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Validity of Electronic Device-Based Application for Visual Acuity Examination: A Systematic Review

Natasya F. Yulianti[1], Al Munawir[2], and Novan K. Adji[3]
[1]Faculty of Medicine, University of Jember, Jember, 68121 Indonesia
[2]Department of Pathology, Faculty of Medicine, University of Jember, Jember, 68121 Indonesia
[3]Departement of Neurosurgery, Soebandi General Hospital, Jember, 68111 Indonesia

Corresponding author: Al Munawir (e-mail: almunawir.fk@unej.ac.id).

ABSTRACT Recent years, advances in the internet and communication technology have enabled the proliferation of digital medical devices with innovations in the form of health applications, including for visual acuity examination. However, the validity of these applications remains unclear. The limited mobility and health service during the COVID-19 pandemic underscores the urgent need to conduct research that validates these electronic device-based applications. Thus, this study aims to critically analyze whether the electronic device-based application is able to provide a valid and high-quality visual acuity examination. A systematic review was conducted through studies search on PubMed, MEDLINE, Springer, and Cochrane Library using specific keywords. After the studies were selected through inclusion and exclusion criteria, extraction was carried out. Publications from 2011 to the end of 2021 were reviewed, yielding in 1409 studies, of which 19 were included. The results showed a lower systematic bias for distance visual acuity testing with electronic device-based applications compared to standard reference tests with a mean difference of -0.08 to 0.10 logMAR. The validity of the near visual acuity examination with the application shows better results than the distance examination which is marked by smaller 95% limits of agreement range. The results of the analysis of Bland-Altman plots in all the studies reviewed showed that the accuracy of the examination results tended to increase in patients who had better visual acuity. In practice, the use of electronic device-based applications for visual acuity examination can increase the work effectiveness of medical personnel and the proliferation of digital medical devices. It can also be one of the breakthroughs in the field of remote medical services and support the implementation of telemedicine policies.

INDEX TERMS Application, electronic device, visual acuity, systematic review

I. INTRODUCTION

Recent years, electronic devices have become an integral part of our lives. The number of smartphone users in 2016 was more than seven billion users worldwide. The rate of internet users also increased globally by about 7-fold from 6.5% to 43% between 2000 and 2015. In 2015, the rate of households with internet access also increased from 18% in 2005 to 46% in 2015 [1]. The advances of the internet and communication technology have enabled the proliferation of digital medical devices with innovations in the form of health applications. Health applications currently cover various fields, one of them is the application of visual acuity examination. This promising approach can help overcome accessibility problems by using electronic devices such as smartphones, tablets, and computers that can be used independently from home, as well as in the clinic [2].

The examination of visual acuity using a computer was first investigated by Michael Bach in 1996. The results showed that there were limitations to image elements or pixels on a computer monitor, so that only certain visual acuity could be tested, at a distance of five meters [3]. Computerized examinations in the following years showed that computerized

systems allowed early detection of true clinical changes in visual acuity in each patient [4].

Visual acuity is a measure of the eye's ability to clearly distinguish the shape and detail of objects at a certain distance [5]. Visual acuity examination is done by comparing a person's visual acuity with the standard normal person which usually begins with an examination using an optotype. Optotypes are marks of different sizes that are placed systematically on a visual acuity chart. The optotype is usually a number, letter, or symbol as an instrument to test visual acuity [6]. Conventionally, symbols have been printed on cards or graphics that are mounted on walls and presented to patients for examination [5].

Human visual acuity can change due to many eye problems, therefore an examination of visual acuity needs to be carried out to help in detecting various eye disorders. Eye disorder such as visual impairment is a health problem that has profound effects on quality of life, educational attainment, and economic productivity [7,8].

World Health Organization (WHO) estimates that 2.2 billion people in the world have near or distance vision problems. The most common causes of visual impairment worldwide are uncorrected refractive errors (48.99%), followed by cataracts (25.81%) and age-related macular degeneration (4.1%). Meanwhile, the most common causes of blindness were cataracts (34.47%), followed by uncorrected refractive errors (20.26%), and glaucoma (8.30%). More than 75% of visual impairments are actually preventable [9]. Nationally, the results of the 2014–2016 Rapid Assessment of Avoidable Blindness (RABB) survey in 15 provinces showed that the blindness rate in Indonesia reached 900,000 people. The main cause of blindness and visual impairment in the population aged over 50 years in Indonesia is untreated cataracts with a proportion of 77.7% [10]. This shows that there are still many cases that are not corrected or even undetected. This fact shows the importance of increasing the affordability of visual acuity examinations to assist in the early detection of visual impairment.

During the COVID-19 pandemic, social distancing, quarantine, and restrictions on face-to-face interactions were enforced to prevent and break the spread of the SARS-CoV-2 virus. This poses a challenge in providing eye care to patients, as eye examinations require the examiner to be in close contact with the patient. In fact, the first case of COVID-19 was reported by an ophthalmologist at the Wuhan Central Hospital, who also died from the new virus [11,12].

Various types of visual acuity testing applications are available and can be downloaded easily on the internet. However, the validity of these applications remains unclear. Meanwhile, the limited mobility and health service during the COVID-19 pandemic underscore the urgent need to conduct research that validates these electronic device-based applications. Thus, this study aims to critically analyze whether the electronic device-based application is able to provide a valid and high-quality visual acuity examination.

II. MATERIALS AND METHODS

A. SEARCH STRATEGY

This systematic review is conducted based on Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) guidelines. We performed a comprehensive search of PubMed, MEDLINE, Springer, and Cochrane Library databases up to January 2011 and updated later to the end of 2021 using keywords as follows: "application", “electronic device”, and "visual acuity". Boolean operators (AND, OR, NOT) and truncation (*) were applied to broaden and narrow the search results. We also used the Medical Subject Headings (MeSH) terms in the search strategy. However, the search language was limited to English and Bahasa Indonesia.

B. ELIGIBILITY CRITERIA

Inclusion criteria were set to filter the results as follows: (1) diagnostic test, observational study, or clinical trial, and (2) investigating the validity of visual acuity examination performed by electronic device-based application. It is worth mentioning that different study designs were incorporated into this review including those with one or more index tests and with any reference method that investigated visual acuity test in the general population. Conversely, the exclusion criteria defined included: (1) irrelevant topics, (2) not having index test as comparison, (3) unknown and/or inappropriate study types and settings, (4) incompatible language, and (5) irretrievable full-text articles.

C. DATA EXTRACTION AND RISK OF BIAS

The following data from articles were extracted, including author and year of publication, study design and location, sample size, index test, reference test, and outcome measures such as mean difference, sensitivity, specificity, and any other reported outcome. The quality of included studies was assessed using the Joanna Briggs Institute (JBI) checklist with $\geq$50% cut-off. Risk of bias assessment was conducted by the reviewers collaboratively and discrepancies were resolved by consensus between reviewers.

III. RESULTS

A. STUDY SELECTION

A total of 1409 studies were initially identified. After removing 324 duplicates, 1085 results were screened based on title and abstract, out of which 132 full texts were identified to be examined (Figure-1). Finally, 113 studies were excluded due to not meeting the inclusion criteria. In total, 19 articles

were included in this review. The quality assessment of all studies using the JBI checklist showed a low risk of bias.

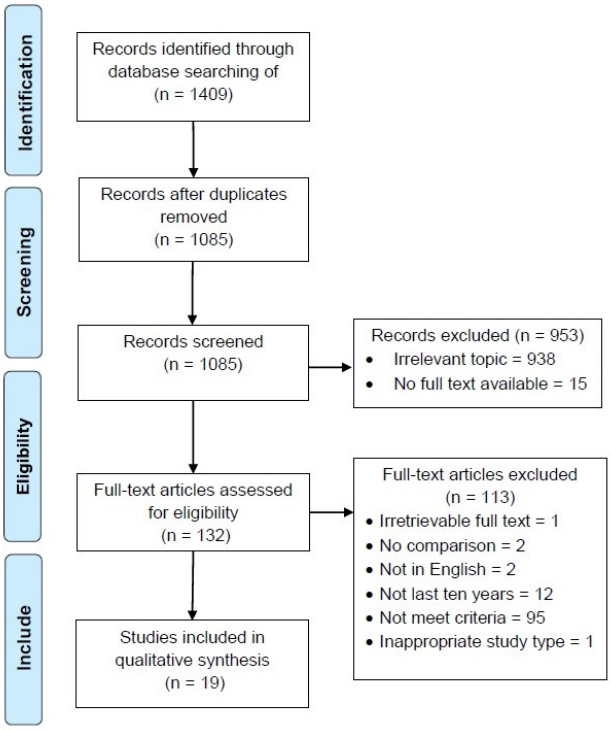

FIGURE 1. Flowchart diagram of the literature search strategy

B. STUDY CHARACTERISTICS

The general characteristics of the selected studies are summarized in Table-1. Thirteen out of nineteen selected studies had a diagnostic study design. Four was a cross-sectional study [14,18,21,26] and two studies were RCT [17,22]. These studies had been published from 2011 to 2021 with worldwide distribution, including USA, Kenya, Australia, Malaysia, India, Thailand, UK, Netherland, China, France, and Canada. Briefly, these studies have included 23,805 population samples. The mean age of the subjects was between 3 to 97 years old. Except for four studies [24, 29–31], gender distribution was described in all studies [13–31]. Most of the studies were validation tests in controlled environments.

IV. DISCUSSION

The results showed 18 of 19 studies stated that visual acuity examination with electronic device-based applications gave valid results. The overall identification results also show lower mean difference between digital applications compared to standard reference tests in assessing distance visual acuity. This indicates a low systematic bias. The mean difference ranged from -0.08 to 0.10 logMAR. The majority of the 95% limits of agreement range on the results of the distance visual acuity examination is quite wide, which indicates the variability.

The study by Satgunam et al. (2021) stated that the Smart Optometry application was not comparable to the reduced Snellen chart, but was declared valid because it only differed by 2 logMAR lines, which means it is still clinically acceptable. This difference is not a problem when digital applications are used for screening to detect visual impairments associated with decreased visual acuity, even though age and refractive errors affect measurements in Smart Optometry applications [13].

Several studies have attempted to link the use of electronic device-based applications to clinical practice. A study stated that the repeatability of using the Eye Chart application needs to be investigated before being integrated into clinical practice even though the study results are reported to be valid [16]. Correspondingly, the study by Perera et al. (2015) has valid results but still needs further research for clinical use [28]. Different things were reported in a previous study by Gounder et al. (2014) who stated that the Eye Snellen application can be used to measure visual acuity in clinical settings reliably on all measures of visual acuity [30]. More specifically, in one application, Eye Chart Pro, it was reported to be reliable for testing if Snellen's visual acuity was better than 20/200 or 0.1 in decimal [31]. The results of the analysis of Bland-Altman plots in all the studies reviewed did show that the accuracy of the examination results tended to increase in patients who had better visual acuity.

In contrast to the results of other studies, one study stated that the Eye Hand Book application was invalid. The application provides an overestimated close-range visual acuity result compared to a conventional near card with an average of 0.11 logMAR, except for the standard measurement result of 20/20. This means that patients tend to perform better on examinations, so eye disorders may go undetected. Overestimated results can result in delays in treatment. This study suspects that the main factor that plays a role in the discrepancy in the results between the application and the standard reference test is the contrast ratio. The contrast ratio of the clean printed Snellen chart or ETDRS is below 33:1, while the iPhone 5 as a digital device used in this study has a contrast ratio of 1151:1 [27]. Other studies have also reported that measurements of visual acuity in subjects can be overestimated with increasing contrast and lighting levels [32]. However, the validity of the near vision test in this systematic review overall shows better results than the remote visual acuity assessment which is characterized by a smaller 95% limit of agreement range. In daily use in clinics, examination time is critical for efficiency.

TABLE 1
DATA EXTRACTION

Author, year	Design, location	Sample size	Application, electronic device	Index optotype	Reference optotype	Outcome
Satgunam et al., 2021 [13]	Diagnostic study, India	68 participants	Peek Acuity, smartphone	ETDRS Tumbling E	COMPlog presenting Tumbling E	Valid (P= 0.3)
		24 participants	Smart Optometry, smartphone	Tumbling E	Reduced Snellen near vs chart with tumbling E	Valid (2 lines LogMAR differences)
Tiraset et al., 2021 [14]	Cross-Sectional, Thailand	295 eyes dari 151 patiens	Eye Chart, smartphone	Snellen chart atau Tumbling E	ETDRS chart	Valid (OD: ICC=0,88; p<0,001, OS: ICC=0,74; p<0,001)
Hazari et al., 2020 [15]	Diagnostic study, Canada	25 patiens normal, 26 patiens visus menurun	Eye Chart Pro, iPad	ETDRS Chart	ETDRS Chart	Valid (Mean diff logMAR= 0.11; p= 0.82)
Ansell et al., 2020 [16]	Diagnostic study, Australia	24 eyes in 24 participants (monocular)	Eye Chart, smartphone	Snellen chart	ETDRS chart	Valid (Snellen: 0.09 logMAR; ETDRS: 0.08 logMAR)
Wisse et al., 2019 [17]	RCT, UK	200 eyes from 100 participants	Easee, smartphone and computer	Tumbling E dan tool specific optotypes	ETDRS chart	Valid (ICC = 0.92; P=0.21)
Han et al., 2019 [18]	Cross-Sectional, China and Australia	326 participants	Vision at home, smartphone	Tumbling E	ETDRS tumbling E and ETDRS near chart	Valid (Mean diff -0.010 – 0.100 logMAR)
Brucker et al., 2019 [19]	Diagnostic study	120 eyes in 78 participants	Odysight, smartphone	ETDRS Tumbling E	Sloan ETDRS chart and ETDRS chart	Valid (Mean diff -0.53 – 1.53 letters)
Zhao et al., 2019 [20]	Cross Sectional, USA	108 participants	Peek Acuity, smartphone	ETDRS Tumbling E	Snellen eye chart	Valid (Sensitivity 83%-86%; Specificity 70%)
Nik Azis et al., 2019 [21]	Cross-Sectional, Malaysia	390 eyes in 195 patients	AAPOS Vision Screening, iPad	LEA Symbols	ETDRS lightbox with the LEA symbols chart	Valid (Sensitivity 86,6%; Specificity 78.9%)
Rono et al., 2018 [22]	RCT, Kenya	10.579 in Peek group and 10.284 in standard group	Peek Acuity, smartphone	ETDRS Tumbling E	Snellen's TumblingE chart	Valid (Sensitivity 77% vs 75%; Specificity 91% vs 97,4%)
Calabrese et al, 2018 [23]	Diagnostic study, USA	165 (normal vision) and 43 (low vision)	MNREAD iPad app, iPad	MNREAD chart	Printed MNREAD chart	Valid (Mean diff 0.03 logMAR)
Pathipati et al., 2016 [24]	Diagnostic study, USA	Phase 1: 57 eyes in 30 patients, Phase 2: 51 eyes in 17 patients	Paxos Checkup by Sightbook, smartphone and tablet	Tool-specific optotypes	Phase 1: Snellen chart, Phase 2: Rosenbaum near card	Valid (Mean diff 0.15 logMAR; p= 0.046)
Bastawrous et al., 2015 [25]	Diagnostic study, Kenya	544 eyes, 300 patients	Peek Acuity, smartphone	ETDRS Tumbling E	ETDRS tumbling E chart and Snellen chart	Valid (Mean diff 0,07 (95%CI: 0,05-0,09) and 0,08 (95% CI: 0,06-0,10) logMAR
Jan-Bond et al., 2015 [26]	Cross-Sectional, Malaysia	101 patients and staff	Rapid Eye Screening Test / REST, smartphone	Tumbling E chart	ETDRS tumbling E chart	Valid (OD: r = 0.829; OS: r = 0.871; p < 0.001; 95% loA ±0.11 (OD) and ±0.10 (OS)
Tofigh et al., 2015 [27]	Diagnostic study, USA	50 patients	Eye Hand Book, smartphone	Tool-specific optotypes	Rosenbaum near card	Invalid
Perera et al., 2015 [28]	Diagnostic study, Australia	80 patients	Snellen DrBloggs Ltd, smartphone	Snellen chart	Snellen chart	Valid (Mean diff 0.02 logMAR; 95% loA = 0,332; 0,372 logMAR)
Toner et al., 2014 [29]	Diagnostic study, USA	60 patients	Handy Eye Check, tablet and computer	Handy eye chart	Handy eye chart	Valid (r= 0.92; Mean diff -0.005 logMAR; 95% loA = -0.003 – 0.02)
Gounder et al., 2014 [30]	Diagnostic study, Australia	122 eyes dari 67 patients	EyeSnellen, smartphone and iPad	Snellen chart	Snellen light box	Valid (Mean diff -0.001 logMAR; 95% loA = -0.169 – 0.171)
Zhang et al., 2013 [30]	Diagnostic study, China	240 eyes, 120 patients	Eye Chart Pro, iPad	Tumbling E	Standard tumbling E light box	Valid (P= 0.001; Mean diff 0.02 logMAR)

This is the reason why the Snellen chart is an optotype for routine examination in clinical practice. The results of the application quality analysis on the operability component show that the Peek Acuity application that uses the ETDRS Tumbling E chart optotype has an average inspection time of 5 seconds faster than the conventional ETDRS Tumbling E chart [24]. Correspondingly, the REST application also recorded an average examination time of 2.8 seconds faster than the standard reference test [26]. These results support digital applications for routine use. Nevertheless, previous research reported there is a slight delay between the time. During this delay, the subject may begin to read the first line of the text. The result would be an underestimate of the reading time, and consequently, an overestimate of reading speed. This possibility is supported by a recent study that compared stopwatch versus automated timing in a computer-based reading test [32].

In addition, visual acuity examination by application is also affected by the basis of the electronic device. Recent studies have reported few differences in test time between paper and screens [33,34]. In a different study, it is still a debate whether reading is better on paper or LCD [35]. Furthermore, previous research found that visual acuity examinations on iPads are particularly susceptible to glare. Utilizing an anti-glare coating can be the solution [36]. However, some of the information that accompanies the valid statement decisions in 18 studies shows that the feasibility of digital applications is currently still limited to early detection and has the potential to be used as an initial examination in remote medical services.

Visual acuity examination with digital applications based on electronic devices has a lot of importance for the development of remote services. This makes various studies state recommendations for the use of digital applications even though there are slight differences between the results of the examination and the application compared to standard references. Conventional examinations in hospitals require the patient to physically come to the clinic. Difficulties that may be faced by patients are living far away, for example, people living in rural areas, elderly patients, and patients who are unable to move [37]. Remote inspection can also reduce costs and speed up early detection [38]. Moreover, a smart mobile application to monitor visual function in diabetic retinopathy and age-related macular degeneration patients already existed and is being investigated [39]. With the increasing flow of digitization, the portability aspect seen from instability supports the quality of digital visual acuity check applications.

The availability and increasing use of electronic devices, especially smartphones and tablets, further emphasizes the potential for digital applications to identify the most common causes of visual impairment in Indonesia and the world, including uncorrected refractive errors. Studies report that half of the visually impaired population actually has a decrease in visual acuity that can be prevented or corrected with glasses or contact lenses [40].

In practice, the use of electronic device-based applications for visual acuity examination can increase the work effectiveness of medical personnel and increase the proliferation of digital medical devices. The results of this systematic review can also be one of the breakthroughs in the field of remote medical services and support the implementation of telemedicine policies.

As in other studies, this review also has several limitations. Due to the novelty of the topic discussed, there are limited study resources. As a result, the study design and validity parameters of the included studies varied. However, all being considered large study using the electronic device-based application as an index and conventional visual acuity examination as the comparison.

V. CONCLUSION

In conclusion, the use of electronic device-based applications provides valid results for early detection in visual acuity examinations. This systematic review also found that electronic device-based application visual acuity examination showed better results in near-range visual acuity assessments than the distance visual acuity assessments. We also found that the results of Bland-Altman plots analysis observed in all included studies showed that the accuracy of the examination results tended to increase in patients who had better visual acuity.

Further research on the repeatability of visual acuity examination with electronic device-based applications is required to support the validity conclusion. In addition, it is necessary to conduct research that examines the potential for remote medical services.

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Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest

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