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Objective Visual Acuity Estimation via the Optokinetic Response to High-pass Filtered Stimuli: An Exploratory Study

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Authors' contributions

This work was carried out in collaboration among all authors. Author CA conceptualized and wrote the original draft, made the formal analysis, and devised the methodology. Authors CR, CT and KD reviewed and edited the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Optokinetic-based paradigms used to derive objective visual acuity suffer so far from low predictive power. Arguably, the contribution of the peripheral stimulation and the discrepancy between detection and discrimination threshold can bias the outcomes. In this respect, high-pass filtered stimuli (HPSs) have the advantage of activating only the foveal region and their detection and discrimination thresholds converge. In this exploratory study a novel optokinetic-based induction method (named "ghost oktotype") that uses HPSs is probed. The aim was to establish whether this type of procedure is worth being extensively investigated.

Study Design: Analytical transversal study.

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Methodology: After testing for their subjective acuity (expressed as logMAR) at ten different defocusing conditions, four normal and cooperative subjects were repeatedly administered sequences of HPS-Landolt rings arranged on a serial pattern that drifted horizontally. Their angular size was logarithmically reduced and objective acuity was computed for each defocusing condition as a function of the smallest size of the rings that evoked the optokinetic reflex (logMAER). The estimate was compared to the subjective values obtained both at the conventional Landolt-C ETDRS charts and with modified ETDRS charts made up of high-pass filtered Landolt Cs.

Results: The repeatability of the HPS-based optokinetic paradigm was good in the three subjects (ICC=0.77; 0.86; 0.89) and the outcomes were significantly correlated with the conventional ETDRS values (R^2=0.96, R^2=0.88, R^2=0.81: $P<0.001$). Nevertheless, objective visual acuity was lower (higher logMAER) compared to the subjective, conventional assessment with the ETDRS chart, especially at the highest acuities. This difference decreased when logMAER was compared to the subjective discrimination acuity (logMAR) measured with the HPS-ETDRS charts, and, supposedly, to detection acuity.

Conclusion: According to these preliminary results, high-pass filtered stimuli reduce the mismatch between subjective and objective acuity. Within this frame, the “ghost” oktotype could be a promising tool to assess visual acuity in non-collaborative patients and is worth being extensively investigated. Forthcoming studies could support our impression i.e., that detection and not resolution is the main requisite for the optokinetic response. This peculiarity must be considered when investigating the potential of the optokinetic-based paradigms to derive resolution acuity.

Keywords: Detection; discrimination; ETDRS; optokinetic reflex; vanishing optotypes; visual acuity.

ABBREVIATIONS

HPS : High-pass Filtered Stimuli
HPS-ETDRS : Modified Version of the ETDRS Table (Landolt “Cs” Insead of Letters)
LogMAER : logarithm of the Minimum angle of the Rings that Evokes the Optokinetic Reflex
LogMAD : logarithm of the Minimum Angle of Detection of the Rings

1. INTRODUCTION

Visual acuity (VA) is a crucial sensory function for everyday life management [1,2] and its measurement is one the most representative tests of the integrity of the visual system [3]. Visual acuity relies on the recognition threshold of the optotypes that are alphanumerical signs or other structured patterns scaled in size. This procedure, being psychophysical, needs collaboration from the patient via verbal feedback, so it cannot be administered to preverbal children, subjects with severe cognitive deterioration, and malingerers.

To address this issue, in the past years research has focused on measuring visual acuity with objective strategies like preferential looking [4,5], visual evoked potential-related procedures [6,7], and optokinetic response-related paradigms (OKR). The OKR paradigms are of particular interest, as they seem free from the flaws encountered in the former two methods [8-11].

The optokinetic paradigm relies on the assumption that the highest spatial frequency of a serial stimulus able to evoke the optokinetic reflex is correlated with the smallest visible stimulus, i.e., visual acuity [12-23]. In these terms, visual acuity can be derived as the inverse function of the angular size subtended by the cycles of that spatial frequency. Unfortunately, the attempts to estimate visual acuity via the optokinetic response suffer from low predictive power [15].

In two previous investigations we described a novel optokinetic procedure for objectively measuring visual acuity: the *oktotype*. The oktotype showed consistent correlation across the whole acuity range (from 0.0 to 1.0 logMAR) and a satisfactory predictive power provided the estimates are corrected by a scaling coefficient [22,23]. To keep high the attention of the observer, the oktotype differs from the other paradigms in that it makes use of horizontal sequences of equally spaced different symbols of the same size instead of serial patterns made of black-and-white stripes. The induction method [17] is used, so the dimension of the symbols making up each stripe is gradually increased until the oculomotor response is observed. Yet, a main issue of the oktotype is the discrepancy between logMAR (subjective acuity) and the logarithm of the minimum angle evoking the optokinetic response (logMAER). Two hypotheses (not mutually exclusive) can be formulated to explain this mismatch:

-first, the thresholds measured by the ETDRS charts and the optokinetic response may be different: logMAR, as obtained by the ordinary optotypes like the ETDRS charts, is a discrimination or recognition threshold whereas LogMAER is likely to be a detection threshold: so the conventional optotypes and the oktotype may target two different types of threshold;

-second, the optotypes aim at central visual acuity. To ensure agreement, the optokinetic procedure should do the same. Yet, even though the foveal region provides the main contribution to the activation of the optokinetic response (according to the central dominance theory [24], the paracentral visual stimulation is involved as well (to an amount depending on the spatial frequency) [25]. As a result, MAER as a measure of (central) visual acuity could be biased by peripheral activation.

Upon these considerations, the threshold computed via the optokinetic response should be the same of the subjective procedureto make the objective measures of visual acuity reliable. In addition, the serial stimulation used to evoke the optokinetic response should activate the foveal detectors, minimizing the response from the rest of the retina.

The use of high-pass filtered stimuli (HPS, or “vanishing” optotypes as defined by Frisén [26] could fulfill both requisites. HPSs are tripole-like stimuli whose mean luminance is the same as the background, being higher at the borders and lower at the center or vice versa [27]. This characteristic makes the HPSs ‘vanish’ as soon as their angular size falls below the discrimination threshold: in other terms, discrimination and detection thresholds of the vanishing optotypes tend to match [26, 28-30].

Moreover, since HPS are high-frequency configurations, they are processed by the foveal visual detectors and not by the paracentral visual channels [31]. It follows that the optokinetic response evoked by this type of stimuli should rule out the misleading contribution of the peripheral retina, satisfying our second assumption.

In this exploratory study the optokinetic response to high-pass resolution symbols of different sizes has been evaluated and compared with the subjective visual acuity measured with a high-pass resolution and a conventional ETDRS chart in three normal volunteers. This experimental condition is expected to remove the objective vs. subjective measurement mismatch reported in previous investigations and might cast light on the effect detection and recognition threshold have on the optokinetic reflex.

2. MATERIALS AND METHODS

2.1 The High-pass Filtered Stimuli (HPS)

The high-pass filtered stimuli used in this experiment were similar to those described by Frisén in his studies on high-pass resolution perimetry [28]: square-wave tripole-like interrupted rings with two dark borders and a clear core whose average luminance matches the luminance of the background. The gap size of the “C” was the same as the width of the tripole-like contour. The width ratio between borders and core was constant across the whole range of stimulus sizes (edge: core: edge: 1:2:1). Likewise, the ratio between the average size of the symbol and its tripole border was constant (6:1). Michelson's contrast between borders and core ([core luminance-border luminance] / [core luminance + border luminance]) was 0.43 (Fig. 1).

The average luminance of the stimuli was 54 cd m^{-2}. This value, previously adopted in other studies [29], is high enough to discount the rod contribution and at the same time provides subjective visual comfort at a wide range of ambient illuminance [32]. The correspondence between the average luminance of the ring and the luminance of the background was checked by inspecting the ring through a blurred lens so as to confirm that no overall luminance difference existed between the background and the stimulus [30].

2.2 Sample Recruitment

Four subjects (the authors of this study) were repeatedly examined (CT, age 21, CR, age 29, CA, age 52, and KD, age 30). Neither of them suffered from systemic diseases or epilepsy. CT and KD were naïve to psychophysical testing and had mild myopia in both eyes (CT: -2.00 spherical diopters in both eyes, KT: -150 spherical diopters in both eyes). CR was emmetropic and naïve to psychophysical testing. CA had mild myopia (right eye: -2.25, left Eye: -2.50 spherical diopters) and was skilled in psychophysical examinations. The refractive error was assessed as the mean of five consecutive measures provided by a refractometer (Tonoref III, Nidek, Japan) in cycloplegic conditions. The best corrected visual acuity was 0.0 logMAR in all cases at the ETDRS charts. Slit-lamp biomicroscopy, tonometry, funduscopy, and orthoptic examination were unremarkable.

2.3 Testing Procedures

At a preliminary stage, a pre-established range of visual acuities was simulated by reducing the best myopic correction in CT, CA, and KD, or by placing positive lenses in front of the eye of CR so to increase logMAR from 0.0 to 1.0. LogMAR at each fogging condition was estimated using a Landolt C-ETDRS chart (4 alternative forced choice: 4AFC), which is the standard optotype to be used in accordance with the International Standard ISO 8596. Optotypes were black on a gray background with a luminance of 36 cd m^{-2} and were presented on a 19" LCD screen (Prechen, resolution 1440x900, refresh rate 60 Hz).

The subject was seated comfortably on a chair 6.5 ft from the screen in a dim room. The right eye (dominant in all the subjects) was examined. Measures were scored according to the letter-per-letter method. At each defocus condition, randomly selected at each trial, two measurements were obtained from each participant, and the average was taken as the (subjective) visual acuity.

The same procedure was repeated using an ETDRS chart with high-pass filtered Landolt Cs ("HPS-ETDRS"). The HPS-ETDRS chart was prepared upon a pre-existing template (Good-Lite.com), and presented on the same LCD monitor adopted for the conventional Landolt Cs ETDRS chart and in the same environmental conditions (Fig. 2).

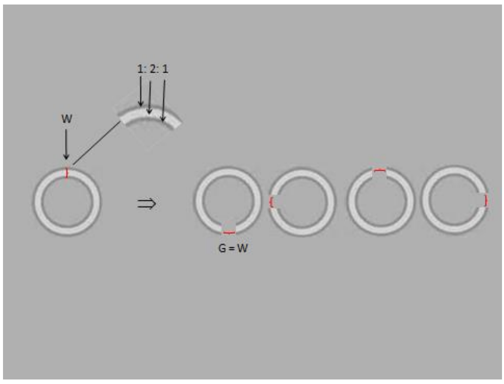

Fig. 1.The high-pass filtered stimuli. G and W correspond to the width of the contour and the gap of the ring, respectively

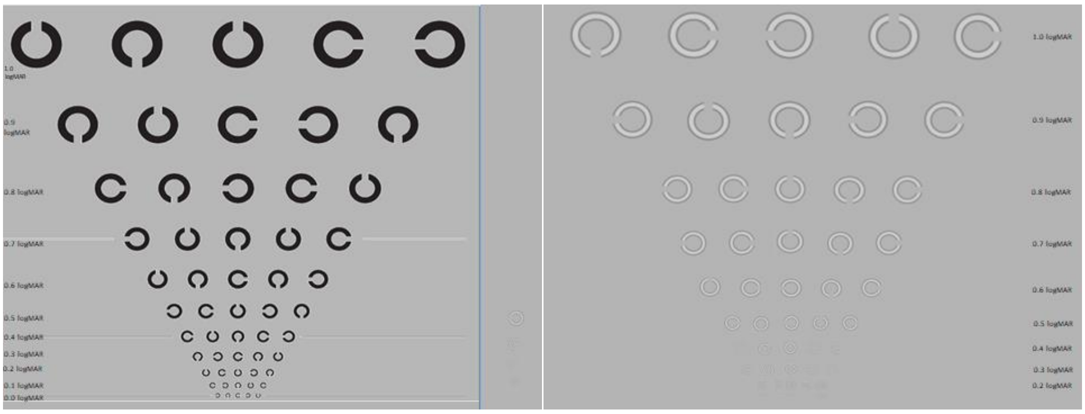

Fig. 2. The conventional- (left) and HPS-ETDRS (right) chart.

Fig. 3. The acquisition system, made of a small infrared camera mounted on a frame lens aiming at the eye not under examination and connected to a second screen placed in front of the operator

The estimates were obtained with the letter-per-letter method at the same fogging values previously selected in the conventional test. LogMAR at each defocusing condition was computed in each participant as the average of two subsequent estimates. Each subject was then administered the HPS-optokinetic stimulation ("ghost oktotype") at the subjective acuity levels (i.e. at each defocusing condition) measured with the standard ETDRS procedure and with the HPS-ETDRS procedure.

2.4 The "Ghost" Oktotype

Eleven horizontal sequences of HPS stimuli were individually displayed on the same LCD screen. Each sequence drifted from left to right and vice versa at a constant rate (from 4.8°/sec to 1.22°/sec at the viewing distance). The velocity was the same for each participant and was established empirically at a pre-examination phase to ensure the best detection of the nystagmoid movements by the operator.

The stimuli making up each sequence had the same size, and each sequence differed from the previous one as the size of the stimuli was logarithmically reduced from 1.0 logMAR (sequence 1) to 0.2 logMAR (sequence 9). The horizontal distance between the stimuli in each sequence was scaled according to the ETDRS rule. The "Cs" were differently oriented (left, right, up, down) to help the subject keep his/her attention on the task, and to help reiterate the fixation/refixation pattern. The tests were performed monocularly and the right eye was examined.

The observer sat in a dim room on a chair 6.5 feet from the screen, wearing a frame with a small infrared video camera secured in front of the left eye (i.e., the eye not under examination). The signal from the camera was transferred to a second, smaller laptop computer placed in front of the operator, who was seated beside the testee (Fig. 3).

The subject was asked to look at the main screen while the operator checked on the screen connected to the camera the onset of the optokinetic reflex during the presentation of the sequences. The optokinetic response was considered as evoked if at least three consecutive beats of nystagmus were observed [19,21]. The time the operator had to decide about the occurrence of the oculomotor response was 10 sec. Each time the occurrence of an oculomotor response was confirmed by the operator, the next sequence with smaller stimuli was displayed via remote control: this way, a stream of serial, progressively smaller sequences were presented to the testee. The procedure was iterated until the operator failed to detect the optokinetic response within the pre-established time interval. At the first negative presentation (no response) the procedure was reversed. Four sessions (yielding four sets of measures per subjective visual acuity) were performed in each testee to assess within-subject test-retest variability. Data on subjective visual acuity were masked to each operator until the completion of the entire procedure. Resting periods of 15 minutes were allowed between each session.

3. RESULTS

Test-retest reliability of subjective VA estimate measured with HPS was satisfying (concordance correlation coefficient: CT=0.98; CR=0.93, CA=0.94, KD=0.93), with an average difference between two repeated measures of 0.038 (SD: ±0.035) log units.

Subjective VA at the conventional "C" optotype was better than that measured with HPS. The average difference was: CT:0.46 (±0.09), CR: 0.57 (±0.08), CA: 0.48 (±0.20), and KD: 0.53 (±0.10) log units (CT t_6=12.87,CR t_5=16.37, CA t_9=7.57, KD t_5=13.28; P<0.001 in all cases).

Objective acuity estimates showed good repeatability (intraclass correlation coefficient, CT: 0.77; CR: 0.86; CA: 0.89; KD: 0.92), with average variability between subsequent estimates ranging from 0.10 to 0.20 log units.

Fig. 4 shows the relationship between subjective visual acuity assessed with the conventional ETDRS charts and the log minimum angle evoking the optokinetic response with high-pass filtered stimuli (logMAER). Despite a high correlation between the two measures (CT: R^2=0.96, P= .0005; CR: R^2=0.88, P= .0001; CA: R^2=0.81, P= .0009; KD: R^2=0.98, P< .0001), the correspondence between estimates was poor, with logMAER higher than expected in all subjects (underestimation of the ETDRS VA), with consistent between-subjects variability. This trend was more evident at the highest ETDRS acuities (from 0.4 to 0.7 log units at logMAR 0.0) and decreased at the lower subjective acuities, dropping to 0.30-0.35 log units at logMAR 0.6 in CT, CR, and CA, and up to about 0.18 log unit in KD.

Fig. 5 shows the relationship between subjective and objective visual acuity measured with high-pass filtered stimuli. The correlation between the two measures remained remarkable (CT: R^2=0.94, P=.003; CR: R^2=0.86, P=.007; CA: R^2=0.74, P=.0007; KD: R^2=0.95, P=.008). Contrary to what was found with the conventional ETDRS charts, in CR and KD an overestimation (better objective acuity, i.e., lower logMAER) was observed especially at the highest acuities. The overestimation increased as the subjective acuity decreased to a maximum of about 0.1 log and 0.2 log units, respectively, at logMAR 0.8. CA showed a similar trend but the overestimation was overall constant across the whole range of subjective visual acuities. On the contrary, in CT an underestimation of the objective acuity (higher logMAER) at the high subjective acuities was observed, even if to a lower degree compared with the conventional subjective acuity, and disappeared at LogMAR 0.9. At the lowest acuity tested (logMAR 1.0), the trend reversed.

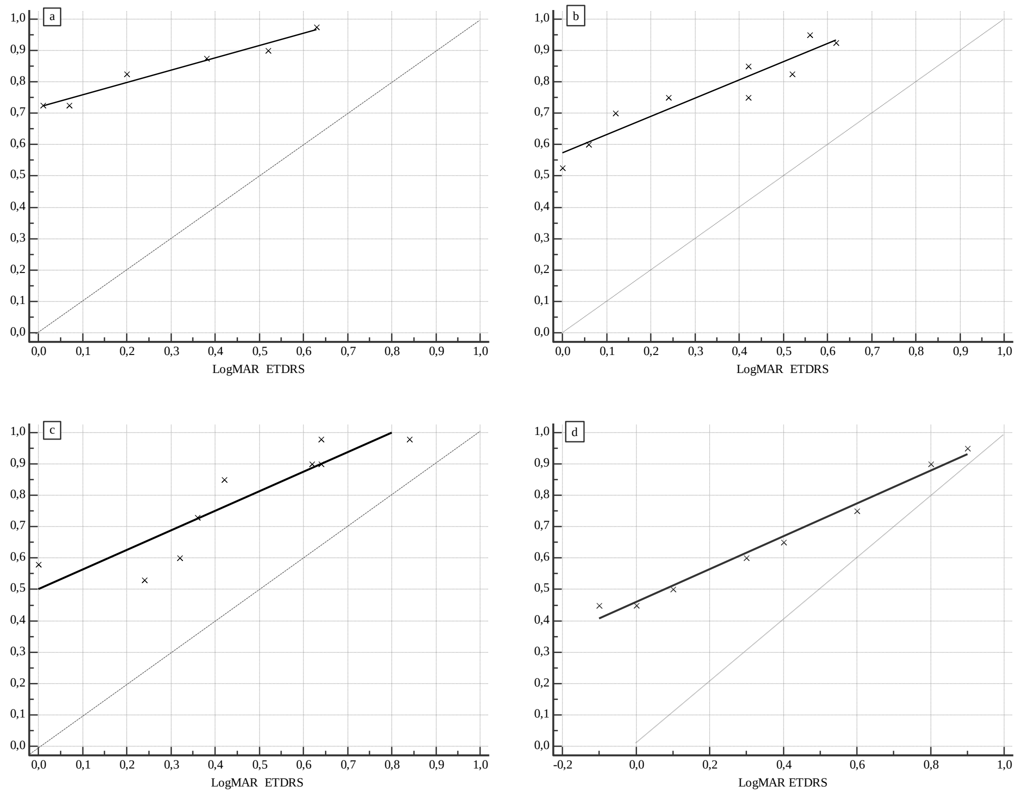

Fig. 4. Regression plot between subjective visual acuity at conventional ETDRS testing and objective visual acuity as HPS-logMAER; a: subject CT; b: subject CR; c: subject CA; d: subject KD

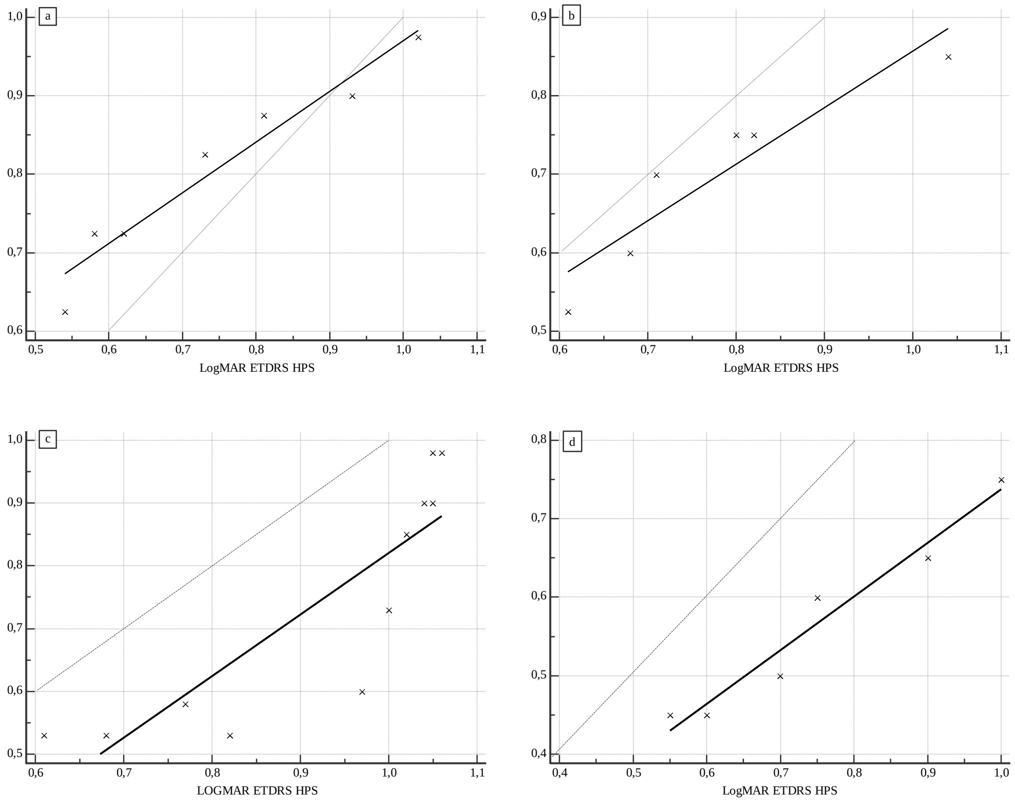

Fig. 5. Regression plot between subjective visual acuity at HPS-ETDRS testing and objective visual acuity as logMAER estimated with high-pass filtered stimuli; a: subject CT; b: subject CR; c: subject CA; d: subject KD.

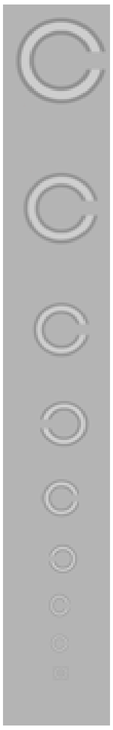

Fig. 6. Detection acuity. See the text for explanation

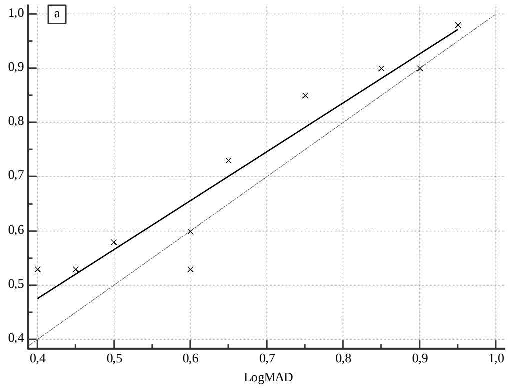

Fig. 7. Regression plot between detection acuity (logMAD) and objective visual acuity (logMAER) estimated with high-pass stimuli in subject CA

The average difference between HPS-logMAR and HPS-logMAER in the four subjects was overall small (CT, CR, CA, KD: mean delta [SD]= -0.06 [0.07], 0.08 [0.06], 0.18 [0.1], and 0.18 [0.06] log units, respectively), statistically significant in KD (for a significance level assumed to be *P*<.01: paired-t test: t=7.42, *P*=.0007), borderline in CR (t=3.29, *P*=.02) and CT (t=2.58, *P*=.04) and not significant in CA (t=1.29, *P*=.22).

It should be noted that the same subjective vs. objective discrepancy is far lower in this experimental condition than with the conventional ETDRS chart (mean difference with conventional ETDRS: CT: -0.53 [±0.14], CR: -0.44 [±0.10], CA: -0.55 [±0.33], KD: -0.25 [±0.19] log units).

To further investigate the contribution of visual resolution and detection in eliciting the optokinetic response, we decided to carry out an additional evaluation, testing the detection threshold in CA, the subject with great experience in psychophysical examination and accustomed to psychophysical testing. A single column of high-pass filtered Landolt Cs with the same size, contrast, and luminance parameters as the HPS-ETDRS was presented at the same viewing distance and in the same environmental conditions (Fig. 6). At each defocusing level, the observer was asked to report verbally the smallest detectable stimulus starting by examining the set from the top of the column (yes/no response model). Detection acuity was computed as the mean of two subsequent measures.

Detection acuity correlated with resolution acuity measured at the HPS-ETDRS (R^2=0.82, t9=6.34, p<0.001), but it was on average about 0.2 log units higher (i.e., better: logMAD-logMAER mean difference: -0.22 (0.09), p <0.001).

Fig. 7 shows the relationship between subjective detection acuity, expressed as log minimum angle of detection (logMAD), and the objective VA (logMAER) estimated with high-pass filtered stimuli in the same observer. The correlation between detection and optokinetic response was striking, even higher than at the subjective resolution acuity (R^2=0.92, p< .001).A modest underestimation of objective acuity was observed at all the logMAD values, more evident at the highest values of detection acuity (lower MADs: -0.13 log units at 0.4 log MAD). The discrepancy narrowed as detection acuity decreased so that at log MAD 1.0 it turned negligible (-0.03 log units).

Overall, the average difference between logMAD and HPS-logMAER (albeit significant) was small (mean delta: -0.04 (±0.06) log units, t_9=2.50, *P*=0.02), and in any case smaller than 0.13 log units across the tested acuity spectrum. It is interesting considering that, based on the data obtained in the observer, this delta value is 3-4 times smaller compared to HPS-logMAR estimated in the same subject (0.18 [±0.05] log units).

4. DISCUSSION

In the clinical setting, the estimation of visual acuity commonly relies on the recognition threshold of high-contrast alphanumerical symbols, called optotypes, scaled in size. This paradigm, being psychophysical, needs full collaboration by the patient, so it is not viable in preverbal children and subjects with severe cognitive deterioration (as well as malingerers).

To address this issue, in the last decades objective strategies have been developed. Among these, optokinetic-based procedures are of particular interest. The optokinetic paradigm aims to identify the highest spatial frequency of a serial stimulus able to evoke the optokinetic reflex. Visual acuity can be derived as the inverse function of the angular size subtended by the cycles of the cut-off frequency.

In two previous investigations, a novel and cheap optokinetic procedure showed an acceptable level of precision across acuities ranging from 0.1 to 1.0 logMAR in normal subjects with simulated ametropias and ophthalmological diseases. The procedure differed from the other paradigms in that it made use of horizontal sequences of equidistant different symbols of the same size instead of serial patterns made of black-and-white stripes. In these cases, a strong correlation was found between the minimum angle of the stimuli able to evoke the optokinetic response (logMAER) and logMAR measured at the ETDRS [22,23]. However, a consistent discrepancy between logMAER and logMAR was observed across the whole range of visual acuity. As a possible explanation, logMAR and logMAER may reflect different acuity thresholds: discrimination threshold vs. (presumably) detection threshold. In addition, a full-field serial presentation stimulates not only the foveal region, which is the anatomical site of visual acuity as measured with conventional procedures (like the ETDRS chart), but also the peripheral retina.

These two biasing variables may be removed if the type of threshold measured by the optokinetic procedure and the ETDRS charts were the same and if the serial stimulation that evokes the optokinetic response was selective for the foveal region. This could be achieved by using high-pass filtered (or “vanishing”) optotypes (HPS).

Vanishing optotypes lack low spatial frequencies, so they cannot but be processed by the foveal detectors. This way, the misleading contribution of the peripheral retina should be minimized. In addition, due to the exclusion of the low-frequency component of the spectrum, discrimination and detection thresholds are expected to converge when measured with this type of stimuli [31].

Upon this basis, it is expected that the acuity threshold derived from the optokinetic response with HPS stimuli provides a more accurate estimate of subjective visual acuity compared to the non-HPS serial stimulation adopted in the previous investigations [33].

First of all, subjective VA measured with high-pass filtered stimuli showed good test-retest reliability. The average difference between two repeated measures at the HPS-ETDRS was 0.002 log units, lower than previously reported by Wen et al. with high-pass filtered tumbling “E” (0.004) [34], and even lower compared to the conventional ETDRS charts (0.02 logMAR) [35]. This means that HPSs are reliable stimuli to be used for this purpose.

In turn, the objective visual acuity estimates derived from the optokinetic response evoked by high-pass resolution stimuli showed a slightly higher variability compared with the correspondent subjective assessment. This may depend, in part, on the subjective criterion of the operator when judging the onset of the optokinetic response, according to the rule adopted by Çetinkaya[21] and reported in the methods section. In addition, HPSs have no tolerance towards minimal fixation losses. Minute deviations, undetectable via the direct observation of the eye, shift the retinal image of the HPS to an extrafoveal location, where the acuity threshold increases and the target is no longer visible [26]. Indeed, the three subjects reported that sometimes the drifting configuration tended to disappear from view. As per previous studies [21,36], direct observation of eye movements has been adopted to detect the optokinetic response. However, the use of an eye tracker (at present not available in our laboratory) is advisable to increase precision.

The consistently lower visual acuity at the HPS-ETDRS compared to the conventional ETDRS procedure is not unexpected and it was reported in previous investigations [26,29,34,37-39]. Frisén reckoned that acuity is about 0.4 log units lower when measured with the high-pass filtered Landolt Cs compared to the conventional Cs [26]. Our results are in line with his finding and depend on the fact that low spatial frequencies, absent in HPS, influence resolution threshold [26] and are important for letter recognition [40,41]. Since low spatial frequencies are absent in the high-pass optotypes, the visual system cannot but rely on the high frequencies for their identification [42]. Shah and colleagues found that the disagreement between conventional and high-pass filtered optotypes changes as a function of the acuity level, being maximal at 0.00 logMAR and proportionally smaller at lower acuities [38]. We found a similar trend in CA.

LogMAER evoked by HPS strongly correlated with logMAR measured at conventional ETDRS charts. The group of Herris found similar results by comparing the estimates obtained with an optokinetic procedure similar to that used in this study and the acuity values obtained at an automated ETDRS chart. The objective vs. subjective acuity correlation was (R^2= 0.93) [43]. Recently, the group of Turuwhenua obtained interesting results using an automated procedure similar to our model, with vanishing discs presented in ascending/descending size order and checking the optokynetic response with an eye tracker [44]. In line with our study, the authors found a strong correlation (R^2 =0.84) between objective acuity derived from the optokynetic response and subjective ETDRS.acuity.

Interestingly, the determination coefficient obtained with HPS-logMAER on average was higher compared to the regression analysis performed in our previous study with a non-HPS optokinetic stimulation that made use of a series of symbols instead of the classical stripes (R^2 = 0.85 vs. 0.74) [22]. It is worth noting that the correlation, albeit significant, was weaker when the optokinetic response was induced by black and white stripes (contrast 85%; r= 0.74-0.75, corresponding to R^2= 0.54-0.56) [15,17] or by a spatial frequency filtered two-dimensional random noise pattern drifting horizontally (r= -0.77 corresponding to R^2= 0.59) [45]. These findings support our hypothesis that when low frequencies are removed, the optokinetic response reflects more faithfully the subjective estimate of central visual acuity. Since low frequencies stimulate the peripheral retina more than high frequencies, their removal rules out the biasing contribution of the peripheral retina in assessing the central (foveal) visual acuity. Despite the high correlation, the optokinetic response with HPS underestimates the acuities assessed at conventional ETDRS: in other terms, the objective visual acuity measured with HPS is lower than the subjective visual acuity evaluated with the current methods. This finding mirrors the underestimation of subjective visual acuity obtained with HPS-ETDRS compared to the conventional ETDRS procedure, and confirms that the overall visual response to HPS targets is weaker compared to conventional stimuli.

The underestimation is at its maximum at the highest acuity and decreases with increasing logMAR, as shown by the coefficient of the regression equation (0.39, 0.57, and 0.62 in the three subjects). The induction method adopted in this study, more effective at low visual acuities [17,18], might in part explain this discrepancy.

As expected, the correlation between LogMAER evoked by HPS and logMAR estimated at the HPS-ETDRS charts was stronger than at the conventional ETDRS charts. In other terms, when high-pass filtered stimuli are employed in both (objective and subjective) conditions, the difference in the acuity values narrows considerably.

Noticeably, and contrary to what was found in the conventional ETDRS charts, the trend in the three subjects examined was not the same: unlike the other three observers, the performance of CT was characterized by a slight underestimation. A greater between-subject variability in acuity threshold with high-pass filtered stimuli compared to the conventional optotypes, together with systematic errors (see Aleci, 2021) [46] could, at least partially, account for the discrepancy between CT and the other three participants. The overestimation of the optokinetic-based visual acuity vs. subjective visual acuity at HPS in CR, CA, and KD leads us to believe that the type of threshold derived from the two procedures is not properly the same.

To shed light on the role detection may have on the optokinetic response, detection acuity has been estimated in CA with high-pass filtered "Cs" and correlated with logMAER using the same type of stimuli. The correlation between logMAD and HPS-logMAER was even higher than that found with the subjective resolution acuity, and the average difference between logMAD and logMAER was 3-4 times smaller than the difference between logMAR and logMAER estimated in the same subject. The first impression, therefore, is that detection, more than resolution, may be at the basis of the optokinetic response. Clearly, this hypothesis needs confirmation with a higher number of participants. It remains that the minimum angle evoking the optokinetic response is slightly higher than the corresponding minimum angle of detection. This mild underestimation suggests that detection per se is not all that is needed to obtain the optokinetic response.

It should be borne in mind that the peripheral retina plays a role in evoking the optokinetic response even if to a lower extent compared to the central region, according to the so-called central dominance theory [24]. With high-pass filtered stimuli, the contribution of the peripheral retina to the optokinetic response is reduced because the stimuli turn invisible in eccentric vision due to the fast decline in resolution outside the foveal region [26]. If on the one hand this effect is desirable to attempt an estimate of (foveal) visual acuity (as explained in the introduction section), on the other hand the lack of paracentral stimulation can be detrimental to the triggering of the optokinetic reflex. So, an HPS whose size is at the detection threshold in foveal projection is not perceived in peripheral projection. It follows that it cannot contribute to evoking the optokinetic response: as a result, the optokinetic response is weaker than expected. Noticeably, the underestimation of the detection threshold by the optokinetic response is more evident at the highest acuities and decreases at the lower acuities so that at MAD 1.0 the underestimation turns negligible in CA. The fact that the underestimation decreases as stimuli are made larger suggests that the higher contrast energy (the square of contrast at each point of the space x,y occupied by the stimulus) [47] of the large stimuli activates, even if to a small extent, the peripheral retina, helping the optokinetic response to occur.

The three observers, who were cooperative, highly motivated, and fully concentrated on the task, reported that the sequences made of small HPS tended to disappear during the optokinetic trials, so they had to pay particular attention to focus on the screen. This seems to depend on the fact that high-pass filtered letters outside the fixation point are no more perceivable due to the fast decline in resolution with eccentricity [26]. This drawback needs consideration within a translational framework.

5. CONCLUSION

In conclusion, high-pass filtered stimuli reduce the discrepancy between the objective and subjective estimation of visual acuity reported in previous studies. Detection, rather than resolution, could be the main requisite for the optokinetic response, even if confirmation is needed with a large sample. In case, this peculiarity must be carefully considered when investigating the potential of the optokinetic reflex to derive resolution visual acuity within the clinical setting.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

CONSENT

Participants have given their informed consent for the publication of the study and accompanying images. A copy of the written consent is available for review by the Editorial office/Chief Editor/Editorial Board members of this journal."

ETHICAL APPROVAL

This study was approved as a Bachelor’s dissertation by the Ethics Committee of the University of Turin (Date: November, 4th, 2022/ No. 730405) and was performed under the ethical standards laid down in the 1964 Declaration of Helsinki. Written informed consent was obtained for the publication of these data and accompanying images.All authors hereby declare that all experiments have been examined and approved by the appropriate ethics committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. West SK, Munoz B, Rubin GS, et al. Function and visual impairment in a population-based study of older adults. Invest Ophthalmol Vis Sci 1997;38:72-82.
2. Lam BL, Christ SL, Zheng DD, et al. Longitudinal relationships among visual acuity and tasks of everyday life: the Salisbury Eye Evaluation study. Invest Ophthalmol Vis Sci. 2013;54:193-200.
3. Levenson JH, Kozarsky A. Visual acuity. In: Walker HK, Hall WD, Hurst JW, editors. Clinical methods: the history, physical, and laboratory examination. Boston: Butterworth; 1990;3.
4. Teller DY. The forced-choice preferential looking procedure: A psychophysical technique for use with human infants. Infant Behav Dev. 1979;2:135-53.
5. McDonald MA, Dobson V, Sebris L, Baitch L, Varber D, Teller DY. The acuity card procedure: a rapid test of infant acuity.

Invest Ophthalmol Vis Sci. 1985;26:1158-62.

6. Steele M, Seiple WH, Carr RE, Klug R. The clinical utility of visual-evoked potential acuity testing. Am J Ophthalmol. 1989;108:572-7.
7. Heine S, Rüther K, Isensee J, Zrenner E. Clinical significance of objective vision assessment using visually evoked cortical potentials induced by rapid pattern sequences of different spatial frequency. Klin MonblAugenheilk. 1999;215:175-81.
8. Mash C, Dobson V, Carpenter N. Interobserver agreement for measurement of grating acuity and interocular acuity differences with the Teller Acuity Card procedure. Vision Res. 1995;35:303-12.
9. Getz LM, Dobson V, Luna B, Mash C. Interobserver reliability of the Teller Acuity Card procedure in pediatric patients. Invest Ophthalmol Vis Sci. 1996;37:180-7.
10. Ridder VH, Tong A, Floresca T. Reliability of acuities determined with the sweep visual evoked potential (sVEP). Doc Ophthalmol. 2012;124:99-107.
11. Vesely P. Contribution of sVEP visual acuity testing in comparison with subjective visual acuity. Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub. 2015;159:616-21.
12. Millodot M, Harper P. Measure of visual acuity by means of eye movements. Am J Optom Arch Am AcadOptom. 1969;46:938-45.
13. Weder W, Wiegand H. Determination of visual acuity using optokinetic nystagmus. A newly developed instrument based on Günter’s principle. Klinische Monbl Augenheilkd. 1987;191:149-55.
14. Kim MS, Choi YS, Lu WN, et al. The development of an objective test for visual acuity assessment using optokinetic nystagmus stimuli presented head-mounted display: Sreohan objective visual acuity test. J Korean Ophthalmol Soc. 2000;41:871-8.
15. Shin YJ, Park KH, Hwang JM, Wee WR, Lee JH, Lee IB. Objective measurement of visual acuity by optokinetic response determination in patients with ocular diseases. Am J Ophthalmol. 2006;141:327-32.
16. Wester ST, Rizzo JF 3rd, Balkwill MD, Wall C 3rd. Optokinetic nystagmus as a measure of visual function in severely visually impaired patients. Invest Ophthalmol Vis Sci. 2007;48:4542-8.
17. Hyon JY, Yeo HE, Seo J, Lee IB, Lee JH, Jeong-Min Hwang J. Objective measurement of distance visual acuity determined by computerized optokinetic nystagmus test. Invest Ophthalmol Vis Sci. 2010;51:752-5.
18. Han SB, Yang HK, Hyon JY, et al. Efficacy of a computerized optokinetic nystagmus test in prediction of visual acuity of better than 20/200. Invest Ophthalmol Vis Sci. 2011;52:7492-7.
19. Han SB, Han ER, Hyon JY, et al. Measurement of distance objective visual acuity with the computerized optokinetic nystagmus test in patients with ocular diseases. Graefes Arch Clin Exp Ophthalmol. 2011;249:1379-85.
20. Dakin SC, Turnbull PRK. Similar contrast sensitivity functions measured using psychophysics and optokinetic nystagmus. Sci Rep. 2016;6:34514.
21. Çetinkaya A, Oto S, Akman A, Alova YA. Relationship between optokinetic nystagmus response and recognition visual acuity. Eye (Lond). 2008;22:77-81.
22. Aleci C, Scaparrotti M, Fulgori S, Canavese L. A novel and cheap method to correlate subjective and objective visual acuity by using the optokinetic response. Int Ophthalmol. 2018;38:2101-15.
23. Aleci C, Cossu G, Belcastro E, Canavese L. The optokinetic response is effective to assess objective visual acuity in patients with cataract and age-related macular degeneration. Int Ophthalmol. 2019;39:1783-92.
24. Abadi RV, Pascal E. The effects of simultaneous central and peripheral field motion on the optokinetic response, Vision Res. 1991;31:2219-25.
25. Abadi RV, Howard IP, Ohmi M, Lee EE. The effect of central and peripheral field stimulation on the rise and gain of human optokinetic nystagmus. Perception. 2005;34:1015-24.
26. Frisén L. Vanishing optotypes. New type of acuity test letters. Arch Ophthalmol. 1986;104:1194-8.
27. Howland B, Ginsburg A, Campbell FW. High-pass spatial frequency letters as clinical optotypes. Vision Res. 1978;18:1063-6.
28. Frisén L, Nikolajeff F. Properties of high-pass resolution perimetry targets. Acta Ophthalmol (Copenh). 1993;71:320-6.
29. Shah N, Dakin SC, Redmond T, Anderson RS. Vanishing Optotype acuity: repeatability and effect of the number of alternatives. Ophthalmic Physiol Opt. 2011;31:17-22.

30. Anderson RS, Ennis FA. Foveal and peripheral thresholds for detection and resolution of vanishing optotype tumbling E's. Vision Res. 1999;39:4141-4.
31. Frisén L. High-pass resolution perimetry: central-field neuroretinal correlates. Vision Res. 1995;35:293-301.
32. Yu H, Akita T. Influence of ambient-tablet PC luminance ratio on legibility and visual fatigue during long-term reading in low lighting environment. Displays. 2020;62:101943.
33. Vanden Bosch ME, Wall M. Visual acuity scored by the letter-by-letter or probit methods has lower retest variability than the line assignment method. Eye (Lond). 1997;11:411-7.
34. Wen Y, Chen Z, Zuo C, et al. Low-contrast high-pass visual acuity might help to detect damage: a structure-function analysis. Front Med (Lausanne). 2021;8:68082.
35. Chang L, Guo P, Thompson B, Sangi M, Turuwhenua J. Assessing visual acuity - test-retest repeatability and level of agreement between the electronic ETDRS chart (E-ETDRS), optokinetic nystagmus (OKN), and sweep VEP. Invest Ophthalmol Vis Sci. 2018;59:5789.
36. Schwob N, Palmowski-Wolfe A. Objective measurement of visual acuity by optokinetic nystagmus suppression in children and adult patients. J AAPOS. 2019;23:272.e1-272.e6.
37. Shah N, Dakin SC, Anderson RS. Effect of optical defocus on detection and recognition of vanishing optotype letters in the fovea and periphery. Invest Ophthalmol Vis Sci. 2012;53:7063-70.
38. Shah N, Dakin SC, Whitaker HL, Anderson RS. Effect of scoring and termination rules on test-retest variability of a novel high-pass letter acuity chart. Invest Ophthalmol Vis Sci. 2014;55:1386-92.
39. Shah N, Dakin SC, Dobinson S, Tufail A, Egan CA, Anderson RS. Visual acuity loss in patients with age-related macular degeneration measured using a novel high-pass letter chart. Br J Ophthalmol. 2016;100:1346-52.
40. Alexander KR, Xie W, Derlacki DJ. Spatial-frequency characteristics of letter identification. J Opt Soc Am A. 1994;11:2375-82.
41. Chung ST, Legge GE, Tjan BS. Spatial-frequency characteristics of letter identification in central and peripheral vision. Vision Res. 2002;42:2137-52.
42. Majaj NJ, Pelli DG, Kurshan P, Palomares M. The role of spatial frequency channels in letter identification. Vision Res. 2002;42:1165-84.
43. Harris PA, Garner T, Sangi M, Guo P, Tutuwhenua J, Thompson B. Visual acuity assessment in adults using optokinetic nystagmus. Invest Ophthalmol Vis Sci. 2019, 60(9), 5907.
44. Turuwhenua J, LinTun Z, Norouzifard M, Edmonds M, Findlay R, Black J, Thompson B.Automated visual acuity estimation by optokinetic nystagmus using a stepped sweep stimulus. Ophthalmic Physiol Opt; 2024.
    DOI: 10.1111/opo.13391
45. Doustkouhi SM, Turnbull PRK, Dakin SC. The effect of refractive error on optokinetic nystagmus. Sci Rep. 2020;10:20062.
46. Aleci C. Measuring the soul-psychophysics for non-psychophysicists. Les Ulis: EDP Sciences; 2021.
47. Pelli DG, Farell B. Why use noise? J Opt Soc Am A Opt Image Sci Vis. 1999;16:647-53.

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