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Remote vision testing of central retinal acuity and comparison with clinic-based Snellen acuity testing in patients followed for retinal conditions

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Abstract

Introduction: The unmet need for remote monitoring of visual function with home-based, patient-centric technologies became increasingly palpable during the COVID-19 pandemic. Many patients with chronic eye conditions lack access to office-based examinations. Here, we evaluate the efficacy of the Accustat® test, a virtual application for measuring near visual acuity on any portable electronic device via telehealth.

Materials and methods: Thirty-three adult subjects from the telehealth remote monitoring service of a retina practice performed the Accustat® acuity testing at home. All patients underwent in-office general eye examination with additional fundoscopic examination and optical coherence tomography retina imaging. Best corrected visual acuity assessment using a Snellen chart was compared with remote visual acuity assessment with the Accustat® test. Visual acuity was analyzed and compared between the best-corrected near visual acuity potential achieved on the Accustat® and in-office distance best-corrected Snellen visual acuity.

Results: The mean logarithm of the minimum angle of resolution (logMAR) visual acuities of all eyes tested using the Accustat test was 0.19 ± 024 and for the office Snellen test 0.21 ± 0.21. A linear regression model with 95% confidence intervals reveals that there is a strong linear relationship between Accustat logMAR and office Snellen logMAR. Bland–Altman analysis demonstrated 95.2% significant agreement between Accustat and Office Snellen's best corrected visual acuity. Intraclass correlation coefficient (ICC = 0.94) demonstrated a strong positive correlation between at home versus office visual acuity.

Conclusion: There was a high correlation between the visual acuity measured with the Accustat near vision digital self-test and the office Snellen acuity test, suggesting the potential utility of scalable remote monitoring of central retinal function via telehealth.

Keywords

Telemedicine, remote monitoring, ophthalmology, retina, Accustat

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Background

Recent advances in mobile technology and telehealth present an opportunity to expand outreach beyond the clinic and provide patient-centric tools for the measurement of visual function. The prevalence of visual impairment in the population is high, yet there are no standardized and easily available tools for patients and doctors to measure and monitor for changes in the functional status of patients with chronic diseases such as age-related macular degeneration (AMD), Diabetic Retinopathy, and others.[1] With the increased improvement of screen technology for

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computers, tablets, and other peripherals, initial efforts are emerging to provide validated tools for home testing and measurement of visual acuity (VA).[2–4] While conventional chart-based methods are the mainstay, mobile technology has advanced significantly to start offering a compelling alternative to printed tests. Screens are a part of many consumer peripherals and their quality has dramatically improved to the point that it can parallel or exceed the utility of paper chart alternatives. Scalability, portability, data analytics, automatic cloud storage, and retrieval are just a few of the perceived advantages of electronic remote testing.

One of the most common tests of central retinal function is the VA test. VA is the most basic ocular vital sign and is essential to the evaluation and management of most ophthalmic diseases. The conventional standard test of foveal vision is the best-corrected distance VA using the Snellen acuity chart which is performed in more than 100 million times a year in the US alone as a part of the standardized eye exam. Another test of foveal acuity and visual potential is the best-corrected near VA and there are many near acuity tests such as Jaeger near acuity test, the Rosenbaum vision card, and others.

Both the best-corrected distance VA test and the best-corrected near acuity test are intended to measure maximum foveal functional vision after correcting for refractive error and media abnormalities. With proper near and distance refractive correction, a strong correlation has been demonstrated between the distance and the near acuity as overlapping surrogate measures of central retinal function.[5] While a few studies report some differences between the two measures of foveal acuity, the disagreement tends to be small, often in the range of a single acuity line.[6]

There is a significant unmet need for remote monitoring of visual function with home-based, patient-centric technologies. This became increasingly palpable during the COVID-19 pandemic in 2020 when many patients with chronic eye conditions such as wet and dry AMD, glaucoma, and diabetic retinopathy did not have access to office-based examination. While many vision applications are being developed and gradually emerging to fill this need, there is a paucity of clinical validation demonstrating their efficacy and utility for self-monitoring. In the case of retinal disease application, there are now studies clearly demonstrating the clinical and population health utility of home monitoring using digital health technology. High sensitivity and specificity for the early detection of recent-onset choroidal neovascularization and disease progression have been demonstrated with the Forsee preferential hyperacuity perimetry device.[7,8] Another example of a smartphone test has also shown promise for remote vision testing.[9]

VA measurement is the cornerstone of every clinical eye exam—it is measurable and quantifiable and is often one of the earliest symptoms of central retinal dysfunction. Yet, we have few quantitative tests of visual function outside the clinic that is readily available to patients and physicians for continuous monitoring of VA status remotely and from home. Many chronic eye diseases such as glaucoma, AMD, and diabetic retinopathy are insidious in nature. Not only are they asymptomatic early in their course, but often exhibit asymmetric presentation, causing the less-affected eye to compensate and mask the visual deficit until late in the disease's progression. Such diseases are of significant public health impact affecting millions in the US and the world and are the leading cause of irreversible blindness (WHO Report 2020).

With the recent advancements in mobile technology and the availability of high-quality consumer electronics, such as smartphones, tablets, laptops, and desktop computers, connected cloud-based access can enable on-demand application-based digital tools for the quantifiable and remote measurement of physiologic functions such as VA. The Accustat® test is a virtual application for measuring near VA on device-agnostic peripherals such as smartphones and laptops. It is based on a modified Rosenbaum near acuity algorithm which is universally available as the near acuity cards used clinically for the past 4 decades. The algorithm has been further optimized for virtualized cloud-based delivery which is responsive and adaptive to the end-client environment depending on most detected parameters of the consumer displays and monitors. Accustat® does not require any specialized hardware and can be deployed over a web application anywhere on any web-connected device.

The current study was designed to evaluate and compare the performance of the remote VA test to the office-based VA test in a real-world assessment of patients from two retina practices. This study is also designed to evaluate the correlation between distance and near-best-corrected VAs as two related surrogates of central retinal function. Near VA is a critical visual function that, when compromised, has been shown to have as great an adverse impact on quality of life and functioning in older adults as a decline in distance VA.[10–12] More importantly, assessment of near VA can be more impactful from a screening and monitoring perspective as it is easier to measure remotely and is better able to leverage existing digital technology.

Methods

Study population

A chart review of consecutive case series of telehealth patients from two retina practices was performed. The study participants were selected from the medical records between June 2021 and September 2021. All patients who were monitored or referred for pre-existing retinal pathology were 18 years and older, and could speak and read in English. Patients had performed remote vision testing

using the Accustat self-test. All subjects were 18 years of age or older, had VA of 20/200 or better in at least one eye, and had updated distance and near eyeglass prescriptions within the past 12 months to help ensure maximum best-corrected distance and near VA potential.

This study qualified for a waiver of consent as it presents no more than minimal risk of harm to subjects and there were no procedures for which written consent is required. This study followed the tenets of the Declaration of Helsinki.

Patient and public involvement

Patients or the public were not involved in the design, conduct, reporting, or dissemination plans of our research.

In-office testing

In the office, patients underwent standard VA testing using the Snellen test. Office-based vision testing was performed by a trained ophthalmic technician in a dimmed room with the Snellen chart illuminated on a screen. Patients were asked to wear their current corrective lens for distance and an eye occluder was used to test each eye separately. They also underwent a full ophthalmologic eye exam with a slit lamp and fundoscopic assessment. In addition, all subjects underwent optical coherence tomography testing of the macula.

Remote physiological testing

The Accustat® VA test is a modified acuity measurement technology for self-administration and assessment of central retinal acuity status using a modified Rosenbaum acuity algorithm. The test is specifically designed for cloud-based remote access self-administration on a consumer electronic peripheral such as smartphone, tablet, laptop or desktop. The Accustat technology uses a proprietary advanced algorithm for adaptive, monitor agnostic optotype scaling and letter display to maintain absolute dimensions for each VA line. The algorithm automatically interrogates the peripheral device at the access point and profiles the monitor and browser specifications. Based on these monitor-specific inputs, the Accustat display is adjusted to display constant letter sizing for each line of VA testing. This ensures that no matter what monitor, device, or peripheral the patient uses, the Accustat test will responsively adapt to the display characteristics to produce a consistent size of letters for the test. This is of particular importance with home-based, remote testing for VA, which can be prone to significant display size variability as different monitors have different resolutions and pixel sizes, and densities. This is in distinction to the office-based displays which use a single monitor display for letter display sizing that has been specifically optimized.

Data collection and analysis

A chart review of all patients who completed the home vision assessment was conducted through the electronic medical record after their clinic visit. Demographics, major ocular conditions, office-based Snellen VA, and home VA were collected and recorded. Data for patients in both eyes were collected and are available in both Snellen and logarithm of the minimum angle of resolution (logMAR) scales. The effect of presbyopia was mitigated by the use of near refractive correction for patients during the exam, with the refraction and prescription for near correction updated within the past 12 months. For data analysis, the median, mean, and standard deviation (SD) for VA between Accustat and Office Snellen were calculated in R using the median, mean, and sd functions, respectively. Paired Student *t*-tests and correlations between Accustat evaluations and office Snellen evaluations were performed in the software package GraphPad Prism 8.4.3 (GraphPad Software, La Jolla, CA). The figures were also created in GraphPad Prism.

The primary outcome was best-corrected VA in the study eye using the home vision test compared to office-based Snellen VA using paired t-test. Bland-Altman plots were used to compare the agreement between the home and office VA.10 In Bland-Altman plots, the *Y*-axis shows the difference between two paired measurements and the *X*-axis shows the mean of these measurements. A sample size calculation indicated 31 patients were needed to detect a logMAR difference of 0.1 between the office and home vision tests, assuming a paired *t*-test, the SD of 0.2, two-sided alpha of 0.05, and 80% power. All VAs were converted to logMAR for analysis. For each patient, only the best line of vision using the home vision test was recorded rather than the number of letters per line. The best line of vision is defined through a drill-down testing protocol with decreasing (large to small) optotype sizing similar to the traditional Snellen VA exam. When a patient incorrectly identifies two or more numeric characters per presentation line on two subsequent presentations, the prior level will then register as the best line of vision. The limits of agreement are reported for the 95% confidence interval. Paired t-test and univariable regression analysis were performed to determine if there were predictors for the difference between home and office VA.

Results

A total of 66 eyes were analyzed. 22 subjects (66.7%) were female and the mean age was 71 ± 12.9 years (min = 28 years; max = 90 years). Educational level was high school or above for all participants and all patients were literate. The median logMAR VAs of all eyes tested using the Accustat test was 0.1 and for the office Snellen test 0.1. The mean logMAR VAs of all eyes tested using the

Accustat test was 0.2095 (SD = 0.2164) and for the office, the Snellen test was 0.1855 (SD = 0.2434) (Figure 1). The mean and median LogMAR VA difference between the Accustat versus Snellen test was 0.021 and zero, respectively, indicating individual differences are normally distributed around zero. A paired Students T-test demonstrated that there is no significant difference between the means (p-value = 0.2115). The histogram in Figure 2 illustrates the evaluations of the Accustat and the office Snellen grouped into categories of 20/20, 20/25–20/30, 20/40–20/60, and < 20/60. A paired Students t-test comparing the compositions of categories of the histogram between the Accustat and office Snellen revealed no statistical difference (p-value > 0.9999). In a scatter plot of Accustat logMAR versus office Snellen logMAR, a linear regression model with 95% confidence intervals revealed that there is a one-to-one linear relationship between Accustat logMAR versus office Snellen logMAR (regression: $Y = 0.9541X + 0.02948$; R^2: 0.715) (Figure 3(a)). Figure 3(b) illustrates the residuals of each data point from the calculated linear regression.

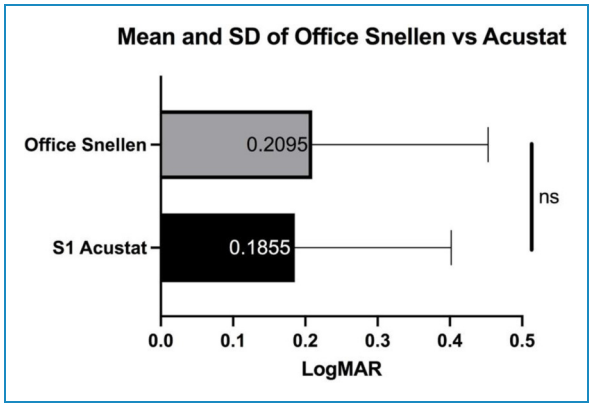

Figure 1. Mean and SD of Accustat® VA measurements (S1 LogMAR) versus office Snellen (Office LogMAR). Paired Student's t-test reveals no significant difference between the means. LogMAR: mean logarithm of the minimum angle of resolution; VA: visual acuity; SD: standard deviation.

The Bland–Altman plot of study eyes below showed that 95.2% of eyes had clinically significant agreement defined as ≤ 0.2 logMAR of difference from the mean difference (Figure 4). 95% of eyes also demonstrated agreement within the 95% limits of agreement (−0.31 to 0.26 logMAR).

In addition, 43 eyes had two Accustat tests of the same eye obtained within 7 days of each other which were used for test–retest reliability. No ocular intervention or change of vision was reported between the two measurements and the tests were taken on the same home peripheral device. The intraclass correlation coefficient of ICC = 0.94 showed excellent reliability and repeatability of the Accustat test.

Discussion

In this study, we investigated the clinical outcomes of the Accustat remote VA monitoring test and the conventional office-based Snellen VA test. We also studied the relationship between distance-best-corrected VA and near-best-corrected VA as two appropriate surrogate measures of central retinal function and acuity potential. Our findings demonstrate a very significant correlation between the

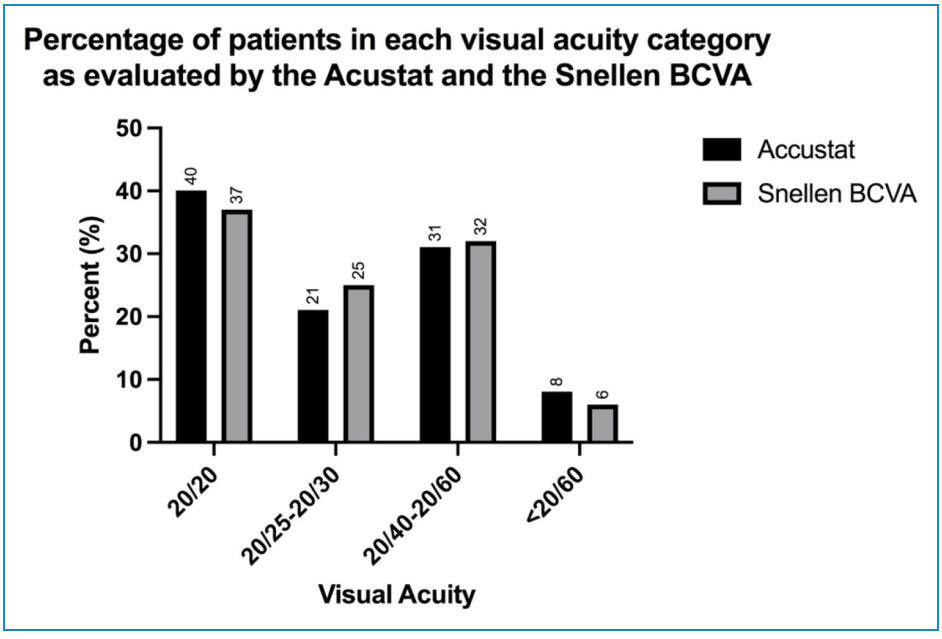

Figure 2. Percentage of patients in each visual acuity category as evaluated by the Accustat® and the Office Snellen.

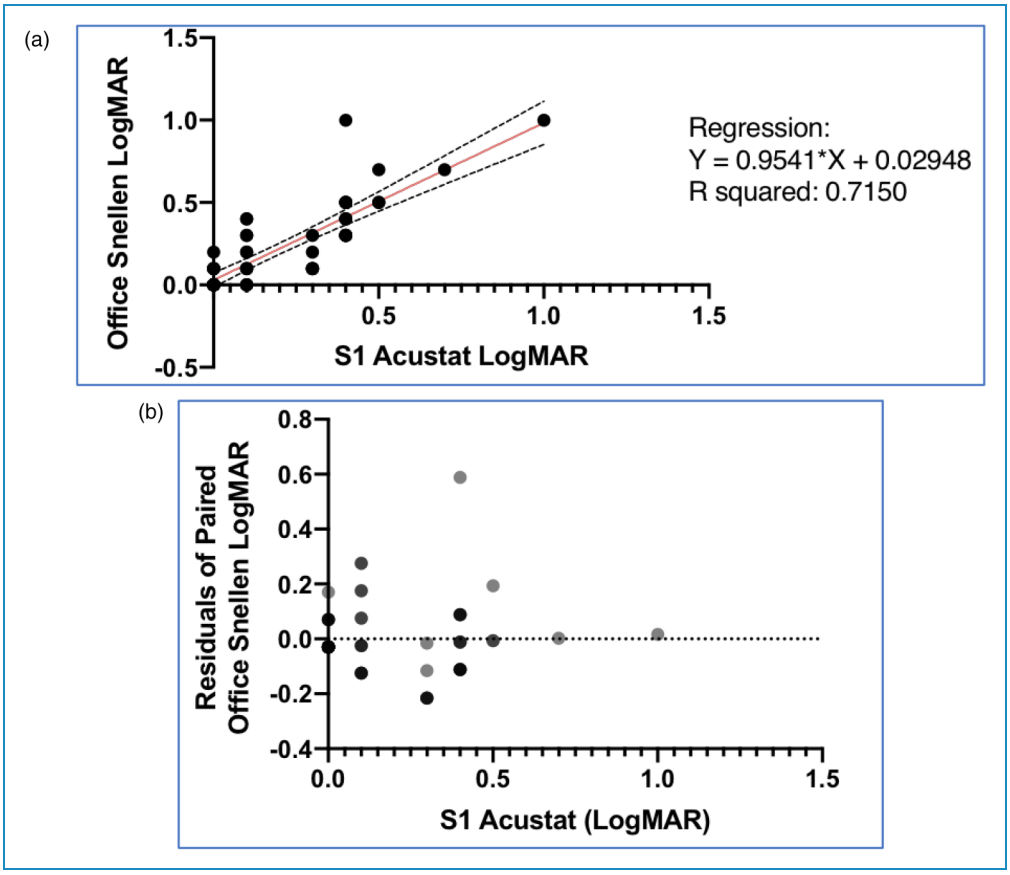

Figure 3. (a) Scatter plot of Accustat® VA measurements (S1 LogMAR) versus office Snellen (Office LogMAR) with simple linear regression model trendline and 95% confidence intervals. The darker data points represent greater overlapping data at a location. (b) Residual plot of Accustat® VA measurements (S1 LogMAR) versus office Snellen (Office LogMAR) with simple linear regression model trendline. The darker data points represent greater overlapping data at a location.
LogMAR: mean logarithm of the minimum angle of resolution; VA: visual acuity.

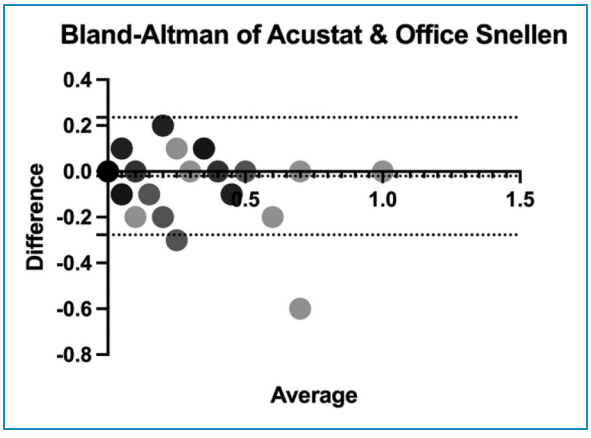

Figure 4. Bland–Altman plot of visual acuity (VA) differences between Accustat® versus office Snellen. The dotted lines represent 95% limits of agreement. The darker data points represent greater overlapping data at a location.

two tests in 66 eyes of patients with a range of baseline VAs and retinal pathologies.

In our study, we found an average difference of 0.021 LogMAR between the Office Snellen Best Corrected Distance VA and the Accustat home self-test of near BCVA. This small difference is well within the established range of variation reported in other studies, which have shown that best corrected near VA and distance Snellen best-corrected acuity are closely correlated with a minimal difference. In one study, there was a strong correlation between distance Snellen and near VA as measured by the Rosenbaum card with LogMAR VA of Near Card of 0.15 ± 0.22 versus LogMAR Snellen Distance of 0.18 ± 0.21 along with a high intraclass correlation coefficient above 0.75 for either test.[13] The difference between the Snellen distance and the near acuity was in the range of six ETDRS letters and was consistent across the range of VAs from 20/20 to 20/800. Although average differences

between Accustat BCVA and Office Snellen BCVA are low in our study, please note that individual differences may be greater in magnitude than the mean deviation.

It is rather informative that despite the difference in technology, delivery, place of testing, self versus technician administration, and near versus distance acuity, the 0.0221 LogMAR difference is not materially different from variability reported with printable home tests where computer screens are not a confounding factor. A study of office Snellen distance VA versus home distance VA in 45 eyes demonstrated a 0.02 logMAR difference.[14] Another study of home versus office distance acuity comparison using printed ETDRS charts in 108 patients showed a mean absolute difference in letter score of only 5.2 letters.[15] These findings also are consistent with another published study of printable home acuity testing in 100 adult patients, where the difference between home and office testing was 0.10 logMAR, the equivalent of 5.0 ETDRS letters.[16] The results of such studies of printable home acuity tests when compared to our findings with the digital home acuity testing suggest that digital delivery is not materially different from printed charts and computer monitor resolution and adaptive sizing algorithms are able to deliver outcomes similar to print charts.

The limitations of this study are several. The Accustat does not have the ability to calibrate luminescence and contrast between different devices, which could confound intra-subject and inter-subject measurements of VA. While we evaluated consecutive real-world patients from the telehealth service, this study is not a randomized controlled trial. The population was also real-world, non-homogenous, and included patients with different retinal pathologies. While we intentionally compared the distance between Snellen office VA to near Accustat home VA to assess the utility of near acuity assessment for remote monitoring and telehealth, the study did not provide data with additional corresponding measurements of an office near acuity and home distance acuity to calibrate the two VA assessment paradigms, which could introduce interference with our results. Further research on the relationship between near and distance BCVAs while using the Accustat may provide insight into how distance from visual stimulus affects exam validity. Future studies of population health efficacy for screening and early disease detection or monitoring of progression can also add further validation of this digital health tool.

Remote self-monitoring of central retinal function using a ubiquitous on-demand digital health application such as the Accustat test offers significant advantages to extend the clinical practice outreach beyond the medical office into the patients' homes. The high correlation between near-best-corrected digital VA and office distance best-corrected Snellen VA opens up new avenues to leverage consumer electronic devices in the assessment of visual function for a range of clinical and public health applications.

Contributorship: All authors contributed substantially to the design of the study and the review of the data and the writing of the manuscript. Dr Gentile contributed clinical data from his practice.

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