Paper

The relationship between dynamic visual acuity and saccadic eye movement

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The purpose of this study was to clarify the relationship between dynamic visual acuity and saccadic eye movement. Twenty-seven young adults, mean age 21.3±2.4 years, participated in this research. Electrooculography (EOG) was employed for analysis of the saccadic eye movement. Saccadic eye movements were recorded during measurements of dynamic visual acuity. Peak velocity, angle, and latency of saccadic eye movement were measured employing EOG. As a result, there were no relationships between dynamic visual acuity and peak velocity and angle of saccadic eye movement. However, there was significant correlation between dynamic visual acuity and latency of saccadic eye movement (at target velocity 49.5 rpm: r=-.734, p=.000, 47.6 rpm: r=-.619, p=.001, 45.1 rpm: r=-.538, p=.004, 42.5 rpm: r=-.600, p=.001, 40.0 rpm: r=-.478, p=.012). It was suggested that early start of saccadic eye movement is one of the important factors in the accurate discrimination of a moving target at high speed.

Key words : Electrooculography, Latency, Peak Velocity

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1. Introduction

While static visual acuity for identifying a stationary target is one of the basic visual functions, there are many other important visual functions. In particular, the visual function designed to identify moving targets has been examined by a considerable number of researchers. Brug (1966) and Ludvigh & Miller (1958) have published a number of reports on dynamic visual acuity (DVA), the ability to identify a target which moves horizontally in front of the eyes. DVA is reported to decline with increasing age after the 20th year of life (Burg, 1966; Ishigaki & Miyao, 1994). In general, the ability to identify a moving object is considered essential for daily activities, such as driving a car or participation in sports activities. It has been reported that athletes have excellent DVA (Stine et al., 1982; Ishigaki & Miyao, 1993), and the effect of training on DVA has also been examined (Long & Rourke, 1989).

While the methods and results of DVA measurement have often been reported, few researchers have examined the elements and mechanisms of DVA. Hoffman et al. (1981) have reported that the human attributes involved in DVA are the resolving power of the retina, peripheral awareness, oculomotor abilities, and the psychological ability of the individual to interpret what is seen. Measured and assessed by a method that requires the individual to track a target which moves horizontally, DVA is thought to have a particularly strong association with eye movement. Some research has been conducted on the relation between eye movement and DVA (Brown, 1972; Reading, 1972). Among the various types of eye movement, saccadic eye movement plays a central role in tracking a target which moves at a high velocity; and DVA is thought to be related to saccadic eye movement (Barmack, 1970; Ishigaki, 2000).

Reading (1972) reported on eye movement during DVA measurement based on the results of analysis utilizing electrooculography (EOG). The velocity of the target, the object of analysis in his study, was low in comparison with that employed by current DVA measurement methods. A similar tendency is observed in other studies on DVA and eye movement conducted around the same period (Barmack, 1970; Brown, 1972). What is more, these studies were rather inadequate in terms of the number of subjects examined in the analysis of DVA and eye movement. In the studies on saccadic eye movement, peak velocity and latency, which is the starting time of eye movement, are often used as an index (Fukushima et al., 2000; Moschner & Baloh, 1994). According to Moschner & Baloh (1994), the saccadic eye movement of young subjects has shorter latency and higher peak velocity in comparison with that of elderly subjects. Brown (1972) has reported that latency becomes longer as the velocity of the target decreases when the target velocity in DVA measurement is comparatively slow. Considering these study results, there may be merit in investigating the relation between DVA and saccadic eye movement for the sake of further clarification.

EOG is a representative method for the analysis of eye movement. Taking advantage of the fact that the cornea has positive electric potential to the retina and the fact that voltage change associated with eye movement has a near proportional relation to eye rotation angle, EOG detects any electric change through the electrodes applied to the skin surrounding the eyes (Arai et al., 2001; Yonemura, 2007; Yamauchi et al., 2003). Because of problems in obtaining accurate positional information in the analysis of eye movement, EOG is thought to be inappropriate for the detection of prolonged eye movement (Kuno et al., 2003; Sakashita et al., 2006). On the other hand, EOG does not require any apparatuses that block vision, such as the video camera that needs to be placed on the examinee when employing the corneal reflex method, another method used in eye movement measurement. Therefore, EOG is less burdensome for the subject than other methods, though the electrodes applied to the skin do have the potential to cause slight discomfort. Employment of EOG also makes it possible to examine a relatively large number of study subjects and to detect a wide range of eye movement (Miyashita et al., 2008; Sakashita et al., 2006).

In actuality, there are relatively few studies that have been published on the mechanism of DVA. Much of the relation between DVA and saccadic eye movement has yet to be clarified. It is meaningful to conduct a basic investigation of DVA in order to elucidate the mechanism and relevant elements of DVA, and to contribute to the enhancement of DVA measurement accuracy. This study aimed to quantify the characteristics of saccadic eye movement and to investigate the relation between DVA and saccadic eye movement.

2. Procedures

2.1. Subjects

The subjects of this study were university undergraduate and graduate students whose corrected or uncorrected visual acuity was 1.0 or higher (static visual acuity) and who exercised on the regular basis or who had experienced 6 to 12 years of participation in sports activities. Subject selection was not based on specialization in any particular sport or sports. The number of the subjects was 27 (including 8 females); namely, 9 subjects with an uncorrected visual acuity of 1.0 or higher, 13 contact lens wearers, and 5 wearers of framed corrective lenses. The mean age of subjects was 21.3±2.4. Prior to entry into the study, written informed consent was obtained from the individual subjects after a detailed explanation of the content of the experiment and the object of the study. This study was conducted with the approval of the Research Ethics Committee of the Juntendo University Graduate School of Health and Sports Science.

2.2. Measurement of Dynamic Visual Acuity (DVA)

DVA measurement was conducted with the use of a dynamic visual acuity analyzer (Kowa Co. Ltd. HI-10). In the HI-10, a Landolt ring, which is projected and reflected by a mirror, moves from left to right on a semi-circular screen with a visual angle of 90º. The screen was situated 80cm in front of the subject. The subject was required to track the Landolt ring and identify the gap in the ring. The subject was also directed to place his or her chin on the chin support and to not move his or her head. The Landolt ring has a visual angle of 10 minutes. Use of a larger-sized Landolt ring causes the measurement values to be topically distributed around the peak value (Kohmura & Yoshigi, 2004). Considering this, a smaller Landolt ring was adopted in this study.

The DVA of each subject was measured according to a method in which the speed of the target gradually decreases. The velocity of the target was set initially at 49.5rpm, the maximum velocity of this measurement device, and reduced gradually thereafter. The subjects were required to flip a switch at the moment the ring gap was identified and to identify the position (up, down, right, or left) of the gap before the Landolt ring appeared at the center of the screen. The rotating velocity at the moment the subjects correctly flicked the switch was recorded as the DVA value. Measurement was repeated until the subjects correctly identified the position of the ring gap 10 times. The subjects were directed to exercise caution in correctly identifying the position of the gap. The mean value of DVA for each subject was calculated from the DVA values for the 10 correct measurements, excluding the maximum and minimum values. The mean value obtained by this method was used as the DVA value for the individual subjects.

2.3. EOG Recording

Following earlier studies (Brown et al., 2006; Reading,1972; Munoz et al., 1998), all EOG signals were electrically amplified by an amplifier (EOG100C) and were digitally recorded with the use of a data collection and analysis system (Biopac Systems Co. Ltd.: MP150; Monte System Corporation). Using AcqKnowledge software, peak velocities, latencies, and angles were calculated as the indexes for analyses. An electrode was placed laterally to each eye and a ground electrode was attached to the frontal region of the head. Trigger stimulus was input to another channel at the moment the eye-tracking target appeared on the screen. Voltage and angle were calibrated with respect to each subject and to each measurement.

The peak velocity of the first saccadic eye movement after the input of the trigger stimulus was calculated. In terms of latency, the length of time from the input of trigger stimulus to the point at which the velocity of saccadic eye movement (including peak velocity) exceeded 100 degree/sec was calculated. The change in angle from the point at which the velocity of saccadic eye movement exceeded 100 degree/sec to the point at which it fell below 100 degree/sec was also calculated. Though the reference velocity varies depending on the researcher, the velocity of 100 degree/sec was adopted in this study based on previously published study literature (Yonemura, 2007). Depending on the subject, when the velocity is 37.5rpm or lower, more than one peak of saccadic eye movement can be observed. Considering this, only those angles obtained when the target velocity was 40rpm or higher were analyzed in this study.

All the saccadic eye movement values with the above-mentioned indexes were averaged to determine the central value for each subject at each velocity, with which analyses were conducted. In principle, any case which failed to fulfill the above-mentioned criteria, which lacked peak velocity, latency, or angle data, or which had major saccadic eye movement prior to the input of trigger stimulus was excluded from analysis.

Any change in the velocity of the target during the recording of EOG can affect the elements of saccadic eye movement. The method in which the subject is required to stop the measurement device at the moment he or she identifies the position of the gap in the target Landolt ring whose velocity is gradually decreasing presents difficulties in the unification of analytical items due to the fact that measurement conditions and recording times can vary depending on subject or measurement. Considering these factors, EOG recording was conducted in this study as follows:

EOG was recorded utilizing a DVA measurement device with fixed target transfer velocity. Each subject was directed to track the target until it passed ahead of him or her 10 times. The examiner counted the number of passes and stopped the measurement device after the 10th pass of the target. No matter whether the subject identified the gap in the Landolt ring or not, EOG continued to be recorded until the 10th pass of the target. The subject was required to identify the position of the ring gap at the moment it was identified and to continue tracking the target thereafter until it passed ahead of him or her 10 times. The results were recorded by the examiner. Velocity was set at 15 levels with approximate intervals between levels set at 2.5rpm. Due to the mechanical constraints of the measurement device, velocity intervals of exactly 2.5rpm were difficult to achieve. The 15 levels of velocity that were adopted were 49.5, 47.6, 45.1, 42.5, 40.0, 37.5, 35.0, 32.6, 30.0, 27.5, 25.0, 22.5, 19.9, 17.5, and 15.0 rpm.

2.4. Analytical and Statistical Processing

The level of statistical significance in this study was 5%.

2.4.1. Relation between DVA and Correctness of Identification

In order to record EOG under stable conditions, the velocity of the moving target and the number of passes were fixed in a unified manner. While DVA measurement is customarily conducted with a fixed target velocity (Burg, 1966, Millslagle, 2004), only the subjects' identification of the ring gap was pursued in this study for the sake of EOG recording. Both the ability to identify the target at a declining velocity and the ability to identify the target moving at a certain velocity can be regarded as the ability to identify a target which moves horizontally; therefore, it is necessary to examine the relation of these two abilities. Since only the subjects' identification of the ring gap was measured in this study, the Pearson's correlation coefficients of the number of correct identifications during the 15-level EOG recording and the evaluated values of DVA were calculated and the partial correlation coefficients thereof, excluding the effects of static visual acuity, were determined.

2.4.2. Relation between DVA and Elements of Saccadic Eye Movement

The relationships between DVA values and the elements of saccadic eye movement were analyzed. A decline of eye movement velocity and an extension of latency were expected when the velocity of the target was low. If the velocity of the target at which most of the subjects correctly identified the ring gap had been used for analysis, the relation between DVA and the respective elements might have been affected. In the EOG record for the velocity of 37.5rpm or lower, the number of the subjects who misidentified the ring gap was less than one third of all the subjects, an extremely small value. Therefore, an analysis of saccadic eye movement recorded when the velocity of the target was 40rpm or higher was conducted. Pearson's product-moment correlation coefficient was used for correlation analysis.

The subjects who correctly and incorrectly identified the ring gap at a target velocity of 40rpm or higher were compared and analyzed in terms of latency. t-test was used for the comparison.

3. Results

From the results of the analysis of the relation between DVA and the correctness of identification during EOG recording, the correlation coefficient was determined to be 0.672 ($p = 0.000$). The partial correlation coefficient between DVA and correct identification excluding the effect of static visual acuity was determined to be 0.661 ($p = 0.000$).

Table 1 shows the mean values and SDs of the elements of eye movement at the velocity of 40.0rpm or higher. Table 2 shows the correlation coefficients between the evaluated values of DVA and the elements of saccadic eye movement. There were significant correlation coefficients between latency and the evaluated values of DVA (target velocity 49.5 rpm: $r = -.734$, $p = .000$, 47.6 rpm: $r = -.619$, $p = .001$, 45.1 rpm: $r = -.538$, $p = .004$, 42.5 rpm: $r = -.600$, $p = .001$, 40.0 rpm: $r = -.478$, $p = .012$).

Table 3 shows the results of the comparison of latencies between the subjects who correctly and incorrectly identified the ring gap. The numbers of subjects of the respective groups (C: subjects who correctly identified; M: subjects who misidentified) at the respective velocities were as follows: 49.5 rpm: C-10, M-17, 47.6 rpm: C-11,

Table1. Saccadic eye movement measurements

Target Velocity (rpm)	49.5		47.6		45.1		42.5		40.0	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Peak Velocity (dgree/sec)	668.8	106.3	665.1	91.4	673.3	80.2	665.1	88.9	666.1	90.5
Latency (sec)	.111	.016	.108	.018	.108	.015	.111	.015	.112	.015
Angle (dgree)	57.1	10.3	57.3	10.4	57.2	10.5	56.5	10.4	57.3	10.2

M-16, 45.1rpm: C-11, M-16, 42.5 rpm: C-16, M-11, 40.0 rpm: C-16, M-11. Figure 1 shows a waveform chart of the subjects with correct and incorrect identification during the EOG recording.

4. Discussion

In this study, investigators attempted to quantify the characteristics of saccadic eye movement and examine the relation between DVA and saccadic eye movement. There are both advantages and disadvantages in analyzing saccadic eye movement by the EOG method. Considering that this method was suitable for the clarification of the characteristics of saccadic eye movement when tracking the target with the use of a DVA measurement device, however, the EOG method was adopted in this study. Since it was difficult to obtain accurate positional data for eye movement by the EOG method (Miyashita et al.,2008; Sakashita et al., 2006) and to define the transferred angles in saccadic eye movement with multiple peak velocities, analysis of angles was only partially conducted.

As a result of analysis, it was clarified that the correlation coefficient between the number of the correct answers and the evaluated values of DVA was 0.672 and the partial correlation coefficient was 0.661 when excluding the influence of static visual acuity. Although both expressed the ability to discern a target which moved horizontally, a sufficiently high correlation coefficient was not obtained. This may have resulted from the difference in measurement methods and from the choice of the number of correct answers as an analysis object. However, both evaluation items have been used for DVA assessment and both have been thought to express the ability to identify a target which moves horizontally. The relation between these methods in terms of DVA is not thought to be affected by static visual acuity. Since the number of correct answers were all the data of DVA obtained during EOG recording in this study, the relation

Table2. Correlation coefficients between DVA and elements of saccadic eye movement

		Target Velocity (rpm)				
		49.5	47.6	45.1	42.5	40.0
Peak Velocity	r	.076	.072	.056	−.090	.059
	p	.707	.721	.781	.656	.770
Latency	r	−.734 **	−.619 **	−.538 **	−.600 **	−.478 *
	p	.000	.001	.004	.001	.012
Angle	r	.155	.012	−.081	−.062	.074
	p	.439	.954	.689	.759	.713

*:p<.05,**:p<.01

Table 3. Comparison of latencies between correct and incorrect answer

Target Velocity (rpm)	49.5		47.6		45.1		42.5		40.0	
Latency (sec)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
correct answer	.101	.012	.100	.018	.105	.013	.105	.014	.110	.012
miss	.117	.014	.114	.015	.110	.016	.121	.010	.115	.018
t-value	2.83		2.21		.83		3.26		.83	
p	.01		.04		.41		.00		.41	

between the saccadic eye movement and the evaluated values of DVA was emphasized in the analysis.

In terms of peak velocities and angles, no significant correlation coefficients were found between DVA and elements of saccadic eye movement. Meanwhile, significant correlation coefficient was seen in terms of latency (Table 2). From this, it was suggested that the subjects who exhibited proficient DVA tended toward being quick to begin saccadic eye movement. Latency of saccadic eye movement has been used as one of the evaluation indexes. It has been reported that latency becomes shorter with the development of saccadic eye movement (Fukushima et al., 2000) and that young subjects have shorter latency than elderly subjects do (Moschner & Baloh, 1994; Munoz et al., 1998). According to Fukushima et al. (2000), latency involves a complex combination of procedures in brain for visual information processing from the trigger towards visual acuity to the start of saccadic eye movement and for exercise signal transformation. They reported the development of latency. DVA has been reported to develop at around the time that latency develops (Ishigaki & Miyao, 1994). While the DVA of athletes often draws public attention, professional cricket players have been reported to have shorter latency than low-level cricket players have (Land & McLeod, 2000). Considering these reports, the results of this study which showed a significant relation between DVA and latency cannot be judged as inconsistent.

The subjects who gave correct answers had shorter latency than those who gave incorrect answers (Table 3). This result was not unexpected due to the fact that there was an association between the evaluated values of DVA and the correctness of the answers during the recording of EOG. It should be considered, however, that this result could include the subjects who answered correctly or incorrectly only at a certain velocity. Figure 1 is a waveform chart of a typical case. It may be possible that correct identification of a target which moves rapidly becomes difficult when a delay in the start of saccadic eye movement occurs. Correct identification of the target is not exclusively attributed to an early start of saccadic eye movement. Considering that the target disappears from the screen in approximately 0.3 second at a velocity of 49.5rpm, however, an early start of saccadic eye movement may be one of the conditions for correct identification.

Judging from the results of this study, it may be difficult to conclude that DVA becomes better as the peak velocity becomes higher and as the angle becomes

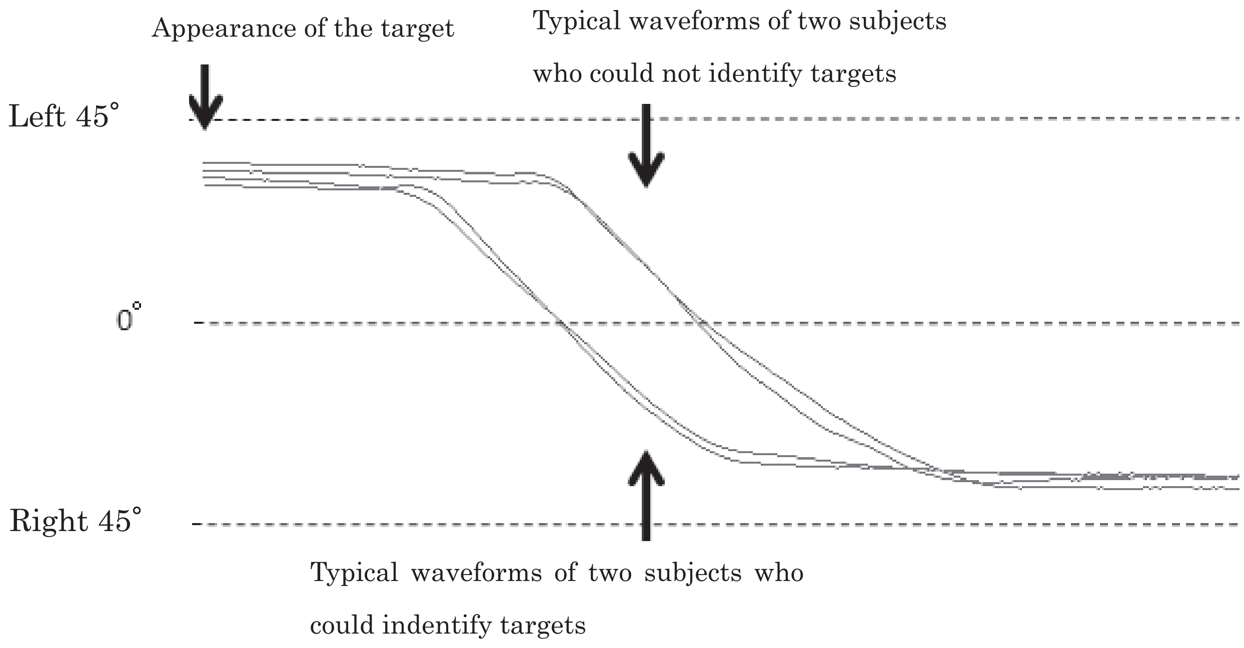

Figure1. Image of typical EOG at a target velocity of 49.5 rpm

larger (Table 2). There is a study reporting that the peak velocity of saccadic eye movement of young subjects is higher than that of elderly subjects (Moschner & Baloh, 1994). The results of this study could be affected by the fact that all the subjects were approximately the same age and that the experiment required them not only to move their eyes quickly but also to track and identify the target as well. Considering that peak velocity develops earlier than both DVA and latency develop (Ishigaki & Miyao, 1994; Fukushima et al., 2000), however, peak velocity of saccadic eye movement may be poorly linked to the level of DVA.

When a subject tracks the moving target, he or she does not perform only saccadic eye movement at a constant velocity but also various types of complex eye movement. In this study, the mechanism of eye movement and accurate positional information of the gaze were not clarified. Therefore, the analyses in this study are supposed to be insufficient in terms of the accuracy of eye movement towards the target. In an earlier study, positional and velocity errors of eye movement towards a target were analyzed, though not employing the EOG method (Brown, 1972). While no significant relation was observed between the transfer angle in one saccadic eye movement and DVA in this study, it will be necessary to consider positional error and angle in future investigations. Considering that a significant relation was observed in this study between latency and DVA, some relation may be observed between the ability to track the target correctly and the level of DVA. In recent years, various types of extremely expensive and highly-accurate eye mark recorders have become available. Quantification of eye movement with the use of one of these newly developed devices will allow researchers to accomplish more detailed analyses. Eye movement employed in the acquisition of a target moving at a declining velocity was not analyzed in this study. This should be investigated with the use of more advanced research methods and equipment in the future studies, while paying attention to partial differences in measurement methods.

5. Conclusion

Based on the results of the analyses of saccadic eye movement by the EOG method in this study, it is suggested that DVA has a stronger relation with latency than with the peak velocity of saccadic eye movement and angle. While having complex physiological elements, latency is reported to develop at around the time when DVA develops. It is speculated that the subjects who are excellent in DVA tend to have a shorter latency. It will be necessary to develop research methods and equipment for the quantification of the accuracy of tracking a target in DVA measurement and to investigate this field further in the future.

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