Influence of target size and eccentricity on binocular summation of reaction time in kinetic perimetry

Akemi Wakayama a,b,* , Chota Matsumoto a, Kazuyo Ohmure a, Masahiko Inase b, Yoshikazu Shimomura a

a Department of Ophthalmology, Kinki University Faculty of Medicine, Osaka, Japan
b Department of Physiology, Kinki University Faculty of Medicine, Osaka, Japan

ARTICLE INFO

Article history:
Received 28 January 2010
Received in revised form 25 September 2010

Keywords:
Binocular summation
Reaction time
Target size
Eccentricity
Kinetic perimetry

ABSTRACT

To assess how target size and eccentricity affect binocular summation (BS) of reaction time (RT) at suprathreshold level, we measured RT using targets of 0.108° and 0.216° at four eccentricities (0°, 5°, 15°, 25°) in six normal volunteers. The difference between the monocular/binocular RT differentials for both sizes significantly increased in the periphery (P < 0.05). The smaller target required significantly longer monocular RT at 25° (P < 0.01) and generated greater neural summation than the larger target (P < 0.01). This suggests that when monocular function has reached its limit in visual processing in the periphery, BS increases, facilitates visual processing, and shortens binocular RT.

© 2010 Elsevier Ltd. All rights reserved.

1. Introduction

Binocular summation (BS) is defined as the superiority of binocular performance to monocular performance. The amount of BS increases with low-contrast stimuli (Banton & Levi, 1991; Bearse & Freemen, 1994; Pardhan, 2003), decreasing stimulus size (Wakayama, Matsumoto, Ohmure, Matsumoto, & Shimomura, 2002), younger age (Pardhan, 1997) and increasing eccentricity (Wakayama, Matsumoto, & Shimomura, 2005); and it decreases with increasing naso-temporal asymmetry (Grigsby & Tsou, 1994). Depending on the target size used, interocular difference in sensitivity can also affect the level of BS (Wood, Collins, & Carkeet, 1992). We have previously found that BS on threshold increases when a recognition task becomes more difficult in the peripheral retina (Wakayama et al., 2005). Although relationships between BS and the above factors (target size, eccentricity, difficulty level of a recognition task) have been well studied at threshold levels, it is still unknown if the relationships will hold at suprathreshold levels.

Reportedly, BS of RT at suprathreshold levels is affected by contrast (Westendorf & Blake, 1988), pupil size (Medina, Jiménez, & Barco, 2003), and presence of stereopsis (Blake, Martens, & Gianfilippo, 1980). RT at suprathreshold level also increases with higher luminance levels either with static stimuli (Schiefer et al., 2001) or kinetic stimuli (Wall, Kutzko, & Chauhan, 2002). The relationship between RT and eccentricity has been studied under monocular condition (Becker, Vonthein, Volpe, & Schiefer, 2005; Schiefer et al., 2001). However, whether and how binocular RT summation is affected by target size and eccentricity is still unclear. By clarifying this, we can better understand the conditions in which binocular functions perform more efficiently than monocular functions regarding threshold and binocular RT. This information is also helpful in assessing patient’s quality of vision.

When evaluating the effect of eccentricity on binocular RT summation across the visual field, we considered it fair to set luminance at the same level to eliminate any RT differences caused by threshold differences at various test locations. We therefore fixed the level of suprathreshold so that the actual threshold could be accurately determined and the true effect of eccentricity on binocular RT summation could be evaluated. In this study, a fixed suprathreshold level (0.47 log threshold energy) was added to the threshold measured at the test location and this would be the luminance level used for that test location. To our knowledge, no previous studies that used RT as a measure of binocular interaction have taken a similar approach.

The present study aimed for two goals: to investigate how target size could affect the level of binocular RT summation, and to determine the effect of eccentricity on binocular RT summation with a fixed suprathreshold level.
2. Methods

2.1. Apparatus and stimulus

We used the Octopus 101 perimeter (Haag-Streit International, Köniz, Switzerland) with a GKP program to measure RT and the precision of the instrument for RT measurement is ±20 ms. To confirm fixation, the examiner used a small infrared video camera to monitor the pupils’ positions. The background luminance was 31.5 asb and view distance was 42.5 cm. White-spot test targets of two sizes, 0.108° and 0.216° of visual angle (equivalent of Goldmann I and II), were used. The test locations were arranged at 16 positions: 0°, 5°, 15° and 25° eccentricities on the meridians of 45°, 135°, 225° and 315°. Targets were moved perpendicularly from the arranged positions toward the horizontal midline with a velocity of 3.0°/s, which is the speed commonly used in clinical examinations. The targets starting at 0° were moved outward along the four meridians. The 16 targets were randomly tested (Fig. 1).

To determine the luminance level for each test location, we first measured the threshold level at the test location with a kinetic stimulus. A fixed suprathreshold level at 0.47 log threshold energy was added to the threshold level already measured. This method could eliminate the influence of stimulus luminance. On the equipment used in this study, 0.47 log threshold energy was the possible suprathreshold level that could be fixed for both target sizes to be detectable at various eccentricities.

Table 1 shows the kinetic targets used in this study.

2.2. Subjects

Subjects were six normal volunteers between 24 and 29 years of age without any systemic or ophthalmic diseases. We selected subjects within a narrow age range to avoid possible variation in motor response time by aging. All experiments were performed in accordance with the Declaration of Helsinki for research involving human subjects. Informed consent was obtained from all subjects after explanation of the nature and possible consequence of the study.

Ophthalmic inclusion criteria were as follows: best corrected visual acuity of 1.2 (−0.1 log MAR equivalent) or better, refractive error within ±3.0 D sphere and ±2.0 D astigmatism. We required normal stereopsis (60 s of arc or better on the TNO stereo test), normal ocular alignment, and normal ocular motility.

2.3. Measurement procedure

RT is defined as the time between the appearance of a stimulus and the subject’s response. We separately measured the RTs for the right, left, and both eyes. The subject was instructed to press the button upon perceiving the target. For the measurement of monocular RT, the non-tested eye was occluded with an opaque cover so that the subject could only perceive the background luminance and not the target. Either RT for the right or RT for the left eye, whichever was the shorter, was used as the monocular RT. Each target was tested six times. The orders of the eyes, the two target sizes, and the 16 target locations to be tested were determined randomly. To avoid the effect of a constant interval, the interval between the target presentations was also determined at random. The target moved until the subject pressed the button or until the target had moved a distance of 10°. The examination could be interrupted at anytime during the test by the subject’s request. Any RT less than 100 ms was defined as false positive and was excluded from data analysis.

2.4. Estimation of probability summation and neural summation

In psychophysics, BS includes probability summation and neural summation (Blake & Fox, 1973; Blake, Sloane, & Fox, 1981); and the performance of BS depends on neural summation. If neural summation is greater than probability summation, BS performs better than probability summation. If neural summation is less than probability summation, BS performs at the level of probability summation. In this study, we calculated probability summation using Blake’s adopted version of John’s statistical decision theory of simple RT (Blake et al., 1980; John, 1967). Briefly, the mean of the predicted values can be obtained by multiplying the standard deviation of a set of monocular RTs by 0.57 and subtracting this value from the mean of those monocular RTs:

\[ \text{Predicted binocular RT} = \bar{X} - \sigma(0.57) \]

(\(\bar{X}\) and \(\sigma\) refer to the mean and standard deviation of the monocular RT distribution, respectively.) The predictable binocular RT was evaluated to confirm if neural summation had exceeded probability summation for better BS performance.

2.5. Statistical analysis

The primary outcome variables were all normally distributed (\(P > 0.05\), Kolmogorov–Smirnov test) and had similar variances (\(P > 0.05\), Bartlett test). We therefore used parametric statistics in this study. Comparisons between monocular and binocular RTs regarding target size and eccentricity used ANOVA and Bonferroni/Dunn test. Differences between the predicted and actual binocular RTs at the four eccentricities were analyzed for both target sizes by Wilcoxon signed ranks test and \(P < 0.05\) was considered to be statistically significant.

**Table 1**

<table>
<thead>
<tr>
<th>White-spot kinetic test regards of two sizes used at all locations.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Goldmann I (0.108° of visual angle)</strong></td>
</tr>
<tr>
<td>0°: I-2e, 5°: I-3b, 15°: I-3e, 25°: I-4e</td>
</tr>
<tr>
<td><strong>Goldmann II (0.216° of visual angle)</strong></td>
</tr>
<tr>
<td>0°: II-1a, 5°: II-1b, 15°: II-2c, 25°: II-3d</td>
</tr>
</tbody>
</table>

Fig. 1. Schematic representation of the target locations. The targets located 16 positions at 0°, 5°, 15° and 25° eccentricities, and were moved from the arranged positions toward the horizontal midline with a velocity of 3.0°/s. The targets starting from 0° were moved outward.
3. Results

3.1. Effects of eccentricity and target size on monocular and binocular RTs

Monocular and binocular RTs were statistically analyzed by a two-factor ANOVA with eccentricity (0°, 5°, 15° and 25°) and target size (larger and smaller) as factors. Differences between monocular and binocular RTs for both target sizes were statistically analyzed by a two-factor ANOVA with the tested eye(s) (left, right, both eyes) and eccentricity as factors. No significant interaction was found between these two factors (F(2, 25) = 0.11, P = 0.99 for size 0.108° and F(2, 25) = 0.04, P = 0.99 for size 0.216°). Binocular RTs were significantly shorter than monocular RTs for both target sizes (F(3, 15) = 10.45, P < 0.001 for size 0.108°; F(3, 15) = 48.74, P < 0.001 for size 0.216°; and P = 0.01 by Bonferroni/Dunn test; Table 2). No significant difference was seen between the right and the left monocular RTs at any eccentricity.

With the smaller target, monocular and binocular RTs significantly increased with increasing eccentricity between 0° and 25° eccentricities (right eye: F(3, 09) = 5.21, P < 0.01; left eye: F(3, 09) = 7.03, P < 0.01; binocular: F(3, 09) = 5.42, P < 0.01 by one-factor ANOVA and P < 0.01 by Bonferroni/Dunn test; Fig. 2). The average rates of the increases for the right, left and both eyes were 2.9 ms, 3.3 ms, and 2.9 ms/°, respectively. With the larger target, neither monocular RT nor binocular RT showed any significant correlation with eccentricity (right eye: F(3, 09) = 1.96, P = 0.15; left eye: F(3, 09) = 2.33, P = 0.10; both eyes: F(3, 09) = 2.75, P = 0.06, one-factor ANOVA).

The effects of target size were separately measured with the tested eye(s) (left, right, both eyes) and eccentricity as factors. No significant interaction was found between these two factors (P = 0.99 for size 0.108°; Table 2). No significant correlation with eccentricity (right eye: F(3, 09) = 1.96, P = 0.15; left eye: F(3, 09) = 2.33, P = 0.10; both eyes: F(3, 09) = 2.75, P = 0.06, one-factor ANOVA).

The average rates of increases for the right, left and both eyes were 15.8 ± 2.1% and 12.1 ± 1.8%, respectively. Repeated measures ANOVA with target size and eccentricity as factors showed no interaction (F(2, 94) = 1.37, P = 0.26). The smaller target showed greater neural summation at all test locations (F(4, 19) = 16.80, P < 0.001; Fig. 6).

Table 2

<table>
<thead>
<tr>
<th>Eccentricity</th>
<th>Target size 0.108°</th>
<th>Target size 0.216°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left eye</td>
<td>Right eye</td>
</tr>
<tr>
<td><strong>0°</strong></td>
<td>R</td>
<td>L</td>
</tr>
<tr>
<td>10.8 ± 2.1</td>
<td><strong>21.3 ± 1.5</strong></td>
<td><strong>21.3 ± 1.5</strong></td>
</tr>
<tr>
<td>5°</td>
<td>R</td>
<td>L</td>
</tr>
<tr>
<td>10.8 ± 2.1</td>
<td><strong>21.3 ± 1.5</strong></td>
<td><strong>21.3 ± 1.5</strong></td>
</tr>
<tr>
<td>15°</td>
<td>R</td>
<td>L</td>
</tr>
<tr>
<td>10.8 ± 2.1</td>
<td><strong>21.3 ± 1.5</strong></td>
<td><strong>21.3 ± 1.5</strong></td>
</tr>
<tr>
<td>25°</td>
<td>R</td>
<td>L</td>
</tr>
<tr>
<td>10.8 ± 2.1</td>
<td><strong>21.3 ± 1.5</strong></td>
<td><strong>21.3 ± 1.5</strong></td>
</tr>
</tbody>
</table>

4. Discussion

This study clearly showed that the difference between the monocular/binocular RT differentials obtained for the two target sizes increased in the periphery. In addition, the smaller target generated greater neural summation than the larger target. More importantly, the smaller target required significantly longer monocular RT than the larger target at 25° eccentricity and yet, this was not observed in the binocular RT.

The relationship between BS and the difficulty of a detection task has been previously studied. Zlakova, Anderson, and Ennis (2001) reported that while no difference in BS is observed between detection and resolution acuities at the fovea, BS for resolution acuity is significantly higher than BS for detection acuity in the periphery. We also reported that BS for resolution threshold is greater than BS for detection threshold in the periphery (Wakayama et al., 2005) and that BS increases with the smallest target size used (0.05°) and with increasing eccentricity (Wakayama et al., 2002). These threshold studies have confirmed that BS facilitates visual processing by improving sensitivity. By showing that the smaller target had generated greater neural summation than the larger target at all test locations in this suprathreshold study (Fig. 6), the current result suggested that BS also facilitated visual processing by shortening binocular RT when a smaller target was used.

Previous studies have reported the relationship between the BS level and the monocular/binocular thresholds. Reportedly, BS is not present at high contrast (Bearse & Freemen, 1994; Home, 1978) or with a long exposure duration (Bearse & Freemen, 1994). Under
these conditions, monocular and binocular thresholds are about equivalent and this indicates the possibility of a saturation effect. The study by Bearse & Freeman also showed that with different contrast levels and exposure durations, monocular discrimination thresholds are higher than binocular discrimination thresholds at a high BS condition. As the BS becomes lower, monocular discrimination threshold decreases to a larger degree than binocular threshold. In the present study with different target sizes, the monocular/binocular RT differentials increased in the periphery (Fig. 4) and only the monocular RTs for the two target sizes significantly differed in the periphery (Fig. 3). The previous and current results all indicated that when the task becomes more difficult, the monocular RT differential affects the amount of BS more than the binocular RT differential. We therefore considered that BS increases at high monocular threshold (such as with a small target, in the periphery, or at low contrast). That is, when the task has become more difficult and the monocular function has reached its limit, the binocular function processes visual information more effectively.

Wall et al. (2002) reported that with static stimuli, RT decreases with higher luminance stimulus and that suprathreshold RT is shorter than the RT at threshold. Moreover, the influence of the differential suprathreshold level on RT differs at various eccentricities. Their results have supported our rationale for setting the suprathreshold at a fixed level to eliminate the effects of other variables such as stimulus luminance when assessing the effects

**Fig. 3.** RTs for both target sizes were about the same within the 15° visual field. Beyond 15°, RTs for the smaller target clearly exceeded RTs for the larger target with significant differences seen only under monocular conditions at 25° (P < 0.001).

**Fig. 4.** Differences between monocular and binocular RTs for both target sizes. Either the right or the left RT, whichever was the shorter, was used for the monocular RT. The smaller target overall had larger RT differentials than the larger target with significant differences seen at 15° and 25° (P < 0.05).

**Fig. 5.** The predicted binocular RTs were plotted against the actually obtained binocular RTs at the four eccentricities for target sizes 0.108° (A) and 0.216° (B). The actual values were significantly shorter than the predicted values (P < 0.001).
of target size and eccentricity on RT in this study. Although this approach alone may not be enough to remove the effect of eccentricity on suprathreshold RT, our result showed that the monocular RT for the smaller target was significantly longer than that for the larger target at 25° eccentricity and this was not observed in the binocular RT. To set the suprathreshold at a fixed level, the threshold energy is calculated as \( \log (L + \Delta L) \times A \), where \( L \) is the background luminance; \( \Delta L \), the stimulus luminance; and \( A \), the stimulus size. Because two different target sizes were used in this study, it would be difficult to determine which of the two (target size and luminance) or both factors had exercised the influence. This was in fact a limitation of the present study. In spite of that, the effect of target size on RT in the periphery with a fixed suprathreshold level had become clear in this study.

Several studies have reported that monocular RT increases with eccentricity. Becker et al. (2005) claimed that within the 30° visual field, monocular RT increases with eccentricity by 2.0 ms/° on average in automated kinetic perimetry. Schiefer et al. (2001) concluded that the increase in monocular RT appears to be modest within the central 15° visual field and becomes more dramatic beyond that. The current study however showed a different result. With the same suprathreshold level for both target sizes, neither monocular RT nor binocular RT for the larger target of 0.216° increased with eccentricity (Fig. 2). On the other hand, the target size (0.431°) used in the studies by Becker et al. (2005) and Schiefer et al. (2001) was much larger than those used in the current study. We suspected that the increase in the monocular RT with a target of 0.431° might have been caused by the disparity resulted from the threshold difference between the central visual field and the periphery; and that when the eyes were stimulated at a fixed suprathreshold level, both monocular and binocular RTs might no longer increase with eccentricity. However, more studies on RT with various target sizes will be necessary to further clarify the association between target size and the saturation of responses. Because RT directly affects the kinetic measurement, the present findings are particularly useful for understanding the results of kinetic perimetry in a clinical setting.

In conclusion, we have evaluated the true effects of target size and eccentricity on binocular RT summation. For better assessment of patient’s quality of vision, our findings help understand the binocular interaction in eyes with disordered visual functions and the circumstance in which binocular functions perform effectively. In the future, we intend to investigate how binocular interaction associates with deep suppression or asymmetric retinal sensitivity in patients with peripheral suppression or unilateral ocular diseases.

Acknowledgment

The authors wish to thank Ms. Reiyo Tahara for her editorial support.

References


