Reliability of Visual Acuity Measurements Taken with a Notebook and a Tablet Computer in Participants Who Were Illiterate to Roman Characters

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Background: *Electronic measurement of visual acuity (VA) has been proposed and adopted as a method of determining VA scores in clinical research. Characters (optotypes) are displayed on a monitor screen and the examinee selects a match and inputs his choice to another electronic device. Unfortunately, the optotypes, called Sloan letters, in the standard protocol are 10 Roman characters. This limits their practicability for measuring VA of patients who are illiterate to these characters. The authors introduced a method of displaying the Sloan letters one by one on a notebook and all 10 Sloan letters on a tablet computer screen. The former is for testing the patients whereas the latter is for them to input their responses by tapping on a letter that matches the one on the notebook screen.*

Objective: *To assess test-retest reliability of VA scores determined with this method.*

Material and Method: *Participants without ocular abnormality were recruited to have their right eyes measured with the same VA measurement method twice, one week apart. Those who were illiterate to Roman characters were enrolled for the aforementioned method for measuring their VA (Tablet group). A 15-inch display notebook computer and a 9-inch display tablet computer (iPad) communicated via a local wireless data network provided by a Wi-Fi router. Those who understood Roman characters were enrolled to have measurements with a 17-inch desktop computer and an infrared wireless keyboard (Keyboard group). Both methods used the same protocols and software for VA measurements. Reliability of VA scores obtained from each group was assessed by the confidence interval (CI) of the difference of the scores from the test and retest. The t test was used to analyze differences in mean VA scores between the test and retest in each group with* $p < 0.05$ *determined as statistically significant.*

Results: *There were 49 and 50 participants in the Tablet and Keyboard group respectively. The 95% CI of the difference between the scores from the test and retest in each group was 2 letters. Approximately 95% of participants in each group had an absolute difference of the scores between the test and retest of 7 letters. The mean of VA scores from the first test was significantly different from that of the second test in the Keyboard group (one-letter difference,* $p = 0.049$*); there was no significant difference between these scores in the Tablet group (0.1-letter difference,* $p = 0.86$*).*

Conclusion: *Tablet computers may be used to assist patients who are illiterate to Roman characters in having their VA measured with the standard electronic protocol. This preliminary study suggested that the proposed method should be useful for reliable measuring VA outcome in multicenter international clinical trials without encountering a language barrier.*

Keywords: *Electronic visual acuity, Computerized visual acuity, ETDRS, Early treatment diabetic retinopathy study visual acuity, Visual acuity measurement, Test-retest reliability, Tablet computer, iPad, Visual acuity*

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For nearly 150 years, visual acuity (VA) has been determined by reading characters, called optotypes, from a chart. The widely used Snellen VA chart contains optotypes arranged from the largest to the smallest size from the top to the bottom line[1]; however, the number of optotypes in each line and the difference in their size from line to line are not uniform. Although the Snellen chart has been used ubiquitously in ophthalmic practice, it may not be reliable enough for measuring VA for the purposes of ophthalmic

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research[2] . A major clinical study of retinopathy entitled "The Early Treatment Diabetic Retinopathy Study (ETDRS)" has proposed and adopted a new VA chart for use in clinical research[3,4]. This ETDRS VA chart contains 5 optotypes on each line with a proportional increment in their size from line to line. These 10 custom-designed Roman characters with approximately equal difficulty in recognition called, "Sloan letters"[5], are used as optotypes in the ETDRS chart. This chart has been widely used as the standard for measuring VA in major clinical research in ophthalmology[6-8] .

Measurement of VA using VA charts, although practical, still has some potential flaws. The testing protocols of each measurement can vary among examiners. Due to physical constraints in the size of the charts, there are restrictions in the size and the number of the optotypes displayed. Memorization of the optotypes in repeated measurements can also be an obstacle to evaluating real VA change over time[9]. The use of the Sloan letters, in addition, has limitations in measuring VA of patients who cannot understand Roman characters. This can be a problem in implementing the chart in multicenter international clinical trials.

To overcome these limitations, electronic VA measurement has been introduced. In this format, optotypes are presented randomly one by one on a computer monitor and examinees may respond to a displayed optotype by inputting their choice to an electronic device. The testing and ending protocols of measurement can be controlled reliably with algorithms coded into computer software. In 1980, Timberlake et al[10]. developed an electronic protocol for measuring VA using a general-purpose microcomputer as hardware. In their protocol, illiterate E (the letter E rotated up, down, left, and right) was displayed on a TV monitor and a staircase psychophysical testing procedure was used. Results from each measurement were reported as the mean and standard deviation of VA. These researchers created a custom-made electronic box, with 4 buttons representing each of the illiterate E forms as their data input device. Since general-purpose personal computers were not generally available at the time, electronic VA measurement was not implemented in ophthalmic practice or research.

Electronic VA measurement was re-introduced in 2003 by Beck et al[10]. They modified the standard ETDRS chart testing protocol in clinical research to enable it to be used with computer hardware and software. The hardware included a 17-inch monitor with 1,600 x 1,200 resolution for displaying optotypes, a personal computer running a Linux operating system with software for measuring VA, and a wired palmtop computer for examinees' data input. This electronic testing protocol was proven to be as reliable as the standard chart testing protocol[11,12] and has been used in recent major clinical ophthalmic trials[13,14].

The Sloan letters were still used as the optotypes in this standard electronic ETDRS testing protocol. This limited its practicability for measuring the VA of patients who did not understand Roman characters and also limited its suitability for use in multicenter international clinical research.

In a country where English is not the first language, the ETDRS chart testing protocol may be modified to measure VA in clinical trials. In the present study, The authors printed the 10 Sloan letters on paper and ask enrolled patients who were illiterate to Roman characters to point at them to identify them with the ones on the chart during VA measurement. This was impractical because two examiners were required: one to record the examinees' choices and another to point at the letters on the chart for testing. This problem may be solved with electronic measurement: instead of pointing to optotypes printed on paper, examinees may tap on optotypes displayed on the screen of a tablet computer to match them with the ones presented to them on another computer monitor. Data from tapping can be recorded and analyzed automatically by software without requiring any examiners. This modified method may potentially provide many other benefits of electronic VA measurement including practicability for patients who are illiterate to Roman characters.

The authors conducted this preliminary study to evaluate whether this applied method of electronic VA measurement could have a potential to be reliably used with patients who were illiterate to Roman characters.

Material and Method

Participants

All participants were required to give written informed consent. Participants who had no ocular abnormality in either eye and were willing to have two VA measurements one week apart were enrolled into two study groups: 1) electronic ETDRS (E-ETDRS) and 2) electronic ETDRS with a tablet computer (E-ETDRS Tablet). If the participants could read Roman characters, they were enrolled into the former; if they could not read the characters, they were enrolled into the latter. Only the right eye of each participant was included.

The participants were excluded if 1) they could not understand or could not perform the procedures required in the measurement protocol in each study group, or 2) they did not return to have the second VA measurement.

Electronic VA measurement protocols in both groups

The measurement of VA in each group was conducted in the same room with the same fluorescent illumination for both the first and the second test. All the participants were also measured with the same protocol with the same research assistant in both tests. The VA score of each participant was determined as the total number of correct letters identified (letter score). The distance for measurement was three meters, the standard test distance for the electronic ETDRS protocol[11] .

The software for electronic VA measurement was written in PHP coding language and required 10 MB of hard drive to install. The algorithm for displaying optotypes on screen in both of these groups was similar to the standard electronic ETDRS protocol, containing a screening and a testing phase. This algorithm is described elsewhere[11]. In brief, when the measurement process was started, the Sloan letters were displayed one by one on a computer monitor. Participants responded to the displayed Sloan letter by inputting their choices to a data input device and a new Sloan letter with smaller size was then randomly displayed. This test cycle continued until the ending protocol was reached.

Hardware in the E-ETDRS group

A 17-inch liquid crystal display computer monitor (MAG®, MAG Technology, Taipei, Taiwan), a personal desktop computer running Windows® XP operating system (Microsoft Corporation, Redmond, WA, USA) and an infrared wireless computer keyboard (Logitech®, Logitech Corporation, Fremont, CA, USA) were used.

The brightness and contrast of the display monitor was set at 100%; the color depth was set at 32 bits and the screen resolution was set at 1,024 by 768 pixels. The display area, the horizontal and vertical adjustment of the monitor, was set as the industry default.

The personal computer had a 1-GHz Intel® microprocessor (Intel Corporation, Santa Clara, CA, USA), 500 MB of Random Access Memory (RAM), and a 128-GB hard drive. The participants in this E-ETDRS group responded to the displayed Sloan letter on the monitor by pressing the corresponding button of the letter on the keyboard.

Hardware in the E-ETDRS Tablet group

A 15-inch display notebook computer (Acer® Aspire T 6500, Acer Inc., Taipei, Taiwan) with a 2.1-GHz Intel Pentium microprocessor, 3 GB of RAM, and a 320-GB hard drive, a tablet computer (iPad®, Apple Inc., Cupertino, CA, USA) with a 1-GHz processor and a 32-GB flash drive and a wireless router (Linksys®, Cisco Systems Inc., Seattle, WA, USA) were used. The router provided a local wireless data network to enable the notebook and the tablet to communicate.

The notebook computer ran the same operating system and software for VA measurement as was used in the E-ETDRS group but had a Web server application (Apache®, the Apache Software Foundation, www.apache.org) and database software (MySQL® Oracle Corporation, Redwood Shore, CA, USA) installed. The setting of the notebook screen display was the same as that of the monitor in the E-ETDRS group.

The participants in this E-ETDRS Tablet group held the tablet computer, with a default Web page showing 10 Sloan letters, in their hands when the measurement process was started (Fig. 3). They responded to the Sloan letter displayed on the notebook screen by tapping on the letter on the tablet which they thought matched it.

Statistical analysis

The test-retest reliability for each study group was assessed from the confidence interval (CI) of the difference between the letter scores obtained from the first test and the retest, as in a model proposed by Bland and Altman[15].

The t-test was used for analyzing differences in mean VA letter score between test and retest in each study group with $p < 0.05$ determined as statistically significant.

Results

A total of 99 participants who met the inclusion criteria were enrolled consecutively with approximately 50 participants in each study group. Only a few participants were excluded because they did not come to have the second test. The baseline demographic characteristics of the participants are presented in Table 1. The mean age of the participants in the E-ETDRS Tablet group was significantly higher than that of the E-ETDRS group members ($p < 0.001$).

The mean VA scores of the test and the retest of each study group are presented in Table 2. The participants in the E-ETDRS Tablet group had a mean score which was significantly lower than that of those in the E-ETDRS group in both the test and the retest (p < 0.001). There was also a significant difference between the mean scores of the first test and the retest in the E-ETDRS group (approximately one letter difference, p = 0.049 respectively) whereas there was no significant difference between these scores in the E-ETDRS Tablet group (only 0.1-letter difference, p = 0.86). The 95% CI of the difference between the scores from the test and the retest in each group was approximately 2 letters.

Table 3 presents the number of participants according to the absolute difference between their scores from the test and the retest in each study group.

Table 1. Demographic characteristics of participants in each group

	E-ETDRS (n = 50)	E-ETDRS Tablet (n = 49)
Male	14 (28.0%)	13 (26.5%)
Female	36 (72.0%)	36 (73.5%)
Age		
Mean (yrs old)	35.4	61.6
Median (yrs old)	36.5	63
Range (yrs old)		
10-20	6 (12.0%)	0
21-30	13 (26.0%)	0
31-40	13 (26.0%)	0
41-50	17 (34.0%)	3 (6.1%)
51-60	1 (2.0%)	17 (34.7%)
61-70	0	23 (46.9%)
71-80	0	6 (12.2%)
> 80	0	0

Values were represented as n (%), E-ETDRS = participants who were measured with electronic ETDRS protocol, E-ETDRS Tablet = participants who were measured with electronic ETDRS protocol using a tablet computer as a data input instrument

Table 3. The number of participants with the absolute difference of VA scores between test and reteast

Absolute difference	E-ETDRS n = 50	E-ETDRS Tablet n = 49
0	15 (30.0)	2 (4.1)
1	17 (64.0)	6 (16.3)
2	10 (84)	10 (36.7)
3	2 (88.0)	9 (55.1)
4	0 (88.0)	9 (73.5)
5	0 (88.0)	5 (83.7)
6	2 (92.0)	3 (89.8)
7	2 (96.0)	3 (95.9)
8	0 (96.0)	2 (100.0)
9	0 (96.0)	0 (100.0)
10	1 (98.0)	0 (100.0)
11	0 (98.0)	0 (100.0)
12	0 (98.0)	0 (100.0)
13	0 (98.0)	0 (100.0)
23	1 (100.0)	0 (100.0)

Values were represented as n (%), E-ETDRS = participants who were measured with electronic, ETDRS protocol, E-ETDRS Tablet = participants who were measure measured with electronic ETDRS protocol using a tablet com puter as a data input instrument

Table 2. Mean visual acuity (VA) score of each group of participants in test and retest

	E-ETDRS(n = 50)		E-ETDRS Tablet (n = 49)	
	Test	Retest	Test	Retest
VA letter scores				
Mean $\pm$ SD	91.0 $\pm$ 5.9	92.2 $\pm$ 4.7	76.9 $\pm$ 4.9	76.9 $\pm$ 4.3
Range	68-95	70-95	70-88	66-89
Mean difference of test-retest	-1.1	-0.1		
p-value	0.049*	0.86		
95% Confidence interval	(-2.3, -0.006) 2.3	(-1.2, 1.05) 2.3		

E-ETDRS = participants who were measured with electronic ETDRS protocol
E-ETDRS Tablet = participants who were measured with electronic ETDRS protocol using a tablet computer as a data input instrument
* significant at p < 0.05

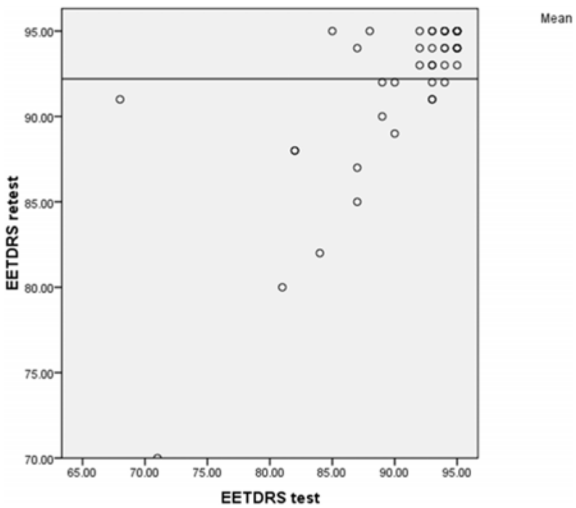

Fig. 1 Bland-Altman correlation graph of test and retest of EETDRS group

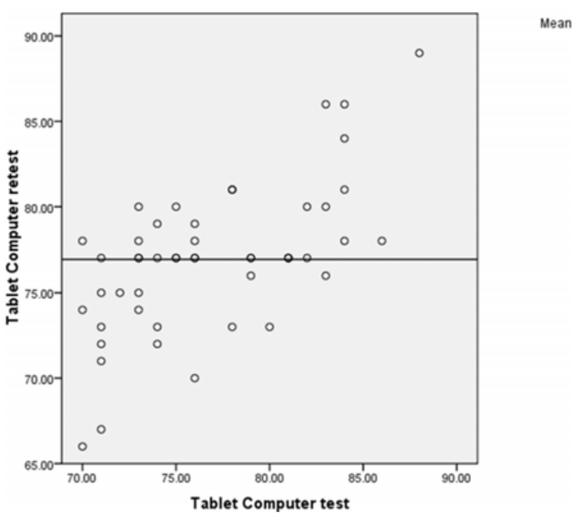

Fig. 2 Bland-Altman correlation graph of test and retest of Tablet Computer group

Approximately 95% of participants in both study groups had an absolute difference of 7 letters (Fig. 1 and 2).

Discussion

The authors found in the present study that a tablet computer could be used as a data input device in the standard electronic ETDRS testing protocol to reliably measure VA scores of participants who were illiterate to Roman characters. The test-retest reliability of the VA scores obtained from these participants was comparable with that obtained from the participants who could read Roman characters in the other group.

Fig. 3 A participant was tapping a Sloan letter on a tablet computer to match the one displayed on a note-book computer screen in our applied method of electronic visual acuity measurement

The CI of the difference, including the absolute difference, of the scores between test and retest of the participants in each study group was also comparable to that obtained from measurements of participants who had English as their first language[11,12] in previous studies. This assessment of reliability, a 7-letter difference between test and retest for 95% of the time, indicated clinical acceptability.

Comparable test-retest reliability was found in both groups despite the fact that the participants who used the tablet computer were significantly older, had lower mean VA and might also have had a lower level of education. This may be explained by the capability of the tablet computer to display all choices of the Sloan letters on the screen at the same time. The participants were able to compare, differentiate, and identify the letters without the necessity for reading them.

For practical reasons, the authors chose to use a wireless keyboard as an input device- instead of a wired palmtop computer as in the conventional protocol- for participants who could read the Sloan letters. This is the method of electronic VA measurement that we reported previously[16]. Tapping on a screen of a tablet computer, however, may be more practical for examinees who are not familiar with electronic instruments than pressing buttons on a computer keyboard: those who used the tablet could choose their responses solely from the 10 choices on the screen whereas those in the keyboard group had to choose among many unnecessary buttons. All responses by tapping on the tablet screen were recorded and interpreted correctly by the software installed in the notebook computer without technical failure.

Displaying the Sloan letters on the tablet in the present study was practical since a Web browser was used and no additional application was required. There is a possibility that this method of electronic ETDRS VA measurement could be feasibly run from the internet without software installation in the notebook computer. The speed of the internet connection, however, should be sufficient to cope with the constant exchange of data between the notebook and the internet Web server, and between the tablet and the internet Web server, during each measurement. Another study focusing on this issue might be conducted to test the feasibility of this method.

Limitations in the present study included having the two different groups of participants, although none had any ocular abnormality, using two different methods. The ideal study design would also enroll participants who could not read the Sloan letters into the keyboard group and participants who could read Roman characters into the tablet group, for comparison. However, it was not feasible to have participants who could not read Roman characters input their responses via a computer keyboard. A larger sample size is also needed to verify our preliminary results. In addition, the method in the present study should also be tested on participants who have ocular abnormality.

In conclusion, electronic measurement of VA has been proposed to enhance reliability of VA scores, especially in clinical research. The standard protocol of the electronic measurement, however, has adopted the 10 Roman characters, called Sloan letters, as optotypes for testing. This creates an impediment for patients who are illiterate to the characters and limits applicability of the protocol in clinical research conducted in countries where English is not the primary language. The present study has suggested that tablet computers may be used to assist the patients who are illiterate to Roman characters in having their VA measured with the standard electronic protocol. This proposed method should be useful for reliable measuring VA outcome in multicenter international clinical trials without encountering a language barrier.

Acknowledgment

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Potential conflict of Interest

None.

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การทดสอบหาความเชื่อมั่นในการวัดค่าความชัดเจนของสายตา ในผู้ที่ไม่รู้ภาษาอังกฤษ โดยใช้เครื่องคอมพิวเตอร์แบบพกพา ในการทำการทดสอบ

ไพศาล ร่วมวิบูลย์สุข, นภิชรียา สุดสาคร, ธนาพงษ์ สมกิจรุ่งโรจน์, ชญาณี อิงคากุล, มนต์ทิพย์ เทียนสุวรรณ

ภูมิหลัง*: การวัดระดับการมองเห็นด้วยเครื่องคอมพิวเตอร์ถูกคิดค้นและนำมาใช้ประโยชน์ในการตรวจคัดกรองผู้ป่วยและทางการวิจัยอย่างกว้างขวาง โดยการแสดงตัวอักษรโรมันมาตรฐานจำนวน 10 ตัว บนหน้าจอคอมพิวเตอร์ อย่างไรก็ดีการตรวจวิธีนี้ยังมีข้อจำกัดในผู้ที่ไม่สามารถอ่านตัวอักษรภาษาอังกฤษได้ ผู้นิพนธ์จึงได้คิดค้นการวัดระดับการมองเห็นในคนกลุ่มนี้ โดยใช้เครื่อง iPad เป็นอุปกรณ์สำหรับการวัดระดับ การมองเห็น*
วัตถุประสงค์*: เพื่อประเมินความน่าเชื่อถือ (Reliability) ของวิธีการวัดระดับการมองเห็น ในผู้ที่ไม่รู้จักตัวอักษรภาษาอังกฤษ ด้วย Tablet PC (iPad) โดยทดสอบหาค่าความเชื่อมั่น โดยการทดสอบซ้ำ (test-retest reliability)*
วัสดุและวิธีการ*: ผู้เข้าร่วมศึกษาที่ไม่มีความผิดปรกติทางสายตาทำการเข้าทดสอบความชัดเจนของสายตาโดยใช้ตาข้างขวาข้างเดียวด้วยวิธีการเดียวกัน 2 ครั้งห่างกันเป็นระยะเวลา 1 สัปดาห์ โดยแบ่งผู้เข้าร่วมวิจัยเป็น 2 กลุ่ม ดังนี้*

กลุ่มที่ 1: Tablet group ผู้เข้าร่วมงานศึกษาที่ไม่สามารถอ่านตัวอักษรโรมัน (ภาษาอังกฤษ) ได้เข้าทำการทดสอบโดยการใช้เครื่องคอมพิวเตอร์แบบพกพา NoteBook หน้าจอขนาด 15 นิ้ว เพื่อ แสดงผลและใช้ Tablet PC (iPad) หน้าจอขนาด 9 นิ้ว เพื่อเป็นตัวรับข้อมูลการ ทดสอบผ่านระบบเครือข่ายไร้สาย (Wifi) เป็นผู้เข้าทำการทดสอบโดยการแสดงผล

กลุ่มที่ 2: Keyboard group ผู้เข้าร่วมงานศึกษาที่สามารถอ่านตัวอักษรโรมัน (ภาษาอังกฤษ) ได้เข้าทำการทดสอบโดยการใช้เครื่องคอมพิวเตอร์ หน้าจอขนาด 17 นิ้ว และใช้แป้นพิมพ์แบบไร้สาย (Infrared wireless keyboard) เพื่อเป็นตัวรับข้อมูลการทดสอบ โดยผู้เข้ารับการทดสอบทั้ง 2 กลุ่ม เข้าร่วมการทดสอบโดยการใช้วิธีการและโปรแกรมคอมพิวเตอร์ในการวัดที่เหมือนกัน ผลทดสอบหาค่าความเชื่อมั่นโดยการทดสอบซ้ำ

(test-retest reliability) ในการวัดค่าความชัดเจน ของสายตา โดยการทดสอบหาค่าความเชื่อมั่น (confidence interval) จากการทดสอบทั้ง 2 ครั้ง และใช้ t-test ในการวัดและประมวลผลความแตกต่างอย่างมีนัยสำคัญของค่าความชัดเจนของสายตา (mean VA scores) ระหว่างการทดสอบทั้ง 2 ครั้ง (p < 0.05)

***ผลการศึกษา**: มีผู้เข้าร่วมศึกษาทั้งหมด 99 คน เป็นกลุ่ม Tablet 49 คน กลุ่ม Keyboard 50 คน พบว่า 95% Confidence interval ของค่าความชัดเจนของสายตาระหว่างการวัด 2 ครั้ง (95% CI of the difference between the scores from the test and retest) เท่ากับ 2 ตัวอักษร โดย 95 เปอร์เซ็นต์ ของผู้เข้าร่วมรับการทดสอบทั้งหมด มีค่าความแตกต่างกันของการวัดความชัดเจนสายตา จากการวัดทั้ง 2 ครั้ง (absolute difference of the scores between the test and retest) อยู่ที่ 7 ตัวอักษร ค่าเฉลี่ยของความชัดของสายตา (mean of VA scores) มีความแตกต่างกัน อย่างมีนัยสำคัญในกลุ่มที่เข้ารับการวัดโดยใช้ Keyboard (one-letter difference, p = 0.049) และจากการทดสอบ ไม่พบความแตกต่างกันของความชัดของสายตา (mean of VA scores) ระหว่างการวัด 2 ครั้ง ในกลุ่ม Tablet (0.1-letter difference, p = 0.86)*

***สรุป**: การวัดระดับการมองเห็นด้วยเครื่องคอมพิวเตอร์ถูกนำมาใช้อย่างแพร่หลาย อย่างไรก็ตามเนื่องจากการวัดด้วยเครื่องคอมพิวเตอร์แบบมาตรฐานเดิมนั้นใช้ตัวอักษรโรมัน จึงเป็นข้อจำกัดในผู้ทำการทดสอบวัดสายตาที่ไม่สามารถอ่านภาษาอังกฤษได้ การศึกษานี้นำเอา Tablet PC มาใช้ในการวัดสายตาซึ่งพบว่าการวัดด้วยวิธีนี้มีค่าความเชื่อมั่นที่ได้จากการวัดสูง สามารถเป็นตัวเลือกในการนำไปใช้วัดระดับการมองเห็นในทางคลินิกและทางการวิจัย โดยไม่มีข้อจำกัดทางด้านภาษา*