (IT). Because, IT neurons respond not only to highly complex stimuli but also to simple stimuli such as edges and bars ; and that they might be stimulus selective (Desimone, Albright, Gross, & Bruce, 1984). Desimone et al. (1984) reported that half of the selective units (neurons) were selective for shape, color, texture, or combinations of the three and they maintained this selectivity throughout their large receptive fields. Some of these units were also sensitive to the length, width, or color of a bar, and thus, resembled units that have been found in striate and prestriate cortex but with much larger receptive fields.

In fine, consistent with a previous study at the cardinal orientation (Karim & Kojima, 2008) our present study demonstrated configuration-selective response property of the visual system at the oblique orientation. Literature on vision research sometimes appeared to report such a surprising fact. As we mentioned earlier, for instance, top-left lighting preference has been claimed to be real in visual spatial judgment (e.g., Elias & Robinson, 2005 ; Gerardin, et al., 2007 ; Mamassian & Goutcher, 2001 ; Sun & Perona, 1998) though it may not be apparent in our conscious awareness and cannot be causally related to any known cortical function. Thus, there is a possibility that we have some anisotropic properties in visual perception. The origin of such anisotropies still remains unknown.

5. Conclusion

We demonstrated that for a pair of vernier bars arranged side-by-side with a large gap at $+45^{\circ}$ orientation, average offset detection threshold was fairly better if the relative position of the upper left-hand bar was to the right of the lower right-hand bar than vice versa regardless of which bar was displaced (Exp.1). Similarly, average vernier offset detection was significantly better at -45° orientation if the relative position of the upper right-hand bar was to the right of the lower left-hand bar than vice versa (Exp.2). This asymmetry persisted even after learning, indicating possibly configuration-selective neural processing of the line vernier stimulus. As the asymmetry was found to be significant or fairly strong roughly for 50% of the individual observers, the preference might have developed through early learning. But, we still do not know clearly about the origin of this configuration-selective response property in the visual system.

The present results along with the previous ones (Karim & Kojima, 2008) suggest that the configuration-selective response to vernier stimuli can be generalized to the oblique orientation. All the results together advance our understanding that spatial relationships between the vernier elements even of simple configuration might be very crucial for spatial discrimination.

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