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Comparison of Assessment of Refractive Error by Autorefraction and Manual Refraction with Digital Visual Acuity Chart
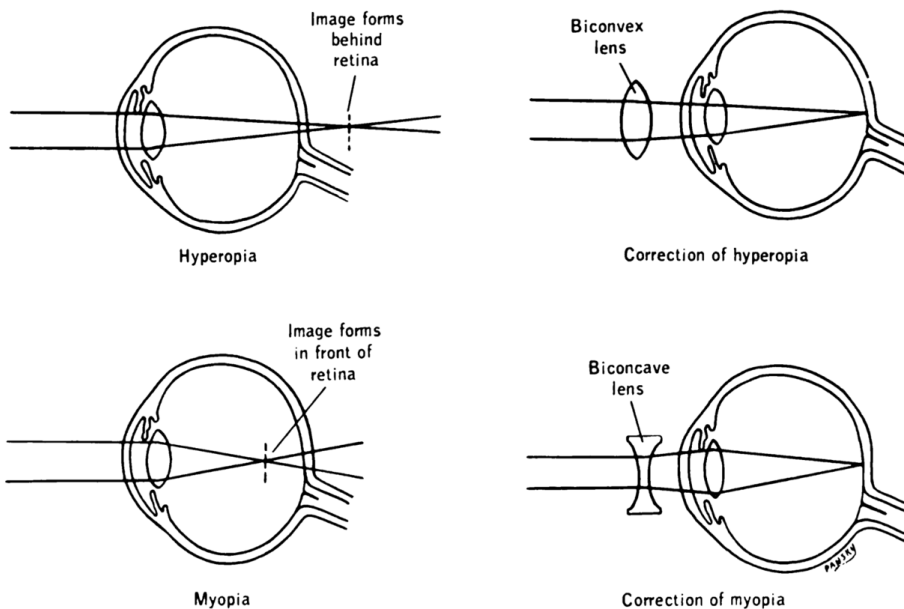
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Abbreviations

ANOVA=Analysis of variance

BCVA=Best corrected visual acuity

VA=Visual acuity

Abstract

Objectives

The purpose of this study was to compare refraction measurements acquired by Topcon Auto Kerato-refractometer KR-1 autorefractor to those of manual refraction with trial frame using digital visual acuity chart and a system for interactive determination of visual acuity, developed at the Uppsala Department of Neuroscience, Ophthalmic Biophysics. Moreover, we investigated the agreement of refraction between different refractive error classes.

Methods

A total of 15 participants aged from 22 to 26 years were included in this study. The participants were evenly divided into five error classes: [-4 -3[, [-3 -2[, [-2 -1[, [-1 0[, [0 +1+] D. Each participant underwent manual refraction and autorefraction on two different occasions conducted by a single refractionist. Only one eye of each participant was included in the study.

Results

In general, no significant difference in refractive error between the two methods could be shown. However, in one refractive error class, a significant difference between the two methods could be identified.

Conclusions

The refractive error measurements obtained by autorefraction are comparable with those obtained by manual refraction in young adults.

Populärvetenskaplig sammanfattning

Standardmetoden för uppmätning av en patients behov för glasögon för att uppnå bästa möjliga synskärpa på avstånd är manuell systematisk prövning av olika glas med provbåge tills patienten uppnår bästa möjliga synskärpa. I kliniken används alltmer automatisk mätning med autofrefraktometer, eftersom den automatiska metoden är snabbare och mindre resurskrävande än manuella metoder. I praktiken avviker ofta resultaten från autorefraktometern från den manuella mätningen. Om bästa synskärpa efter korrektion konstateras med ett felaktigt uppmätt bryningsfel med autorefraktor, medför det en felaktigt låg uppmätt synskärpa. Skillnader i resultat av synskärpamätning mellan olika metoder har i tidigare studier kunnat påstås vara små men ändå ha klinisk betydelse. Därför föredras manuell mätning i all klinisk bruk, medan i forskningen används autorefraktion i en ökande utsträckning. Bästa synskärpa uppmätt efter korrektion med manuell mätning av brytningsfel, är ett mått på synsinnets upplösningsförmåga med det testade ögat och ligger i dagsläget till grund för avgörande om patienten behöver utredas vidare. Autorefraktometer används än så länge kliniskt endast som en utgångspunkt för manuell mätning.

I denna studie deltog 15 unga och friska försökspersoner i mätningar av synskärpa med både autorefraktometer och manuell refraktionering med provbåge och olika glas. Båda mätningarna genomfördes vid två olika tillfällen. I en jämförelse mellan resultaten uppnådda från refraktionsbestämning med hjälp av dessa två metoder, kunde ingen signifikant skillnad i synfel påvisas. Försökspersonerna var delade i fem olika grupper enligt deras grad av synfel, som konstaterades under refraktionsbestämningarna. I en av grupperna kunde man påvisa en signifikant skillnad mellan mätningsmetoderna. För att kunna bekräfta att ingen skillnad mellan manuell och automatisk synskärpamätning finns, behövs det en studie med fler försökspersoner och eventuellt bredare ålders- och synfelsvariation.

Background

The standard method for measuring a patient's need for corrective lenses, in order to achieve best corrected distance visual acuity, is manual systematic sampling of lenses with different corrective power until the best possible corrected visual acuity is reached. In clinical use a method that is being increasingly used for this purpose, is automatic measuring with an autorefractor. In actual practice the results attained from manual measurement often differ from those measured with an autorefractor. Best corrected visual acuity (BCVA) obtained by manual refraction is a measure that describes the resolution of the eye and provides the basis for evaluating a patient's need for further examination.

Visual acuity

Visual acuity (VA) is the most widely used measure of visual function. It is most optimally measured as best corrected distance visual acuity. Distance VA is a key indicator of ocular health and is used for assessment of refractive error and the adequacy of spectacle corrections. It is a practical and simple clinically used measure of sight that describes the ability of the eye to visually discern fine detail at all distances, more specifically, to distinguish between two points a short distance apart i.e. the resolution of the eye. This is an ability defined by three factors mainly – the optical system composed of the cornea and the lens, the function of cells in fovea centralis located in the centre of the macula lutea of the retina, and optic nerve conduction. If one's VA is measured normal, it provides a useful and quick estimate of the healthiness of this ocular pathway, but an abnormal VA does not distinguish between various possible causes for that abnormality.

Accommodation

Accommodation of the eye is a phenomenon by which the eye changes its optical power in order to focus a clear image on the retina when changing the distance from a far point to a near point. This ability is controlled by zonular fibres and ciliary muscle, a smooth muscle that changes the shape of the lens when contracting or relaxing. When the ciliary muscle contracts, it moves toward the axis of the eye which releases tension of the zonular fibres attached to the lens, which causes the lens to become more spherical, increasing the eye's focusing power and enabling clear vision at a near point. In the opposite scenario, when the ciliary muscle relaxes, the zonular fibres become tense, which flattens the lens and decreases the eye's focusing power. This is when the eye is in far accommodation and the focal distance is increased to a far point. Accommodation is an ability that deteriorates with age, usually starting from the age of 40.

Refraction

Refraction is synonymous with the optical power or focusing power of the eye in far accommodation. It is the degree to which the eye's optical components converge or diverge light. Refraction is a phenomenon based on the optical system composed of the cornea and the lens that enable image formation when light is focused onto the retina. Cornea is the transparent and spherical front part of the eye. It plays the most important part in refraction, i.e. the eye's focusing power. It is accountable for approximately two-thirds of the eye's total optical power. In the ideal refractive state of the eye the refractive powers of the optical system focus parallel rays of light from a distant object onto the retina as a single point.

A refractive error occurs if the eye has too much or too little refractive power and fails to emerge parallel light rays and focus an image onto the retina. The main refractive errors are hyperopia (farsightedness) and myopia (near-sightedness) that result from the visual image being focused behind and in front of the retina, respectively. Hyperopia and myopia are examined and corrected with spherical lenses. Another common refractive error is astigmatism, that is caused by an irregularly shaped cornea or lens that result in different refractive powers in different sectors of the cornea or the lens. This asymmetry creates an impaired optical system that generates multiple focal points instead of one on the retina and gives the patient blurred vision at all distances. Astigmatism is examined and corrected with cylindrical lenses of a specific power and axis.

In optics, refraction is also used as a synonym for determining the degree and type of refractive error and measuring visual acuity. The goal of clinical refraction is to determine the power of the corrective lens that will produce a single focal point on the retina and obtain BCVA. A recent refraction with visual acuity testing is required to adequately assess an up-to-date BCVA. The distance used to measure BCVA should be at least 4 meters when using a high contrast chart with letters, as explained below. The result should be presented as a logMAR value (log of the minimum angle of resolution). In general, decimal values are used as the unit in clinical praxis while logMAR is widely preferred in research. Normal visual acuity for adults is approximately 0.0 on the logMAR scale.

Methods of refraction and visual acuity test

Methods used to measure refraction and obtain best corrected visual acuity are either subjective, such as manual refraction with trial lenses, or objective, such as automatic measuring with an autorefractor. At present, manual refraction is the golden standard for refraction and the measurement of BCVA. The most remarkable disadvantages of manual refraction as the method of choice are that it is time consuming and requires an experienced refractionist. Moreover, excluding

the bias of both human refractionist and the subject during manual refraction is unachievable. There are several ways of conducting a manual refraction, but the principle is the same, the use of an illuminated chart with letters at a standard distance from the examined subject.

The standard method for manual refraction is a method called Donder's subjective method that can be used either as a single method or in combination with objective methods. In this study we compared Donder's subjective method with digital eye chart to autorefraction. In addition, a system for interactive determination of visual acuity, developed at the Uppsala Department of Neuroscience, Ophthalmic Biophysics was implemented. This system is based on the same principles as manual subjective refraction with paper chart and can be considered to generate the same end-result while also allowing faster change of letters (optotypes). It is a less demanding and more comfortable alternative for both the examiner and the examined. Further details of the system for interactive refraction can be found in chapter Methods.

Donder's method

Donder's method is implemented with the eye in far accommodation A rule of thumb is that a person's refraction equals either the positive lens with most refractive power, alternatively the negative lens with least refractive power that gives the best possible vision for that individual. For most adults, best possible vision is 0.0 on the logMAR scale as mentioned before, however for some individuals the maximal vision can be either higher or lower. In determining adequate spectacle correction, a BCVA of 0.0 logMAR or lower is aspired. BCVA should be measured in far accommodation. The far accommodation is represented at a distance of theoretical infinity which in practice refers to a distance of at least 4 meters. The use of this distance has the advantage of being one-quarter of a dioptre (the unit of measurement of the optical power of a lens) in lens power from testing at a theoretical infinite distance. For individuals under the age of 40, refraction begins with applying a spherical plus lens in front of the eye in order to accomplish completely relaxed ciliary muscles and hence minimizing accommodation to avoid a biased refraction. Donder's method implemented with digital eye chart is explained in further detail in Methods.

Autorefraction

As a method of refraction, the autorefractor's mechanism is based on the accommodation of the eye. The autorefractor measures the change in refraction of the eye while the subject accommodates from a distant to near target, representing an objective measurement of accommodation (1).

In general, automated refracting technology can be classified into three main categories: automated objective refractors with or without visual acuity capability, fully automated refracting systems with

subjective capabilities and wavefront refractors. In this study, an automated objective refractor without visual acuity capability was used.

Autorefraction has for many years been widely accepted among clinicians and researchers as a clinically valuable starting point for manual subjective refraction (2–6), providing an estimate of refractive error as a support for the manual refraction. Autorefractors have gained popularity especially as screening devices for nonverbal patient, children and patients with dementia. It has been shown to have high specificity and sensitivity for screening of refractive error among children (4,7). However, autorefractors have not been embraced as replacements for traditional (time-consuming) trial frame refraction. Satisfactory correlations have been displayed in previous studies between results obtained by autorefraction and manual refraction or when different autorefractors are compared to each other (8–12). Although the results of autorefraction highly correlate with those of trial frame refraction, the differences are sometimes substantial, making autorefraction an unsuitable substitute for trial frame refraction (4). There are many cases in which results can be unreliable or unobtainable such as patients with poor fixation, high refractive errors, small pupils, cataracts, keratoconus, nystagmus and amblyopia. The autorefraction has for instance been shown to be an inadequate method as a single tool for screening of amblyopia in children (13) and has a tendency for biased results in diagnostics of myopia amongst children under non-cycloplegic conditions (i.e. when the eye's accommodation is not manipulated with cycloplegic eye drops that relax the ciliary muscle) (14). However, in addition to providing an estimate of refractive error, the autorefractor may have value for follow-ups of refractive error progression in adults (2).

What makes autorefraction appealing in clinical use is that it has many positive qualities regarding practicality when comparing to trial frame refraction. It is a faster and simpler method and saves resources. Autorefraction can be performed by clinical assistants and other professions and therefore frees up the optometrists' time. In addition to acting as a timesaver, the autorefractor has the advantage of reduced probability of examiner error or bias which may occur with subjective refraction (8). Furthermore, no response is necessary from the patient during measurements which allows autorefraction to be used in a larger variety of patients including uncommunicative patients.

Although subjective refraction is at present considered the golden standard for determining one's refractive error, it may have limitations as a reference, considering its dependency on the clinician's abilities (2,9,15,16). In a previous study, results obtained by autorefraction were found to be more repeatable than those of manual refraction for both spherical and astigmatic components when two different examiners were conducting the measurements (9).

However, autorefraction is not free from fluctuation in refraction over time and some variation of refractive state has been distinguished in previous studies (8). In most cases the contribution of the autorefractor on the variation has appeared to be small (2,8). Nonetheless, the eye as an optical system presents a variety of causes for refractive variation, partly as a result of accommodation of the lens, or the changing curvature of refractive surfaces, for instance the cornea, intraocular pressure or natural changes in the tearfilm. A possible explanation for the variation in such cases may be the consequence of blinking. (8). However, the variability of refractive error has been found small, both in regards to results obtained from the same autorefractor and in comparison to other methods, such as manual refraction (2). This may signify that autorefraction can be used in various purposes such as for studies observing the change in refractive error in myopia control studies and screening in children for refractive errors (2).

The purpose of this study was to compare the results from manual subjective refraction using trial lenses and a standard visual acuity protocol to results from autorefraction in young adults.

Methods and materials

Subjects

Fifteen students with refractive error, (aged 22 to 27 years) were recruited from Uppsala university. Subjects were initially inquired about the power of the lenses determined on their latest eyeglass prescription. Based on this estimate the subjects took part in an eye examination to determine their current refractive error. The inclusion range of refractive error in this study was from -4 to +1 D. The included subjects were divided into five refractive error classes as shown on Figure 2.

Equipment

- Digital eye chart (Figure 2 and Figure 3)
- Tablet for controlling the digital eye chart
- Trial frame (Figure 1)
- Cylindrical concave lenses, spherical convex lenses (+), spherical concave lenses (-)
- Plain occluder
- Topcon Auto Kerato-refractometer KR-1 autorefractor
- A well illuminated examination room without natural light

Figure 1 Trial frame

Procedure

In general, the measurements were distributed into two occasions, on both which autorefraction and manual refraction with trial frame were conducted. On the first occasion manual refraction was performed first, followed by autorefraction immediately. On the second occasion this arrangement was reversed, autorefraction being followed by manual refraction. All measurements, both manual and with autorefractor were conducted by one person. Only one eye of each subject was examined, the same eye on both occasions for both autorefractions and manual refractions. No spectacles or contact lenses were worn during measurement.

Subjects with refractive error were recruited among medical students of the Uppsala University based on the power of the lenses marked on their latest eyewear prescription. Based on this information the selection of the examined eye was made and the subjects were dealt into primary refractive error classes from 1 to 4 each class consisting of 4 subjects. Measurements were carried out in numerical order premised on the refractive error class, so that no subjects from the same classes were called in consecutively. The subjects were asked to attend the first refraction to be able to ensure that the prescription was in fact up to date and the subjects' BCVA coincided the requirements of this study. After the first measurement the subjects were divided into the actual 5 refractive error classes, shown in Experimental design.

The setting was standardized for each measurement. Good illumination of the examination room was ensured. Screen brightness of the digital chart was set to a standard. All lenses were cleaned with a wiper before setting them into trial frame to ensure complete visibility. All equipment the subjects touched were disinfected both before and after the conducted measurements.

The procedure was explained to each subject. The subjects were instructed not to guess if they could not see the letters, not to delay their answer too long and not to squint their eyes in attempt to improve their vision.

Donder's method was implemented with the use of trial frame and the system for interactive refraction, that consists of a digital eye chart and an android tablet that are controlled by the examiner. The subjects were placed sitting in a chair at a distance of 4 meters from the digital eye chart screen. A letter-chart for each eye was chosen, red for the left eye, blue for the right eye (Figure 2). The chosen chart was viewed for the examined in black and white (Figure 3). The digits over in the upper end of the letter chart state visual acuity in logMAR unit (from 1.0 to -0.3) and in in relative decimal unit (from 0.1 to 2.0).
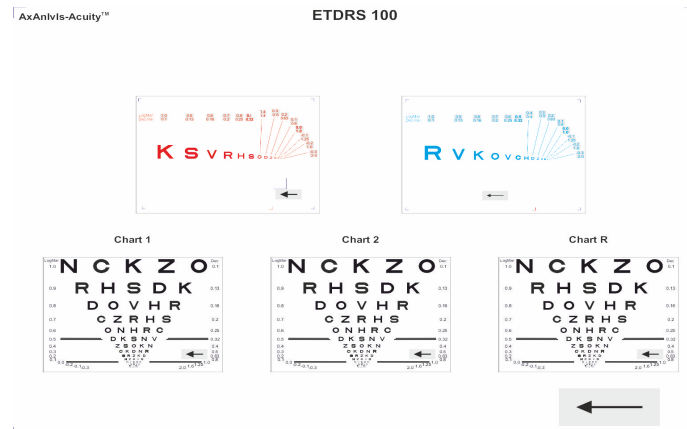
Figure 2 Digital eye chart, starting page for refraction.

Figure 3 Digital eye chart for refraction.

A trial frame is an adjustable spectacle frame that includes compartments into which all the various lenses required to measure a patient's refractive error can be placed. The trial frame with 4 compartments for lenses was set in place and adjusted by subject so that the trial frame's circular holes were centred over the subject's eyes. The type of optics used were cylindrical concave lenses, spherical convex lenses (+) and spherical concave lenses (-). These lenses were set in trial frame.

Only one eye was examined on each subject, the other eye was covered with a black plain occluder for covering the non-examined eye in the trial frame. Due to the fact that all subjects were under the age of 40, a spherical plus lens with +1 in refractive power was placed in one of the trial frame's compartments in order to relax the eye's accommodation.

The subjects were asked to read the bolded letters on the digital chart from left to right, i.e. from the larger to smaller letters. When the subject could no longer focus their vision and a letter was too small to read, the focus was brought to the previous letter i.e. the last optotype the subject could read. This was done by pressing the corresponding visual acuity value of the letter on the tablet to show an isolated optotype (Figure 4). While focusing on the last letter the subject was able to identify, a spherical minus lens was held in front of the trial frame and the subject was asked if their vision changed for the better or for the worse. Secondarily, a spherical plus lens was shown to the subject. In either case, if the subject's vision was improved, the lens was applied in the trial frame.

The refractive power of the lenses was dependent on how far in the digital chart's optotype the subject reached initially with only the spherical +1 lens. If the subject reached no further than the first half of the chart i.e. the first seven letters from the left, a lens with refractive power of full dioptres was used. If the subject reached the second half of the chart i.e. the last seven letters, a lens with refractive power of half dioptres was used.

By pressing the arrow pointing to the right under the optotype (Figure 4), following smaller optotype appears in a similar image, by pressing the arrow to the left a larger optotype appears. This procedure was repeated until the subject's vision could no longer be improved with applying spherical lenses.

Clinically, reaching logMAR 0.0 is considered a satisfactory result but in this study the refraction proceeded as long as the subject's vision could be improved by adding lenses.

Normally, in accordance to Donder's method, if the patient does not reach logMAR 0.0 despite applying spherical lenses, cylindrical lenses are tried out to correct or exclude the possibility of an astigmatic refractive error. In this study, cylindrical lenses were tested on every subject, regardless of the BCVA acquired with spherical lenses. The choice of the refractive power of the cylindrical lens was dependent on which optotype (as in Figure 4) the subject got stuck on after sampling spherical lenses (same principle as for the spherical lenses, as explained above). Only negative cylindrical lenses were used, and they were tested and applied as an addition to the spherical lenses. The subject was shown an axis chart, that was opened by pressing the star shaped symbol on the lower right corner in the optotype screen (Figure 4). The axis chart displays straight lines drawn from a single point in angles from 0° to 360°. The subject was asked if any of the lines appeared to be sharper. If some of the axis beams appeared sharper, a cylindrical lens was applied in the trial frame in an axis that corresponded the answer the subject gave. The subject was asked to adjust the cylindrical lens by rotating the lens both ways to find the optimal meridian for vision improvement. Then more cylindrical minus was sampled in front of the trial frame in the meridian the subject chose and in case of improvement of vision a smaller optotype was displayed by pressing the arrow on the right below the optotype. This was carried on until the subject's VA was maximal i.e. when BCVA was reached.

Finally, after sampling of cylindrical lenses, spherical convex (+) lenses of half diopters were applied until the subject experienced deteriorating vision. This final step was carried out in order to cancel out the bias of myopia (nearsightedness) caused by cylindrical lenses.

Figure 4 Isolated optotype for refraction.

The BCVA, the final refractive power of lenses and in some cases angle of cylindrical lenses used in manual refraction with trial frame were recorded immediately after each completed refraction. Results from autorefraction were automatically printed by the machine. Further the spherical equivalent was calculated by adding the sum of the sphere power with half of the cylinder power.

Experimental design

Altogether 15 subjects were included and evenly divided into five refractive error classes: [-4 -3[, [-3 -2[, [-2 -1[, [-1 0[, [0 +1] D (Figure 5)
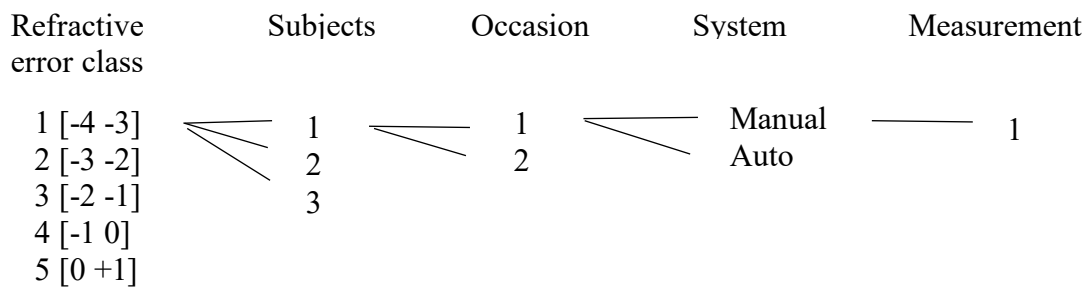

Figure 5 Experimental design.

Each subject was measured with both systems on two occasions.

Statistical analysis

Analysis model for measurement of refractive error

A measurement, x_{ijkl}, is equal to the population mean, μ, and a term for the fixed factor method type, α_i (i=1,2), a term for the fixed factor refractive error level at inclusion, β_j (j=1,2,3,4,5), and a term for random variation among subjects, $C_{k(j)}$ (k=1,2,3), a term for interaction between method type and refractive error level at inclusion, $\alpha\beta_{ij}$, a term for interaction between method type and

subjects, $\alpha C_{ik(j)}$ and a term for random variation between occasions defined as a measurement error, $\varepsilon_{l(ijk)}$ (Eq. 1).

$$x_{ijkl} = \mu + \alpha_i + \beta_j + C_{k(j)} + \alpha\beta_{ij} + \alpha C_{ik(j)} + \varepsilon_{l(ijk)}$$

Equation 1.

The outcome of the measured refracted visual acuity is analyzed with analysis of variance according to Equation 1 resulting in Table 1.

Table 1. Analysis of variance for the estimates of the measured refracted visual acuity			
Source	Degree of freedom	Mean square	Expected mean square
Methods	1	MS_1	$\sigma_\varepsilon^2 + n\sigma_{\alpha C}^2 + bcn\kappa_\beta^2$
Refractive error levels	4	MS_2	$\sigma_\varepsilon^2 + an\sigma_C^2 + acn\kappa_\alpha^2$
Subjects	10	MS_3	$\sigma_\varepsilon^2 + an\sigma_C^2$
Methods Vs levels	4	MS_4	$\sigma_\varepsilon^2 + n\sigma_{\alpha C}^2 + cn\kappa_{\alpha\beta}^2$
Methods Vs Subjects	10	MS_5	$\sigma_\varepsilon^2 + n\sigma_{\alpha C}^2$
Occasions	30	MS_6	σ_ε^2

The analysis of variance allows to test the zero hypotheses:

1) H0: There is no systematic difference between two methods

Test statistic = MS_1/MS_5, significance level = $F_{1:10;0.95}$.

2) H0: There is no systematic difference between the charts depending on visual acuity level

Test statistic = MS_4/MS_5, significance level = $F_{4:10;0.95}$.

Statistical parameters

The significance level was set to 0.05 and the confidence coefficient to 0.95, considering the limited sample size.

Results

Initially 16 subjects with refractive error were recruited. There was one dropout amongst the subjects in the second phase of the measurements due to a hold-up abroad caused by the current

situation with Covid-19 outbreak. Consequently, a total of 15 participants and 15 eyes were included in this study.

Subject characteristics

Participants were aged from 22 to 26 years. Median age of the participants was 24 years. 6 of the participants were men and 9 were women. BCVA (logMAR) range was from -0.2 to 0. Spherical equivalent of refractive error ranged from -3.75 dioptres (D) to +1.25 D and the cylindrical error ranged from -0.75 to 0. Median time between first and second visit was 21 days.

Difference of refractive error estimated between the two methods as a function of refractive error class

Figure 6 shows a scatter plot of difference between the two methods at the different refractive error classes.
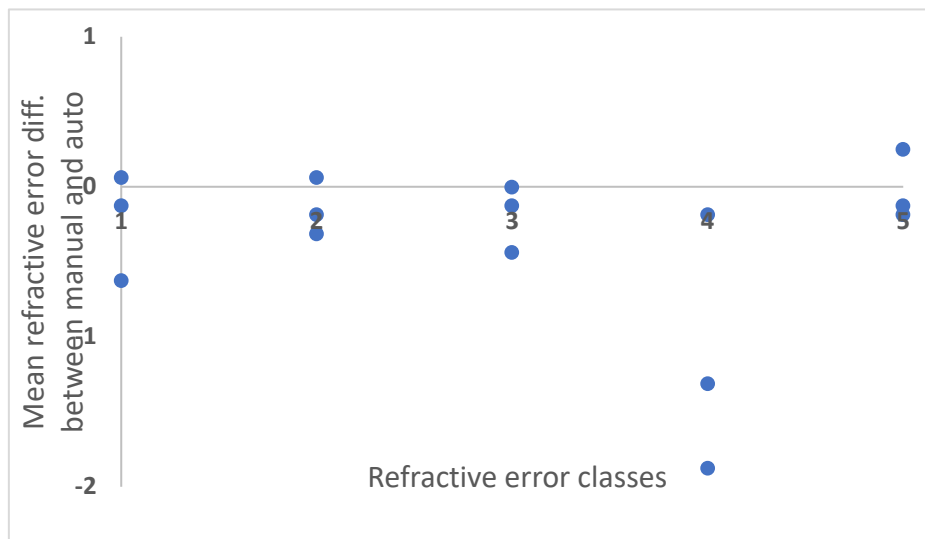

Figure 6 Confidence interval for mean difference at each class

Estimates of variance components for estimates of spherical equivalent

A nested ANOVA showed no significant difference of refractive error estimated between the two methods (Test statistic =8.69, $F_{1,10,0.95}$ =4.96). There was a significant difference between the two methods depending on refractive error classes (Test statistic =0.59, $F_{4,10,0.95}$ =3.47). Estimated variance components for random factors in the model (Equation 1) can be seen in Table 2.

Table 2. Estimate of variance components.

Source	Variance component
Subjects	0.10716
Methods x subjects	0.09193
Occasions	0.01771

Discussion

In this study, we examined the level of agreement between autorefraction and manual refraction with trial frame lenses and digital visual acuity chart in determining refractive error. Moreover, we studied the agreement more specifically between different refractive error classes. The results of this study show that when measuring refractive error, results obtained from autorefraction are comparable with those obtained by manual refraction in young adults. This concludes that the results agree with our primary hypothesis, which predicted there to be no significant difference in refractive error between the two methods. The hypothesis was tested with variance analysis with a factor model of the variation for each refractive error class. Overall, these results were in accordance with previous studies (2,5,7,11,12,15,17–20). However, in one refractive error class, a significant difference between the two methods could be identified.

Typically, months of practical experience and practice of technique on many patients with varying levels of visual acuity and types of refractive error are needed for the manifest refraction to be performed competently and reproducibly (21). In this study, due to practical reasons the manual trial frame measurements were performed with less experience. However, the variation in measurements in manual refraction was minimized by following a standard protocol in stabilized conditions regarding lighting and surroundings. Moreover, the measurements were carried out in numerical order, so that no subject from the same refractive error class was called in consecutively, minimizing the bias of the examiners increasing abilities as a refractionist between the refractive classes.

Common errors in manual refraction were acknowledged in advance and avoided to the furthest extent possible. Firstly, subjects were not allowed to decide their BCVA by guessing, only a rapid correct answer was approved. By this procedure, the bias of young adults' good ability to accommodate and improve their BCVA, was minimized. Secondly, the subjects were not permitted to squint their eyes and improve their BCVA by doing so. Thirdly, the result of manual refraction was recorded immediately, to avoid the need of guessing the result at the end of the examination. Moreover, manual refraction was conducted by one examiner. By using a single refractionist, the practitioner bias can be considered minimized in this study. Some bias may have been introduced in the manual refraction, in that the examiner had knowledge of the subjects' latest spectacle prescription, although the protocol was standardized for each participant. Although the end point was defined by the same criteria on each subject i.e. the best possible visual acuity and the clearest sense of vision with lenses, the end result is dependent on each participants' individual experience

of vision, leaving room for interpretation rather than exact data. In addition, the limited number of subjects included in this study, increases the likelihood of random chance.

A few possible factors were considered as likely explanations to the differences in results obtained by subjective refraction between the two occasions. The most unlikely one was that subjects' refractive state may actually have changed between the measuring occasions. A more probable factor is that the subjects' refraction remained constant while their subjective response changed as a result of uncontrollable factors. Finally, the examiners abilities as a refractionist may have increased during the repetition of refraction while conducting manual refraction on the subjects included, meaning that the endpoint criteria may have unconditionally and unnoticeably changed, or by failing to completely relax the subjects' accommodation. In general, these kind of uncertainty factors may be reflected even amongst more experienced refractionists when comparing results obtained by two or more examiners.

Due to the relatively extensive amount of training and time that is required for an examiner to be qualified to refract and determine BCVA, substituting the protocol of manual refraction with automated refraction could result in substantial savings of time and resources in both research and clinical use. In contradiction to many studies with similar results, a previous study conducted in rural India considers the autorefractor to be a viable substitute for subjective refraction done by a trained refractionist in low-resource setting (18).

As discussed in previous studies, subjective refraction poses a factor of uncertainty even under standardized measuring conditions. Subjective refraction is controlled by examined individuals, reporting their visual perception making it a psychovisual test to a certain extent (9). This creates the possibility of natural fluctuation over time. The matter could be recognized in practice under measurements – some subjects reported an experience of fluctuation in vision depending on for example the time of day, their level of stress or strain they had undergone anterior to the occasion of measurements. However, the best corrected visual acuity is in fact ultimately the individual's experience of maximum vision that determines the refraction. Autorefraction measures merely the optical effect created by the eyes optical system, eliminating the effect of the individual's central nervous system in the visual sensation. A very useful but under-utilized approach is to use some measure of patient satisfaction as the gold standard. Therefore, autorefraction cannot replace a subjective refraction as a single method when determining refractive error and BCVA.

In future studies, it may be worthwhile to include a larger number of subjects and from a broader scale of age. Further studies could be conducted also on the differences in accuracy in measurements between different refractive error classes. Previous studies have tended to focus on

comparing subjective methods to objective methods, and there has been little comparison of the various methods used in subjective refraction. It would be interesting to explore the correlation between different subjective methods with each other.

In conclusion, these findings are in accordance with previous studies and are clinically significant indicating that autorefraction can be considered in routine clinical practice and research.

Acknowledgements

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