Objective Measurement of Distance Visual Acuity Determined by Computerized Optokinetic Nystagmus Test

Joon Young Hyon,1,2 Hwan Eok Yeo,3 Jong-Mo Seo,4 In Bum Lee,5 Jin Hak Lee,1,2 and Jeong-Min Hwang1,2

PURPOSE. To investigate the efficacy of a computerized optokinetic nystagmus (OKN) test in evaluating the objective distance visual acuity and to determine the correlation between subjective and objective visual acuities.

METHODS. This prospective, noninterventional study included 83 eyes of 83 volunteers. Objective visual acuity was defined as the smallest size stripe that evoked the OKN response (induction method) or as the smallest dot size that suppressed the OKN response (suppression method). Distance visual acuity was measured by computerized OKN and infrared oculography at distance. The reproducibility of the test was evaluated by intraclass correlation coefficient (ICC). The correlation between measured objective and subjective visual acuity was then evaluated with linear regression analysis. Subjects were grouped according to their objective visual acuity, and the mean subjective visual acuities were compared with those of the objective visual acuity groups.

RESULTS. There was a significant correlation between distance objective and subjective visual acuity (correlation coefficient $R^2$; induction method: suppression method $= 0.566:0.832, P < 0.05$). The mean subjective visual acuity was significantly different in the objective visual acuity groups (Welch’s ANOVA, $P = 0.000$ for induction and suppression methods). The objective visual acuity test showed good reproducibility (ICC; induction method: suppression method $= 0.945:0.988, P < 0.05$).

CONCLUSIONS. The computerized OKN test could serve as an objective and reliable tool for assessing distance visual acuity.

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Clinical and Epidemiologic Research


Conventional visual acuity tests with vision charts rely heavily on the patient’s subjective statements concerning his or her ability to see the target. Visual acuity measurement can be challenging in patients with significant visual impairment and in patients with functional visual loss. The preferential-looking technique, visual evoked potential, and optokinetic nystagmus (OKN) testing have been attempted for the objective assessment of visual function.1–3

OKN represents a series of reflective smooth-pursuit movements followed by a quick-return movement, all of which are induced by an object moving across the visual field. However, the OKN test is usually performed at near working distance, and the assessed near visual function may not be translatable to distance visual function.4–6 Although distance visual acuity and near visual acuity correlate to a certain degree, they are not interchangeable.7–9

Other researchers have reported that OKN is useful in assessing visual function.10–12 However, there is no published report assessing visual acuity with OKN at a distance. We developed a new assessment system to measure objective visual acuity at distance by computerized OKN. The purpose of this study was to investigate the efficacy of a computerized objective visual acuity test involving OKN induction and the suppression method at distance and to evaluate the correlation between subjective and objective visual acuities.

MATERIALS AND METHODS

This study adhered to the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board of Seoul National University Bundang Hospital. Eighty-three eyes of 83 volunteers (16 men and 67 women) were included in the study. Informed consent was obtained from the subjects after explanation of the nature and possible consequences of the study. The subjects were prospectively enrolled between December 2007 and February 2009. The mean patient age was 48 ± 11.9 (range, 20–68) years. Exclusion criteria were a physical condition causing inability to complete the test, ocular motility disorders such as congenital nystagmus or strabismus, and age younger than 15 years (because reliability of visual acuity measurements is insufficient at this and younger ages).

Ophthalmic examination with slit lamp biomicroscopy, tonometry, and funduscopy revealed cataracts in two subjects, a corneal opacity in one subject, and high myopia (≥6 D) in three subjects. Other than mild to moderate refractive errors, no abnormal ocular findings were noted in the remaining 77 subjects.

To evaluate the correlation between subjective and objective visual acuities across the full range of measurement, we measured visual acuity without refractive correction (in 56 subjects) or with plus lens fogging (in 27 subjects).

Subjective distance visual acuity was measured with the Early Treatment Diabetic Retinopathy Study (ETDRS) chart in patients with

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visual acuity better than 20/200, or with the Feinbloom chart in patients with visual acuity of 20/200 or worse.

Objective visual acuity was determined by analyzing the OKN responses measured by one experienced examiner. Each subject was asked to rest his or her head on a chin cup and a horizontal forehead rest to maintain head position during the test. Alternating black and white vertical stripes (contrast, 85%), serving as horizontal optokinetic stimuli, were projected by a digital projector (CP-X300, Hitachi, Tokyo, Japan) on a 127-in. (diagonally measured) screen located 10 feet in front of the patient in a dark room. The subjects were instructed to stare at the center of the screen while keeping the stripes in focus during the test. An infrared camera attached to the headrest frame captured eye movements during OKN stimulation (Fig. 1). Captured video was imported into oculography software. The presence of nystagmus was determined by image analysis (Fig. 2).

In the induction method, the width of stripes varied from 0.6° (0.833 cyc/deg) to 0.2° (2.5 cyc/deg) with a decrement of 0.1° in each step. The stripes were presented from right to left at a velocity of 10 deg/s. Objective visual acuity by the induction method was defined as the smallest size, or the smallest visual angle, of the stripe that induced an OKN response. In the suppression method, stripes large enough to elicit an OKN response (20°) were presented from right to left at a velocity of 10 deg/s, and a suppression stimulus (a white dot) was superimposed in the center of the screen for 10 seconds. The size of the suppression stimulus increased from 0.036° to 0.36° in eight steps, and objective visual acuity by the suppression method was determined to be the earliest step of the suppression stimulus (the smallest size white dot) that suppressed the OKN response.

All measurements were performed in triplicate. If there were any repeated values among the three measurements, they were taken as the result. If there were no repeated values among the three measurements, the median value was taken as the result.

The correlation between logMAR visual acuity and objective visual acuity was evaluated by linear regression analysis. Subjects were grouped according to their objective visual acuity, and the mean subjective visual acuity in each of the objective visual acuity groups were compared by using Welch’s analysis of variance (ANOVA) and Dunnett’s multiple comparison test. The reproducibility of the objective visual acuity test was determined by intraclass correlation coefficient (ICC). Differences reaching $P < 0.05$ were considered statistically significant (SPSS ver. 15.0, SPSS, Chicago, IL).

**RESULTS**

The mean subjective logMAR visual acuity was $1.01 \pm 0.78$ (mean ± SD). The mean objective visual acuity was $0.30 \pm 0.13$ (arbitrary unit) with the induction method. With the suppression method, 25 eyes did not respond (OKN response was not suppressed) even to the largest suppression stimulus. The mean objective visual acuity among the responders was $3.81 \pm 2.90$ (arbitrary unit). There was a statistically significant linear correlation between subjective and objective visual acuities, with both the induction ($R^2 = 0.566, P < 0.019$) and the suppression ($R^2 = 0.832, P < 0.001$) methods (Figs. 3, 4).

When objective visual acuity was determined by the induction method, the mean subjective logMAR visual acuity was significantly different among the groups, with objective visual acuity of 0.2, 0.3, and 0.4. Mean subjective logMAR visual acuity was not significantly different among the groups, with objective visual acuity of 0.4, 0.5, and 0.6 (Table 1, Fig. 5). With the suppression method, mean subjective logMAR visual acuity was significantly different among the groups with objective visual acuity of 1, 5, and 8 and those who were not suppressed when the suppression method was used (Table 2, Fig. 6).

Objective visual acuity testing with both the induction method and the suppression method showed good reliability among the three sets of objective visual acuity measurements (Table 3).

**DISCUSSION**

OKN is a series of involuntary ocular movements elicited by visual stimulus across the visual field. It involves the macula, the lateral geniculate body, the occipital lobe, the cerebellar flocculus, the paramedian pontine reticular formation, and the ocular motor neuron. Many investigators have reported the feasibility of the OKN test for measuring visual function. However, one of the pitfalls in interpreting the OKN response as a parameter of visual function is that the OKN stimulus is usually presented at near, whereas conventional visual acuity and the requirement criteria for visual impairment are usually measured at distance.
In earlier work, we developed a computer-assisted OKN vision test system to evaluate objective visual acuity at near. In this study, we modified the previous system to measure objective visual acuity at distance. A new distance OKN vision test system introduced a 127-in. screen, instead of a 17-in. monitor, to project OKN stimuli onto the wide range of visual fields. An adequate test distance was calculated to get the same amount of visual angle as the OKN stimulus from the 17-in. monitor screen at near. We also developed a computer program to generate OKN stimuli and analyze OKN responses from the captured motion pictures. As shown in Figure 2, this software provides real-time captured video from the infrared oculography, which allows the physician to monitor the status of pupil acquisition, fixation, and accommodation and to determine whether the patient is cooperating or malingering. This monitoring window would be especially useful in uncooperative or noncommunicative patients who may lose visual fixation of the target, intentionally or unintentionally, during the test.

Our results showed that there was a significant correlation between objective visual acuity by two OKN methods and subjective visual acuity at distance. Objective visual acuity measurement with OKN methods also had good reproducibility. Linear regression showed that the subjective visual acuity had a higher correlation with the suppression method than with the induction method. This difference may be partly due to the similar nature of visual acuity, which is recognition visual acuity, measured by the suppression method and with a Snellen chart.

We used only one direction (right to left) for OKN stripes—that is, the temporonasal direction for the right eye and the nasotemporal direction for the left eye. Although monocular OKN is known to be nearly symmetrical for stimulus in the temporal-to-nasal and nasal-to-temporal directions in adults without any history of binocular disruption in early life, all subjects in this study underwent a history and pretest ocular examination to exclude any ocular disease, including strabismus or congenital cataract.
In the induction method, both the central and peripheral retina would contribute to the OKN response. However, in the suppression method, the central retina gains input to suppress OKN, whereas the peripheral retina still has input to generate OKN. Abadi and Pascal\textsuperscript{15} have reported that although the peripheral retina also provides input to generate OKN, the OKN response is strongly influenced by the central retina. Thus, this central dominance of OKN could explain the suppression of OKN with two opposite stimuli to those for the central and peripheral retina.

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**TABLE 1.** Mean Distance logMAR Visual Acuity in Objective Visual Acuity Groups by the Induction Method

<table>
<thead>
<tr>
<th>Objective Visual Acuity by Induction Method</th>
<th>Distant logMAR VA (Mean ± SD)</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>0.47 ± 0.58</td>
<td>44</td>
</tr>
<tr>
<td>0.3</td>
<td>1.16 ± 0.40</td>
<td>11</td>
</tr>
<tr>
<td>0.4</td>
<td>1.69 ± 0.34</td>
<td>15</td>
</tr>
<tr>
<td>0.5</td>
<td>1.95 ± 0.41</td>
<td>6</td>
</tr>
<tr>
<td>0.6</td>
<td>1.94 ± 0.36</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>1.01 ± 0.80</td>
<td>83</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Arbitrary units.
Although mean subjective visual acuity differs among certain objective visual acuity points, we also found that there was a wide range of subjective visual acuities at each objective visual acuity point. This range of acuities would make it difficult to predict precise subjective visual acuity on the basis of the measured objective acuity in the individual patient. In practice, objective visual function could be assessed more effectively by combining the induction and suppression methods. In the induction method, 87.8% (36/41) of the patients whose vision was 20/200 or better responded to the smallest stimulus. In the suppression method, on the contrary, the OKN response was not suppressed with the largest suppression stimulus in 91.3% (21/23) of the patients whose vision was 20/800 or worse. This result indicates that the induction method would be helpful in the patients whose visual acuity is expected to be very poor (20/800 or worse), whereas the suppression method would be more feasible in the patients whose visual acuity is expected to be 20/200 or better.

Another limitation of this study is that each test method measured a different type of visual acuity. The induction method evaluated the minimum resolvable acuity, since the OKN response is elicited only when the patient perceives the separation of the stimulus stripes. Meanwhile, the suppression method evaluated the minimum visual acuity that the patient must have to recognize the presence of a suppression stimulus. Subjective visual acuity testing measured the recognition visual acuity (letter) and resolution visual acuity (Landolt). We assumed that each type of visual acuity is not independent from the others. Still, certain types of visual acuity could be more greatly affected in patients with ocular disease.

We tested cooperative volunteers. Although the subjective visual acuity test is based on the involuntary OKN response and equipped with the monitoring device to surveil the status of gaze during the test, it still requires the patient’s ability or intention to communicate or cooperate.

In conclusion, objective distance visual acuity measured with a computerized OKN system correlated well with subjective visual acuity, with good reproducibility. Further studies to enhance the effectiveness and efficiency of the test, along with development of the various patterns of induction and suppression OKN stimuli, are warranted.

**Table 2.** Mean Distance logMAR Visual Acuity in the Objective Visual Acuity Groups by the Suppression Method

<table>
<thead>
<tr>
<th>Objective Visual Acuity by Suppression Method*</th>
<th>Distance logMAR VA (Mean ± SD)</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.14 ± 0.26</td>
<td>28</td>
</tr>
<tr>
<td>5</td>
<td>0.82 ± 0.46</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>0.87 ± 0.40</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>1.40 ± 0.20</td>
<td>14</td>
</tr>
<tr>
<td>Not suppressed</td>
<td>1.90 ± 0.32</td>
<td>25</td>
</tr>
<tr>
<td>Total</td>
<td>1.01 ± 0.80</td>
<td>85</td>
</tr>
</tbody>
</table>

* Arbitrary units.

**Table 3.** Reliability Analysis for Distance Objective Visual Acuity Testing

<table>
<thead>
<tr>
<th>Method</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Induction</td>
<td>0.30 ± 0.12</td>
<td>0.31 ± 0.14</td>
<td>0.31 ± 0.13</td>
<td></td>
</tr>
<tr>
<td>Suppression</td>
<td>3.79 ± 2.93</td>
<td>3.76 ± 2.88</td>
<td>3.67 ± 2.83</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 6.** Distance logMAR visual acuity among objective visual acuity (determined by the suppression method) groups. Results are presented as in Figure 4. Statistically significant difference, $P < 0.05$. Error bars, 95% CI.
References


