A new quantitative method for the assessment of dynamic visual acuity

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Existing methods for the assessment of dynamic visual acuity (DVA) include the following three factors: 1) prediction of target movement, 2) subjective assessment, and 3) response time. We propose a new method which employs forced choice instead of these factors and measured the DVA of athletes and nonathletes to evaluate its validity. In this study, we defined the type of a randomly selected target and its movement as the intensity of visual stimulation (physical quantity), and assessed intensity based on a visual sensitivity to the moving object (psychological quantity). We defined the moving speed of the target (°/sec) that allowed an identification (psychophysical quantity) rate of 75% as the DVA of the person. This method enabled assessment of the DVA, and comparison between the two groups confirmed the validity of the method.

Key words: DVA, psychophysics, athletes


1. Introduction

A number of investigators have pointed out the importance of vision in sports performance (Christenson & Winkelstein, 1988; Hitzman & Beckerman, 1993; Kioumourtzoglou et al., 1998; Stein et al., 1982). In the study of sports and vision (“sports vision”), several types of vision tests have been conducted to assess athletes (Ishigaki, 2002; Kakiyama et al., 2004; Nakamura et al., 2005). The American Optometric Association (AOA) advocates vision measurement consisting of 17 test items. In Japan, this measurement was conducted for sports players by The Sports Vision Academy Society. Eliminating test items that were assessed as unrelated to sports performance, the Society developed a new method by selecting relevant test items, improving the original method, and modifying the assessment criteria (Anan & Maeda, 2001; Ishigaki, 2001). Nowadays, sports vision assessment is based on the total score for 8 test items including static visual acuity (SVA). However, there is need for an even better method of sports vision measurement/assessment (Kohmura and Yoshigi, 2004).

In response, we proposed a new measurement/assessment method in order to reduce the effect of 3 factors (prediction of target movement, subjective assessment, and response time) included in the existing method of horizontal dynamic visual acuity (DVA) assessment using HI-10 (manufactured by Kowa Co., Ltd., Japan) on measurement results. In this study, the effectiveness of this method was investigated through the measurement/comparison of DVA in an athlete group and a non-athlete group.

2. Objective Quantification Method

In order to establish a new objective quantification method for DVA measurement/assessment, improvement was made on the following 3 aspects of testing:

2.1. Target Presentation

In the existing method of measurement, a target (Landolt ring) moves in only one direction, either from left to right or from right to left, and reduces its movement velocity gradually at a certain rate, allowing participants to predict
the direction and timing of the appearance of the target on the display screen. This may affect the assessment of DVA. A study by Fukushima et al (2002) demonstrates that prediction of target movement contributes to the adjustment of the start of eye movement. Taking this factor into account, we developed a new method of DVA measurement in which movement direction (left, right) and velocity (200°/sec, 300°/sec, 400°/sec, 500°/sec, 600°/sec, 700°/sec, 800°/sec, and 900°/sec) were controlled by computer. Using this method, conditions for target emergence were randomly changed to prevent participants from predicting target movement.

2.2. Assessment

In the existing assessment method, participants press a button on a response panel when the location of the target gap is detected to report the location to the examiner. DVA is defined as the highest velocity at which participants identify the target gap location. There is, however, no universal criterion for defining moment when individual participants identify a target gap location. Some participants do not press the button until they are confident of their identification of the target gap while other participants press the button based rather on estimation. This difference among participants may affect measurement results.

Considering this, the forced choice method, a method used in psychophysical research, was adopted in this study when obtaining responses from the subjects. DVA was objectively defined by fitting a psychophysical curve to the correct response rates at the respective target movement velocities. The forced choice method used in this study allowed evaluation of visual stimulus intensity, physical quantity, consisting of 128 combinations of target (8 varieties), velocity (8 varieties), and direction of movement (2 varieties) based on sensitivity, psychological quantity of human eyes against the moving target. The psychological quantity that corresponded to each of the 128 physical quantities was acquired by this method. This quantity is known as “psychophysical quantity,” a basic international system of units (SI). The parameters (maximum correct response rate, minimum correct response rate, amount of curve shift, and curve slope) for psychophysical curve (1) used in this experiment to clarify psychophysical quantity were determined so that square errors of the correct response rates acquired in the experiment would be minimum (Yamamoto and Kitazawa, 2001). Since there were 4 gap locations for each target size, correct responses could be made at a rate of 25% in approximation by psychophysical curve. Therefore, a correct response rate of 25% was regarded as the chance level. The correct response rate of 75% was specified as the reference value for “identified” or “not identified,” and the movement velocity (°/sec) at which the psychophysical curve intersected with the correct response rate of 75% was defined as the DVA of the subject.

\[ p_u(t) = \left(p_{\text{max}} - p_{\text{min}}\right) \int_{-\infty}^{\tau} \frac{1}{\sqrt{2\pi} \sigma_u} e^{-\frac{(t - d_u)^2}{2\sigma_u^2}} \, d\tau + p_{\text{min}} \quad (1) \]

\( p_u \): Rotation velocity
\( p_{\text{max}} \): Maximum correct response rate
\( p_{\text{min}} \): Minimum correct response rate
\( d_u \): Amount of curve shift
\( \sigma_u \): Curve slope

2.3. Response Method

In the existing response method, participants press a button immediately after identifying a target gap location, and DVA is defined as the target movement velocity at the moment the button is pressed. This indicates that the response time needed for the process from target gap recognition to action is included in DVA measurement. This method is effective for investigating the relation between DVA and sports performance. On the other hand, it is unsuitable for the accurate evaluation of DVA itself. In this study, therefore, subjects were compelled to respond using a selector positioned in front of them after the display of each target. This was based on the assumption that the effect of response time on measurement results would be reduced by fitting a psychophysical curve to the correct response rates acquired by the forced choice method and thereby on the assessment of DVA.

3. Methodology

3.1. Subjects

The subjects of this study were 7 male college students (mean age: 20.4±1.2 years) who belonged to a baseball club and 7 healthy male adults (mean age: 21.9±1.7 years)
who had never belonged to any sports club. The former were categorized into an athlete group and the latter into a non-athlete group. All subjects had corrected visual acuity (VA) that was not lower than 1.0 (mean VA: 1.2±0.4). After a thorough explanation of the purpose and methods of the experiment, written consent for voluntary participation in the experiment was acquired from each subject prior to the start of the study.

3.2. Experiment Apparatus

Subjects were asked to sit on a chair with their heads stabilized with a chin-holder. A screen for target display was placed 90 cm ahead of the head of the subject (See Figure 1A). On the screen, a large target was presented at a visual angle of 2.7° (equivalent to a static vision of 0.025) and a small target was presented at a visual angle of 0.9° (equivalent to a static vision of 0.1). Each target size consisted of four Landolt rings with a gap located at the top, bottom, right, or left (See Figure 1B). One of the 8 targets was randomly selected by computer and automatically inserted in a projector to be mirrored on the screen (See Figure 1C). Simultaneously, one of the 8 movement velocities and one of the 2 directions of movement were also randomly selected by computer. As a result, one of a total of 128 combinations of gap location, velocity, and direction was selected in random order. Each time, the selected target moved horizontally on the screen at a certain angular velocity (See Figure 1D).

3.3. Experiment Procedure

As stated earlier, a target randomly appeared on the screen either from the right or left. In order to prevent an increase in correct response rate attributable to correct predictions, subjects were instructed prior to the start of the experiment to focus their eyes initially on the central part of the screen and to track the target visually as soon as it appeared on the screen. They were to indicate gap location by pressing a selector button immediately after the disappearance of the target from the screen (See Figure 1D).

Figure 1. Setup of the apparatus

(A) : Target display screen. A target moves on the semicircle screen located 90 cm ahead of the participant at the angle of 90°. On the screen, a large Landolt ring is presented at a visual angle of 2.7° (equivalent to the static vision of 0.025) and a small Landolt ring is presented at a visual angle of 0.9° (equivalent to the static vision of 0.1).

(B) : A total of 8 large and small Landolt rings are used as targets. Each target size consists of four rings with a gap located at the top, bottom, right, or left.

(C) : Target display apparatus. A target inserted in the projector is mirrored on the screen.

(D) : DVA measurement apparatus. Selection of target/movement direction/movement velocity, operation of rotating mirror for target display, and display of response/measurement result are all controlled by computer dedicated to operation of the apparatus.
4. Results

4.1. Establishment of an Objective Method of DVA Quantification

Figure 2 shows a typical approximation of the correct response rates by psychophysical curve. Using the proposed DVA quantification method, the DVA in this subject was calculated to be 489.4°/sec. A goodness-of-fit test (Pearson’s chi-square test) was performed to assess how accurately the psychophysical curve fit the correct response rates acquired at the respective velocities in the experiment. The bigger the difference between the experimental values and the theoretical values calculated using equation (1), the smaller the p-value becomes. The smaller the difference, the closer the p-value approaches 1. In other words, the closer the p-value approaches 1, the higher the equivalence between the experimental and theoretical values. In the example presented in Figure 2, the p-value for the goodness-of-fit between the correct response rates at the respective velocities and the theoretical values obtained using equation (1) was higher than 0.9 (p>0.9) (Pearson’s chi-square test). This demonstrated the appropriateness of approximating the correct response rates by psychophysical curve.

![Figure 2. Example of approximation of the correct response rates](image)

A typical example of approximation of correct response rates at the respective target movement velocities by psychophysical curve regarding one of the subjects in the athlete group. DVA is defined as the movement velocity at which a psychophysical curve intersects with the correct response rate of 75%.

4.2. Comparison of the Athlete Group and the Non-Athlete Group Using the Objective Quantification Method

The mean correct response rates at the respective target movement velocities were calculated for the 7 subjects in each group and were approximated by psychophysical curve. As a result, the target movement velocities that intersected with a correct response rate of 75% for the small target were 287.5°/sec in the non-athlete group and 400.4°/sec in the athlete group (See the upper chart of Figure 3). For the large target, the corresponding velocities were 396.9°/sec and 577.2°/sec, respectively (See the lower chart of Figure 3). The p-values for the goodness-of-fit between the correct response rates at the respective target velocities were calculated for the athlete group (○ ⋅ ⋅ ⋅) and the non-athlete group (● ⋅ ⋅ ⋅) and were approximated by psychophysical curves (lines).

![Figure 3. Mean correct response rates and their psychophysical curve](image)

For each target size, mean correct response rates (circles) at the respective target movement velocities in the athlete group (○ ⋅ ⋅ ⋅) and the non-athlete group (● ⋅ ⋅ ⋅) are approximated by psychophysical curves (lines).
movement velocities and the theoretical values gained from the psychophysical curve were all higher than 0.9 (p>0.9) (Pearson’s chi-square test).

For the sake of a closer inter-group comparison, DVAs in the individual 7 subjects in each group were calculated from the psychophysical curves and their mean values were obtained. For the small target, the mean values were 302.3±31.2°/sec in the non-athlete group and 389.7±71.0°/sec in the athlete group. For the large target, the mean values were 387.6±81.3°/sec in the non-athlete group and 576.5±24.4°/sec in the athlete group. The mean fitting p-value of the curve approximation for DVAs in the 7 subjects in each group was higher than 0.8 (p>0.8) (Pearson’s chi-square test), demonstrating the excellence of the psychophysical curve in terms of goodness-of-fit (See Table 1). In a comparison of DVAs between the athlete group and the non-athlete group for each size of the targets, the results were p<0.05 (two-sided t-test) for the small target and p<0.01 (two-sided t-test) for the large target. As shown in these results, the DVAs in the athlete group were significantly higher than those in the non-athlete group regardless of target size (See Figure 4).

5. Discussion

In this study, a new method of DVA measurement was developed, which contributed to quantitative DVA assessment using the forced choice method. The validity of this new method was verified from the fact that a significant difference in DVA was demonstrated between the 2 subject groups when using it for comparison. It is also considered to be useful for the measurement, assessment, and comparison of DVAs from which the earlier-mentioned 3 factors are eliminated. Based on recent investigations of relationships between DVAs and eye movements using electro-oculogram (EOG), it has been suggested that early saccadic movement is needed for accurate identification of a target moving at high velocity (Kohmura et al., 2008). Our assessment method, in which eye movement performance is reflected in DVA, is evidently effective for the evaluation of such performance through psychophysical behavioral indicators.

In measurements using the existing method, it was reported that no significant difference in DVA was detected between the athlete group and the non-athlete group when target size was large and that the difference between the 2 groups increased with the decrease in size of target (Ishigaki and Miyao, 1993). In this study, however, a significant difference was observed between the 2 groups even when using the large target. This suggests a possibility of clarifying inter-group differences in DVA regardless of target size when a comparison is made with a focus on DVA alone, eliminating the potential effects of prediction of target movement, subjective assessment, and response time.

A further accumulation of data of correct response rates for the respective target sizes at the respective target movement velocities may be helpful for future evaluation of eye movement performance. This method, when its efficiency is improved further, may also be useful for

### Table 1. DVA and p value when fitting a psychophysical curve

<table>
<thead>
<tr>
<th></th>
<th>Nonathletes</th>
<th>Athletes</th>
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<tbody>
<tr>
<td></td>
<td>AVE.</td>
<td>SD</td>
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<tr>
<td><strong>Small</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DVA value (°/sec)</td>
<td>302.3</td>
<td>±31.2</td>
</tr>
<tr>
<td>Fitting p value</td>
<td>0.8</td>
<td>±0.1</td>
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<tr>
<td><strong>Large</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DVA value (°/sec)</td>
<td>387.6</td>
<td>±81.3</td>
</tr>
<tr>
<td>Fitting p value</td>
<td>0.9</td>
<td>±0.1</td>
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The mean DVAs and their standard deviations in the 7 subjects in each group for the large/small target, and the fitting p-values of the psychophysical curves against the correct response rates and their standard deviations
examination of eye movement performance after recovery from eye disease or after eye muscle training.

References


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