CHANGES OF PERCEIVED LINE ORIENTATION DURING PROLONGED VIEWING OF TILTED LINES: THE NORMALIZATION EFFECT*

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J. J. Gibson has noted that during prolonged viewing a line perceptually rotates towards the nearest vertical or horizontal meridian. This is known as the normalization effect, but the phenomenon remains poorly investigated. According to our experimental results, the adapting line perceptually rotates to the nearest of three orientations: vertical, horizontal or diagonal. The orientation of these three lines does not change during prolonged viewing. Furthermore, the orientation of lines tilted by either 22.5° or 67.5° does not change subjectively, either. Any changes in the orientation of these lines cause subjective drift towards the nearest vertical, diagonal (oriented by 45°) or horizontal line.

Key words: *line orientation, adaptation, normalization effect.*

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Introduction

The effect of adaptation on the perceived orientation of a line was originally described by J. J. Gibson (1933, 1937) and J. J. Gibson & M. Radner (1937). They reported two phenomena that occur during prolonged viewing of a line: the tilt after-effect and the effect of normalization. The tilt after-effect describes how the perceived orientation of a test line depends both on the actual (physical) orientation of the line and on the orientations of lines that were previously presented to the subject (Köhler & Wallach 1944; Mitchell and Muir 1976; Campbell and Maffei 1971; Bednar & Miikkulainen 2000; Clifford et al., 2000; Schwartz, et al., 2007). The normalization effect results in a change of the perceived orientation of the line during prolonged viewing, i.e. the line perceptually rotates, or drifts, towards the nearest vertical or horizontal straight line (Gibson, 1933).

The tilt after-effect has been intensively investigated (Gibson, 1933, 1937; Köhler & Wallach, 1944; Ganz, 1956; Blakemore et al., 1970, 1971; Over et al., 1972; Tolhurst, 1972; Dealy & Tolhurst, 1974; Sekuler & Littlejohn, 1974; Mitchell & Muir, 1976; Regan and Beverley, 1985; Wenderoth & Johnstone, 1987; Bednar & Miikkulainen, 2000; Clifford et al., 2000, 2001). But there has been relatively little examination of the properties of the normalization phenomenon. J. J. Gibson & M. Radner (1937) indicate that the orientation of any straight line continuously changes throughout prolonged viewing, the line is perceived as drifting towards the nearest of the two intrinsic standards, or norms: vertical and horizontal. Vertical and horizontal lines are perceived as stable, however, diagonal lines are equally far from both the vertical and horizontal lines, and consequently these lines could also conceivably be perceived as stable. This paper sets out to examine in greater detail the properties of this normalization phenomenon.

Methods

Stimuli

In view of the fact that adaptation effects have spatially local components (prolonged viewing gives rise to changes in the vicinity of stimuli (Cleland & Freeman, 1968; Dragoi et al., 2000, 2003)), we chose two different stimuli presented in different parts of the visual field (Figure 2) to assess changes in the perceived orientation of a line.

The subjects were exposed to three adapting straight lines L_A, which were spaced apart by 20 min of arc visual angle (Figure 1a). We used five different line orientations $\varphi_a = \varphi_{unad} \pm 10°$ and $\varphi_a < 90°$, where $\varphi_{unad} = 0°$, 45° and 90°. Figure 1a also demonstrates the matching line, L_M. The distance between L_A and L_M was equal to 6 deg of arc.

A small solid black fixation point was placed in the centre of the middle adapting line. All the lines were 2 deg of arc in length, 10 min of arc in width and were generated by a PC, on a Philips 201CS monitor (refresh rate = 75 Hz, screen diagonal length = 50.4 cm).

The stimuli were presented on a blank screen of luminance equal to 80 cd/m^2. Subjects viewed the stimuli with one eye through a circular aperture positioned 1 meter from the screen. The size of the circular visual field was 20 deg of arc. A special bite bar was used to minimise movements of the subjects' head.

Procedure

Figure 1b demonstrates the timeline of the stimulus sequence. Subjects were exposed to 10 min of complete darkness at the beginning

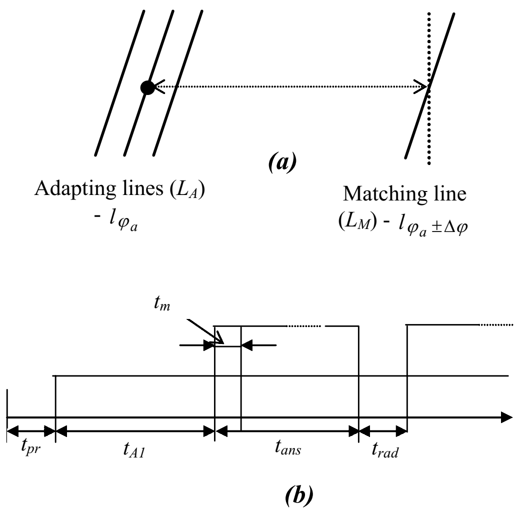

Figure 1. ***Stimuli and the sequence of their presentation:***
(a) **L_A** ***three adapting and*** **L_M** ***matching straight lines,***
(b) ***sequence of stimuli presentation.*** **t_{pr}** ***– dark adaptation time;*** **t_{A1}** ***– preliminary adapting time (***t_{A1} **= 1*****min;*** **t_m** ***– the presentation time of matching line (***t_m ***= 0.2 – 1 s);*** **t_{ans}** ***– time needed to answer;*** **t_{rad}** ***– readaptation time (***t_{rad} ***= 10 s)***

of each experiment (t_{pr}). After that, three adapting lines appeared on the screen and remained visible to the subjects for the remainder of the experiment. After 1 min (t_{A1}), matching lines were presented for 1 sec (t_m). The orientation of these matching lines was varied randomly by 0.5*n* degrees, where *n* is a random integer ranging from –10 to 10. There were total of 21 orientations generated. The orientation angle can be expressed as $\varphi = \varphi_a + 0{,}5° n$ (i.e. $\varphi_a - 5° \leq \varphi \leq \varphi_a + 5°$).

A subject was asked to choose if the matching line L_M was rotated clockwise or counter clockwise relative to the adapting lines (2-alternative forced choice method). The subject had an unlimited time (t_{ans}) to make this decision. Each response by the subject was followed by a 10-second period (t_{rad}) of re-adaptation after which the process was repeated until the subject had made 105 decisions.

Subjects

There were four male observers, their age ranging from 30 to 60 years. All subjects had normal or corrected-to-normal vision with no astigmatism. Three subjects were not aware of the purpose of the experiment. All subjects were experienced with psychophysical experiments.

Data Analysis

There are two hypothetical circumstances under which a subject is forced to choose the direction of the rotation:

- the subject perceives the predicted adaptive drift;
- the subject does not perceive any adaptive drift (no normalization takes place).

Figure 2 demonstrates an example of per-

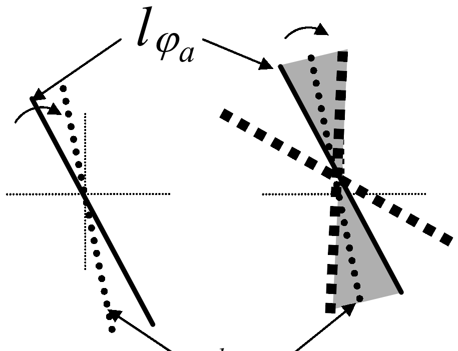

Figure 2. ***Assessment of perceived orientation after prolonged viewing of the line tilted by –10° from the vertical (for clarity, all angles between the lines are enlarged):***
(a) – l_{φ_a} ***true adapting line,*** $\mathbf{l}_{\text{perc}}$ ***– perceived line;*** (b) ***– all matching lines are generated within the range spanned by the heavy-dotted lines; a continuous line represents the adapting line*** l_{φ_a} ***which divides the range into two equal sectors (grey and white). The perceived adapting line (***$\mathbf{l}_{\text{perc}}$***) is rotated clockwise and is represented by a dotted line which divides the range into two unequal parts. The counter-clockwise sector is larger as compared to the sector oriented clockwise from the*** $\mathbf{l}_{\text{perc}}$ ***line***

ceived orientation assessment during which the orientation angle φ is set to –10° and the test lines appear within the range spanned by the heavy-square dashed lines (for clarity, all angles among lines are enlarged). The subject is forced to decide whether each matching straight line is rotated clockwise or counter-clockwise in relation to the adapting line. If the orientation of the adapting line (l_{φ_a}) is perceived as constant, the perceived orientation of the test line coincides with the true orientation. In this case, the frequency of responses "rotated clockwise" (f_c) and "rotated counter-clockwise" (f_a) (or the number of responses "rotated clockwise" (R_c) and "rotated counter-clockwise" (R_a)) will be equal. If the adaptation effect causes subjective clockwise rotation of the l_{perc} line, the frequency of (f_a) responses will increase and will exceed the (f_c) responses (Figure 2b). On the other hand, if the adapting line subjectively rotates counter-clockwise, then the number of (f_a) responses will decrease. As demonstrated in Figure 2, the adapting line divides the range of test lines into two equal sectors, hence any subjective deviation from this line causes these sectors to become uneven, leading to corresponding changes in the frequency of (f_c) or (f_a) responses. During the experiments, we were able to use changes in response frequency to quantify the subjective effect of adaptation.

We used the Kolmogorov–Smirnov and Shapiro–Wilk tests to confirm that our data were normally distributed. We used the t-test to identify significant differences in our datasets. We also used nonparametric analysis methods to compare and estimate the effect of adaptation on the perception of two groups of lines. The first group of lines was oriented by –10°, 35°, 80° and the second group by 10° and 55°.

We tested the following hypothesis: the first group of lines should be subjectively rotated clockwise, and therefore the number of (f_a)

responses (the matching line is rotated counter-clockwise relatively to perceived adapting line) should be greater than the (f_c) responses.

Results

During the experiments, the subjects were forced to identify the direction of the test line rotation as "clockwise" (f_c) or "counter-clockwise" (f_a) relative to the adapting line. The frequency of these responses had a normal distribution as determined by Kolmogorov–Smirnov criterion ($p \leq 0.2$).

A summary of the results from the subjects is presented in Figure 3, which shows the average number and frequency of responses "rotated clockwise" (R_c) and (f_c) as a function of adapting line orientation. The positive angles mean that the adapting line is rotated clockwise from the vertical. Note that the dashed line in Figure 3 represents the point where the frequency of (f_c) responses is equal to (f_a) responses. Error bars correspond to a 95% confidence interval. Continuous thick arrows show the direction of the subjective adaptive drift. Dashed arrows point towards the theoretical orientations of the adapting line at which normalization effect should not occur.

As demonstrated in Figure 3, the subjects were less likely to have (f_c) responses when the adapting line was set at –10°. This means that the adapting line was perceptually rotated clockwise. The same line in Figure 2 is depicted as a dashed line and divides the sector, marked by two heavy-square lines, into two unequal parts, the counter-clockwise sector being the larger of the two. Thus, the subjects were more likely to subjectively orient the test line within the larger sector.

The other results presented in Figure 3 can be explained similarly. For example, the subjects were more likely to choose (f_c) responses when the adapting line was at +10°. This means that the adapting line is subjectively rotated counter-clockwise. In this case, the perceived adapting line divides the test line orientation range unequally, the clockwise sector being the larger of the two (analogously to Figure 2); therefore, the subjects were more likely to subjectively orient the test line within the larger clockwise sector.

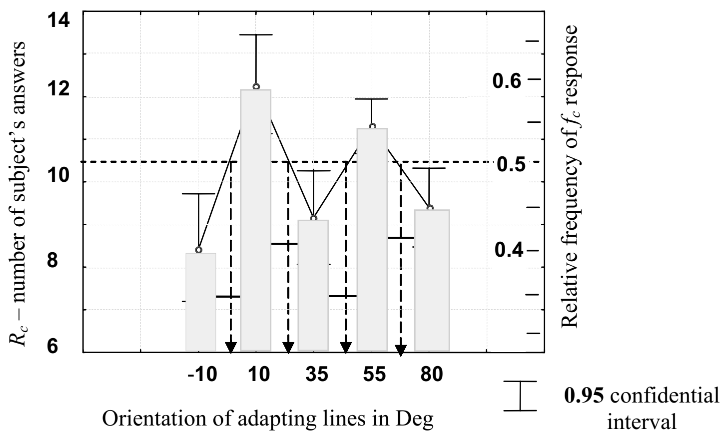

Figure 3. ***The number (R_c) or relative frequency (f_c) of responses versus adapting line orientation. The abscissa represents the orientation of adapting straight lines in degrees, and the ordinate shows the "rotated clockwise" response frequency; error bars – 95% confidence interval***

We compared the (f_c) response frequency when the adapting line was set at –10°, 35° and 80° with the response frequency when the adapting line was set at 10°, 55° using non-parametric methods (Mann–Whitney U test-($U = 252$, $Z = -5.41$, $p < 0.05$), Wald–Wolfowitz runs test ($Z = -3.00$, $p < 0.05$), and 2 × 2 Tables (McNemar, Fischer exact $\chi^2 = 124.88$, $p < 0.05$)). There was a significant increase in (f_c) responses when the adapting line was set at 10°, 55° as compared to the responses when the adapting line was at –10°, 35° and 80°. Additionally, the difference in responses remained significant independently of the presence or absence of time for adaptation.

Discussion

In summary, the results of our experiments were as follows:

1. During adaptation, the adapting line subjectively rotates towards the nearest vertical (0°), horizontal (90°) or diagonal orientation (45°).
2. Lines tilted by 22.5° and 67.5° are perceptually stable during adaptation, but the smallest deviation from these angles gives rise to adapting drifts. The direction of the drift depends on the sign of deviation and could be random.

What physiological mechanisms might account for the observed properties of the normalization phenomenon? According to one theory, such changes in the perception of line orientation are caused by adaptation of orientation-sensitive detectors in the striate cortex (Tolhurst, 1972; Dealy and Tolhurst, 1974; Bednar & Miikkulainen, 2000; Clifford et al., 2000). Increased excitation of these striate cortical detectors decreases their sensitivity to contrast without changing the orientation tuning characteristics. As a result of this decrease in sensitivity, the same line before and after adaptation maximally excites different orientation detectors. However, to explain the normalization effect, we need to introduce some special, rather complex, distributions of detectors in the orientation domain. Experimental data have indicated that the number (or density) of detectors tuned to vertical and horizontal orientations is greater than the number of detectors tuned to diagonal orientations (Bednar & Miikkulainen, 2000). In view of the decreasing sensitivity of orientation detectors distributed in the orientation domain described above, all lines (except vertical, horizontal and diagonal (i.e. 45°)) will be subjectively rotated to the nearest vertical or horizontal line during prolonged viewing, where the detectors are most numerous. Diagonal lines should be perceptually stable, but any changes in the orientation of such lines should cause a subjective drift of the orientation towards the nearest vertical or horizontal line. This contradicts the data obtained in this study (Figurre 3). Therefore, in order to explain these data, we need to have a more complex distribution of detectors in the orientation domain: namely, if the observed normalization phenomenon stems from the unequal distribution of the detectors in the orientation domain, then the density of these detectors should be maximal around the three orientations (vertical, diagonal (about 45°) and horizontal). Currently, there are no data to confirm this speculation. Moreover, there is a strong evidence to suggest that adaptation is not only a result of a decreasing detector sensitivity, but that it also stems from the decreasing value of signals transmitted from the inputs of detectors (Movshon & Lennie, 1979; Vidyasagar, 1990; Solomon et al., 2004).

Furthermore, if adaptation results from changes in the sensitivity of orientation detectors, the optimal orientations of single detectors should not change during prolonged viewing. However, we have demonstrated here that is not the case and, in support of our findings, neurophysiological data indicate that the optimal orientation of detectors during adaptation does change (McMahon & MacLeod, 2003; Dragoi et al. 2000, 2003; Jin et al., 2005).

Conclusions

We have demonstrated that during a prolonged viewing of a straight line, the perceived orientation of this line changes: the line perceptually rotates towards the nearest of the following orientations: 0°, 45° or 90°. The observed perceptual drifts change their direction within the following ranges of angles: 10–35° and 55–80°.

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ILGAI STEBIMOS TIESĖS SUVOKIMO POLINKIO POKYČIAI: NORMALIZACIJOS EFEKTAS

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S a n t r a u k a

Dar J. J. Gibsonas pastebėjo, kad ilgai stebimos tiesės suvokiamas polinkis kinta – ji subjektyviai sukasi link artimesnės vertikalios arba horizontalios tiesės. Šį efektą J. J. Gibsonas pavadino normalizacijos efektu. Iki šiol šis gerai žinomas reiškinys mažai tyrinėtas. Mes eksperimentais parodėme, kad ilgai stebima tiesė subjektyviai sukasi link trijų stabilių tiesių (vertikalios, horizontalios ir tiesės, palinkusios 45 laipsniais). Stabilių tiesių polinkis viso stebėjimo metu subjektyviai nekinta. Be šių trijų tiesių, yra dar dvi tiesės, kurių polinkis stebėjimo metu irgi nekinta. Tai tiesės, palinkusios į horizontalę 22,5 ir 67,5 laipsnio. Tačiau mažiausias šių tiesių atvaizdų tinklainėje orientacijos pokytis sukelia subjektyvų šių tiesių sukimąsi link artimiausios stabilios tiesės.

Pagrindiniai žodžiai: tiesės suvokiama orientacija, adaptacija, normalizacijos efektas.

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