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Three-rods test as drivers' license vision test from the viewpoint of reproducibility, eye deviation, and functional visual acuity

Toshihiko Matsuo [a,b,*], Yuki Morisawa [c], Takeshi Yoshinaga [c], Mari Ikebe [c], Ryosuke Hosogi [c], Chie Matsuo [b]

[a] *Department of Ophthalmology, Okayama University Medical School and Okayama University Hospital, Japan*

[b] *Okayama University Graduate School of Interdisciplinary Science and Engineering in Health Systems, Japan*

[c] *Undergraduate Course for Medicine, Okayama University Medical School, Japan*

[*] Corresponding author.

E-mail address: matsuot@cc.okayama-u.ac.jp (T. Matsuo).

Abstract

Background: Three-rods test is required as depth perception vision test to obtain motor vehicle license to drive taxies, buses, and trucks in Japan. Functional visual acuity is measured automatically by successive visual target presentation in a fixed period of time. This study examined three-rods test from the viewpoint of reproducibility, eye deviation, and functional visual acuity to assess the feasibility for drivers' license vision test.

Methods: At three-rods test, a central rod was moved at the speed of 50 mm/sec forward and backward automatically against two fixed rods on both sides inside an illuminated box. An examinee at the distance of 2.5 m observed the rods inside the box from a small window and pushed a button to stop the central rod in alignment with the fixed rods. Erred distance of the central rod from the fixed rods as a mean of 4 measurements was used. At functional visual acuity test, an examinee moved a joystick to the same direction as Landolt-C opening as a

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visual target which was sequentially presented every 2 seconds for 30 times in 1 minute.

Results: The mean erred distance of three-rods test was reproducible between two tests done on separate occasions (n = 44, ρ = 0.679, $P < 0.0001$, Spearman rank correlation). Exophoria induced by wearing 4-prism-diopter base-out prism did not significantly influence the mean erred distance while vertical diplopia induced by wearing 4-prism-diopter base-up prism disrupted the measurement (n = 9). The mean erred distance of three-rods test was better correlated with functional visual acuity tested with both eyes open than with conventional visual acuity with both eyes open (n = 17, ρ = 0.2 versus ρ = 0.179).

Conclusion: In the context of the small sample size in the present study, the three-rods test was reproducible, and testable in the presence of phoria, but not testable in diplopia, indicating the feasibility as a depth perception vision test.

Keyword: Ophthalmology

1. Introduction

Three-rods test is a vision test to examine depth perception and is used routinely for a vision test for automobile license in Japan and Germany in addition to visual acuity testing [1, 2, 3]. A central rod between two peripheral fixed rods moves forward and backward, and an examinee is asked to tell the timing and to push a button when the central rod is in alignment with the peripheral fixed rods. The three-rods test has a merit to be done with both eyes open in a naturally viewing condition. The test examines a kind of dynamic stereopsis in response to a moving rod and also analyzes the speed of response by eye-hand coordination to push a button to stop the moving rod.

We previously elucidated that the results of three-rods test had correlation with stereoacuity which was measured with static stereopsis tests used in ophthalmic practice [3]. We also showed that erred distance of 2 cm or less, adopted as the current criteria to pass three-rods test, was indeed appropriate from the viewpoint of statistical distribution [3]. Recently, some citizens in Japan raise a question why three-rods test is required in vision tests for drivers' license in addition to visual acuity testing. Under the circumstances, scientific evidence is lacking from the viewpoint of government enforcement of three-rods test as an additional vision test in drivers' license.

Functional visual acuity measures the response of an examinee to successive presentation of a visual target in a certain period of time [4]. An examinee is asked to move a joystick by fingers towards the direction which aligns with the opening of Landolt-C as a visual target. This test can be done at the setting of both eyes open and analyzes the speed of response by eye-hand coordination to move a joystick towards the direction of Landolt-C.

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In this study, we examined the reproducibility of three-rods test as well as the effect of phoria and diplopia on three-rods test in order to assess the limitation of three-rods test in drivers' license visual examination. In addition, we compared the result of three-rods test with functional visual acuity from the viewpoint of eye-hand coordination. These measures in this study would be expected to obtain scientific evidence for three-rods test.

2. Methods

2.1. Design and participants

This study consisted of three parts of experiments: the first was to analyze the reproducibility of three-rods test in 44 subjects (28 men and 16 women with the mean age of 20.9 years, ranging from 19 to 25 years), the second was to analyze the effect of exophoria and vertical diplopia on three-rods test in 9 subjects (9 men with the mean age of 20.7 years, ranging from 20 to 22 years), and the third was to analyze the relation of three-rods test with functional visual acuity in 17 subjects (9 men and 8 women with the mean age of 20.1 years, ranging from 18 to 22 years). Each of these three parts of experiments had different participants from one another. The number of participants in each part of the study was based solely on recruitment in each study period. Two separate occasions were determined simply based on each participant's convenience in the first part of the study. A 4-prism-diopter prism was chosen to induce exophoria or vertical diplopia, based on the fact that a 4-prism-diopter prism definitely induced vertical diplopia in all participants in the second part of the study.

All participants had no past or present history of neurological, mental, or physical diseases. They had no past or present history of eye diseases including amblyopia and strabismus (manifest deviation or tropia). The visual acuity of 0.8 or better were set only in the first part of this study to test the reproducibility. The subjects were undergraduate students in this Medical School who were recruited by 4 authors (Y. M., T. Y., M.I., and R.H.) who were also undergraduate students. The participants gave informed consent to join the study. The study conformed to the tenets of the Declaration of Helsinki and was approved by Ethics Committee of Okayama University Graduate School of Medicine, Dentistry, and Pharmaceutical Sciences.

2.2. Stereoacuity

TNO Stereotest (TNO test for stereoscopic vision, fifth edition, Lameris Ootech, Nieuwegein, The Netherlands) and Titmus Stereotest (Stereo Fly Test, Stereo Optical Company, Inc., Chicago, IL, USA) were done at 40 cm apart from the examinee's eyes while Distance Randot Stereotest (Stereo Optical Company) was at 3 m. The TNO Stereotest detected stereoacuity ranging from 15, 30, 60, 120, 240 to 480 seconds of arc by the Plate V, VI, and VII. The Titmus Stereotest detected

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stereoacuity ranging from 40, 50, 60, 80, 100, 140, 200, 400 to 800 seconds of arc by the figure of circles. The Distance Randot Stereotest detected stereoacuity ranging from 60, 100, 200 to 400 seconds of arc.

2.3. Three-rods test

Three-rods test was done with Electric Depth Perception Tester (AS-7JS1, Kowa, Tokyo, Japan) [3]. Three black-colored rods with the diameter of 3 mm were placed 30 mm apart from one another. The two peripheral rods were fixed while only the central rod was moved backward (away from an examinee) in the range of 100 mm and then forward (nearing to an examinee) in the range of 110 mm at the speed of 50 mm/second. The examinee, keeping the head straight and still without the head fixed, sat on a chair at the distance of 2.5 m apart from the fixed rods inside the box illuminated with white light. The fixed rods were located inside the box at the distance of 262 mm from the outer wall of the viewing window. The height of the chair was adjusted so as to align the examinee's eyes with the center of the rectangular viewing window with 44 mm vertical length and 104 mm horizontal length to observe the three rods inside the box. The examinee pushed the button when he or she noticed the central moving rod in alignment with the two peripheral fixed rods while the central rod was moving backward and forward. The examinee was instructed for these procedures and the measurements were repeated 4 times. The direction of movement of the central rod, either backward or forward, at the start of measurements, was chosen arbitrarily in each individual. The sound of a moving rod could be heard even at the measuring distance of 2.5 m.

The erred distance of the stopped central rod relative to the two fixed rods was recorded as a plus value (mm) when the central rod was far away, relative to the fixed rods, from the examinee, and as a minus value when the central rod was nearer, relative to the fixed rods, to the examinee. A mean of 4 measurements in an absolute value without minus or plus tags was calculated and used for statistical analysis [3].

2.4. Functional visual acuity test

Functional visual acuity was measured by a visual acuity tester (AS-28, Kowa, Tokyo, Japan) [5]. An examinee looked through eyepieces with both eyes open at a Landolt-C target and moved a joystick towards the direction of the Landolt-C opening. The target was presented inside the tester as appeared to be placed at 5 m from the eyes of an examinee by the use of optical lens system. Using a shutter for the right eye or the left eye, visual acuity in the right eye was tested first, then the visual acuity in the left eye tested, and finally the visual acuity with both eyes open was tested. At first, best visual acuity was detected in the right eye and the left eye, and with both eyes open. Thereafter, functional visual acuity testing was started. When an examinee moved a joystick in the correct direction, the next Landolt-C

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in smaller size was presented. When an examinee made an error, the next Landolt-C became larger in size. The visual target was sequentially presented every 2 seconds for 30 times in the time period of 1 minute.

Functional visual acuity was defined by the mean of visual acuity with correct answer. The maximum visual acuity, minimal visual acuity, mean response time, visual acuity maintenance rate, the number of blinking in 1 minute (not analyzed in this study) were also outputted. The visual acuity in decimals was expressed as logarithm of the minimal angle of resolution (logMAR) for statistical analysis. The visual acuity maintenance rate was roughly the ratio between the mean visual acuity and the initial visual acuity. More accurately, the area under the curve of all measured visual acuity was divided by the area under the curve when the initial visual acuity was supposed to be maintained for 1 minute.

2.5. Statistical analysis

Spearman rank correlation test was used to check the relation between two measurements. Bland-Altman plot was applied to analyze test and retest reliability of three-rods test. Wilcoxon signed rank test was used to analyze paired data.

3. Results

3.1. The reproducibility of three-rods test

All participants in the first study to test the reproducibility had the visual acuity in both eyes of 0.8 or better in decimals with or without glasses or contact lenses correction and had no strabismus (tropia) at the distant (5 m) and near (0.3 m) fixation. Three-rods test was repeated on two separate occasions in each participant. The mean erred distance of the first test and the mean erred distance of the second test showed high correlation ($n = 44$, $\rho = 0.679$, $P < 0.0001$, Spearman rank correlation test, Fig. 1A). Bland-Altman plot of the first and second measurements showed neither proportional error nor systematic error (Fig. 1B).

At the first test, a median and a quartile in the mean erred distance of the three-rods test were 8.75 mm and 5.87 mm, respectively, with the maximum of 25.75 mm and the minimum of 1.75 mm. A mean and standard deviation of the mean erred distance were 9.7 mm and 4.4 mm, respectively. At the second test, a median and a quartile in the mean erred distance of the three-rods test were 6.25 mm and 6.75 mm, respectively, with the maximum of 47.5 mm and the minimum of 1.25 mm. A mean and standard deviation of the mean erred distance were 9.4 mm and 9.0 mm, respectively.

In TNO Stereotest, both median and mode were 60 seconds of arc, with the maximum of 360 seconds of arc and the minimum of 15 seconds of arc. In Titmus

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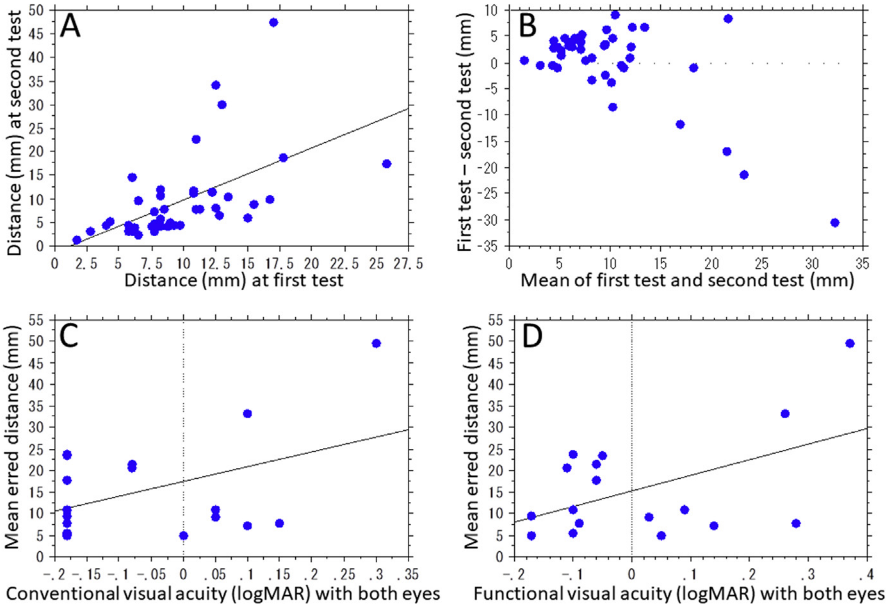

Fig. 1. Correlation (A) between the mean erred distance in first and second three-rods test on two separate occasions. ($n = 44$, $\rho = 0.679$, $P < 0.0001$, Spearman rank correlation test). Bland-Altman plot (B) of the mean erred distance in first and second three-rods test on two separate occasions ($n = 44$). Correlation of the mean erred distance of three-rods test with conventional visual acuity (C, $n = 17$, $\rho = 0.179$, $P = 0.5982$) and functional visual acuity (D, $n = 17$, $\rho = 0.200$, $P = 0.4335$) with both eyes open.

Stereotest, both median and mode were 40 seconds of arc, with the maximum of 240 seconds of arc and the minimum of 40 seconds of arc. In Distance Randot Stereotest, both median and mode were 60 seconds of arc, with the maximum of 400 seconds of arc and the minimum of 60 seconds of arc.

3.2. Exophoria and diplopia in three-rods test

Exophoria induced by wearing 4-prism-diopter base-out prism in the right eye abolished the stereoacuity measurement in 3 participants with TNO Stereotest, in 2 participants with Titmus Stereotest, and 3 participants with Distant Randot Stereotest, out of 9 participants. In the remaining participants, stereoacuity was measured but reduced at near viewing with TNO Stereotest and Titmus Stereotest and also reduced at far viewing with Distant Randot Stereostest (Table 1). Three-rods test could be measured in all 9 participants wearing 4-prism-diopter base-out prism in the right eye. The mean erred distance of three-rods test before and after prism wearing was 25.8 ± 17.8 mm and 26.3 ± 19.8 mm, respectively, as a mean and standard deviation, and did not change significantly by exophoria induced with prism-wearing ($P = 0.4413$, Wilcoxon signed rank test, Table 1).

Vertical diplopia induced by wearing 4-prism-diopter base-up prism in the right eye abolished stereoacuity measurements in all participants by TNO Stereotest and

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Table 1. The effect of wearing 4-prism base-out or base-up prism in the right eye on stereotests and three-rods test.

Subject/gender/age	TNO stereotest (sec)			Titmus stereotest (sec)			Distant randot stereotest (sec)			Mean erred distance of three-rods test (mm)		
	Normal	Wearing 4-prism base-out	Wearing 4-prism base-up	Normal	Wearing 4-prism base-out	Wearing 4-prism base-up	Normal	Wearing 4-prism base-out	Wearing 4-prism base-up	Normal	Wearing 4-prism base-out	Wearing 4-prism base-up
1/Male/21	240	u.m.	u.m.	80	400	u.m.	60	u.m.	u.m.	5.8	9.5	25
2/Male/21	30	60	u.m.	40	80	u.m.	60	200	u.m.	19.5	6.7	31
3/Male/21	30	60	u.m.	40	60	u.m.	60	400	u.m.	19.3	19.5	20.5
4/Male/20	60	120	u.m.	200	400	u.m.	400	u.m.	u.m.	25.7	29	u.m.
5/Male/20	60	60	u.m.	400	400	u.m.	60	400	u.m.	8.3	17.5	18
6/Male/22	120	120	u.m.	140	140	u.m.	400	400	u.m.	43.8	60	u.m.
7/Male/20	120	240	u.m.	40	80	u.m.	60	400	u.m.	10.2	11.3	u.m.
8/Male/21	480	u.m.	u.m.	200	u.m.	u.m.	400	400	u.m.	52.2	58.5	u.m.
9/Male/21	480	u.m.	u.m.	100	u.m.	u.m.	400	u.m.	u.m.	47.8	25.3	u.m.

u.m., unmeasurable.

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Titmus Stereotest at near viewing and also by Distant Randot Stereotest at far viewing. In three-rods test, the mean erred distance became longer in 4 participants while the remaining 5 participants said that the test was unmeasurable due to diplopia (Table 1).

3.3. Three-rods test and functional visual acuity

Three-rods test was repeated on two separate occasions in each participant and a mean of two tests as regards to the mean erred distance of three-rods test was used in statistical analysis for correlation with visual acuity expressed as logMAR. The mean erred distance of three-rods test was 15.75 ± 12.03 mm as a mean and standard deviation. Conventional visual acuity (logMAR) in the right eye and the left eye, and with both eyes open was 0.094 ± 0.17, 0.086 ± 0.24, and −0.05 ± 0.15, respectively. Functional visual acuity (logMAR) in the right eye and the left eye, and with both eyes open was 0.26 ± 0.22, 0.19 ± 0.27, and 0.012 ± 0.16, respectively. Functional visual acuity maintenance rate in the right eye and the left eye, and with both eyes open was 0.94 ± 0.04, 0.96 ± 0.03, and 0.97 ± 0.02, respectively.

Conventional visual acuity and functional visual acuity were highly correlated with each other in the right eye ($n = 17$, $\rho = 0.882$, $P = 0.0004$) and the left eye ($n = 17$, $\rho = 0.925$, $P = 0.0002$), and with both eyes open ($n = 17$, $\rho = 0.855$, $P = 0.0007$, Spearman rank correlation test). The mean erred distance of three-rods test showed low correlation with conventional visual acuity ($n = 17$, $\rho = 0.179$, $P = 0.5982$, Fig. 1C) and functional visual acuity ($n = 17$, $\rho = 0.200$, $P = 0.4335$, Fig. 1D) with both eyes open.

4. Discussion

The goal of this study is to assess the feasibility and limitation of three-rods test as a depth perception vision test. The three-rods test was originally described by Helmholz in 1866 [1, 2]. Since 1960 when the Road Traffic Act was enacted in Japan, three-rods test in the current method has been enforced as a depth perception vision test to obtain drivers' license for large vehicles such as trucks and buses and also for commercially-used cars such as taxies. Some citizens in Japan question that the enforcement of three-rods test as a vision test in addition to visual acuity testing would not be appropriate, and also argue that there would be learning effect on three-rods test. We have no intention to argue for or against three-rods test as a vision test for drivers' license. Or rather, we planned to elucidate scientific evidence for three-rods test from the different standpoint. At the first step of this study, the results of three-rods test were shown to be reproducible on two different occasions. Bland-Altman plot showed no systematic error, indicating no learning effect on the testing.

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Diplopia is the absence of binocular fusion in the background of simultaneous perception with both eyes. Diplopia is caused by a wide range of diseases such as extraocular muscle diseases and ocular motor cranial nerve palsy. Diplopia does not necessarily influence body stability [6], and thus, we planned to test the effect of diplopia on three-rods test. The presence of vertical diplopia induced by wearing 4-prism-diopter base-up prism made the participants not detect the alignment of rods in three-rods test. Vertical prism was used in this study because the vertical fusion range is narrower than the horizontal fusion range. This study demonstrated that three-rods test could not be accomplished by individuals with diplopia.

In this study, the influence of exophoria induced by wearing 4-prism-diopter base-out prism, as a kind of control, was also tested in three-rods test. All participants with induced exophoria could detect the alignment of rods. Exophoria was induced in the participants because the horizontal fusion range is wider than the vertical fusion range. The induced exophoria did not have influence on actual testing of three-rods test. In contrast, the induced exophoria deteriorated the level of static stereopsis at near viewing with TNO Stereotest and Titmus Streotest and also at far viewing with Distant Randot Stereotest in the same participants. Individuals with phoria should be detected as normal in vision tests for drivers' license. In this sense, three-rods test is appropriate as a depth perception vision test to be performed in a drivers' license vision test. In other words, three-rods test is, of course, not so accurate as static stereotests, but would be a more appropriate screening test in general population.

Time component is not considered in conventional testing of visual acuity. In contrast, Landolt-C as a visual target is presented successively in the sequence of time in functional visual acuity test. Thus, functional visual acuity is considered to be more like seeing or reading in the real world. Functional visual acuity has been assessed in different kinds of eye diseases to detect the reduction of visual function which was indeed not detected by conventional visual acuity testing [7, 8, 9, 10, 11, 12, 13, 14]. The present study demonstrated that the results of three-rods test were more correlated, although not significantly, with functional visual acuity than with conventional visual acuity. Better functional visual acuity in the left eye, compared with the right eye, could be attributed to the sequence of testing from the right eye to the left eye, followed finally by the testing with both eyes open.

The better correlation between three-rods test and functional visual acuity could be explained by the common method of testing which used fingers to give an answer in response to a visual target. In other words, eye-hand coordination is required to give an answer in both three-rods test and functional visual acuity test. A reason for no significant correlation of three-rods test with conventional and functional visual acuity would be that normal participants in the present study had basically good visual

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acuity. In other words, the present study did not include individuals with poor visual acuity. Another reason would be that it remains unknown whether or not visual acuity and depth perception would be correlated with each other.

A major limitation of this study is that the number of participants in each part of this study was small. There are also technical limitations which are present in the testing apparatus for three-rods test. Given that the moving rod made sound and moved at a fixed speed, it was possible that participants could give consistent response even with their eyes closed simply by timing or counting and that they could press the button. The participants in this study were observed constantly at testing and asked not to do such cheating. It remains unknown that the speed of the rod, set at 50 mm/second in the testing apparatus, would have any relation with motion perception. Furthermore, perceived speed as a function of contrast would have unknown effect on the testing results by the current apparatus in which black rods were set at high contrast in the background of white illumination.

In conclusion, three-rods test was reproducible, and testable in binocular fusion with exophoria, but not testable in diplopia. Three-rods test had better correlation with functional visual acuity tested with both eyes open. Eye-hand coordination plays an important role in answering at three-rods test. The results in this study, accepting the limitations of the small sample size, provide evidence to support three-rods test as a simple depth perception vision test in drivers' license enforcement.

Declarations

Author contribution statement

Toshihiko Matsuo, Chie Matsuo: Conceived and designed the experiment; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Yuki Morisawa, Takeshi Yoshinaga, Mari Ikebe, Ryosuke Hosogi: Performed the experiments.

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Competing interest statement

The authors declare no conflict of interest.

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Additional information

No additional information is available for this paper.

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