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ORIGINAL PAPER

The optokinetic response is effective to assess objective visual acuity in patients with cataract and age-related macular degeneration

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Abstract
Purpose To estimate objective visual acuity in subjects suffering from cataract and age-related macular degeneration via the optokinetic response evoked by a non-conventional induction method (*oktotype*); in addition, to compare such objective outcome with the subjective acuity based on the ETDRS charts.
Methods Patients were presented with 13 sequences of symbols arranged horizontally to form a serial pattern, moving from left to right at a constant rate. In each sequence, the size of the stimuli was reduced progressively, while the operator checked for the disappearance of the optokinetic response via a small video camera mounted on the test lens frame. The minimum angular size of the serial pattern able to evoke the optokinetic response (MAER) was referred to as the objective visual acuity of the subject.
Results Correlation between logMAER and logMAR was significant in the cataract and macular degeneration group ($R^2_{cat} = 0.70$, $p < .0001$; $R^2_{AMD} = 0.63$, $p < .0007$). In the two samples, the correspondence between subjective and objective visual acuity (as, respectively, decimal units and arbitrary decimal units) was satisfactory (concordance correlation coefficient: cataract group = 0.91 and AMD group = 0.93). Test–retest reliability of the oktotype was good for the cataract group and moderate for the AMD sample (K 0.81 and 0.59, respectively).
Conclusion The oktotype seems a promising tool to objectively assess visual acuity in noncooperating subjects with cataract or macular degeneration. Further research on other clinical conditions is needed to clarify the suitability of the procedure in the clinical setting.

Keywords Age-related macular degeneration · Cataract · Optokinetic nystagmus · Oktotype · Test–retest reliability · Visual acuity

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Introduction

It is well known that the measure of visual acuity (VA) in the everyday clinical practice requires the collaboration of the patient. In fact, the current psychophysical methods that make use of optotype charts cannot provide an estimate in preverbal children, in subjects affected from severe cognitive deterioration, in patients with suspected functional visual loss, as well as in malingerers. Still, objective techniques introduced for this purpose like the Teller acuity test [1–5] and the sweep VEP [6–9] suffer from a number of flaws (including but not limited to significant interobserver variability at the Teller test [10] or to the expensive electrophysiological equipment) that hamper their widespread use within the clinical setting.

As an alternative, in the last decades, a consistent bulk of research focused on procedures based on the optokinetic reflex (OKR) [11–17].

The OKR refers to the physiological fixation/refixation pattern of the eye when viewing a sequence of vertical stripes sweeping horizontally across the screen. In this condition of stimulation, a periodical, not inhibitable back-and-forth movement of the eye (that is a reiterative pattern of fixations) can be observed along the plane of the shift.

Evidently, the OKR does not take place if the size of the stripes is beyond the detection threshold of the observer: It follows that the visual acuity of a subject can be derived from the smallest angular size of the stripes (that is inversely proportional to the spatial frequency of the serial stimulation) able to elicit a well-detectable optokinetic reflex at a given viewing distance. To achieve this goal, in the so-called *induction method,* the spatial frequency of a full-field serial pattern is increased progressively until the OKR is no more recordable.

In the late 1960s, a number of studies have confirmed the substantial validity of these approaches, showing a correlation between subjective (optotype-based) and objective OKR-based visual acuity [11, 13–19]. Yet, even if in its actual form the induction method seems more reliable [13, 15, 17], the procedure suffers from low predictive power. As a matter of fact, it is not effective in measuring visual acuities beyond 0.3 [13] and even below this level, and the range of subjective acuity corresponding to each objective measure is too wide to allow sufficiently accurate estimates [17].

To solve these problems, Han suggested to adjust the velocity of the serial presentation across the range of stimulations, as well as the size and contrast of the stimulus [17].

Taking into account these suggestions, in a previous paper, we have described a cheap and user-friendly OKR-based acuity estimator suitable for the clinical practice (*oktotype*), and the results obtained in a group of poorly and non-collaborative children have been reported [20]. Based on the good correspondence between optotype- and oktotype-based acuity estimates in the first sample (concordance correlation coefficient 0.83), on the strong correlation between the latter and Teller acuity in the second class of patients (concordance correlation coefficient 0.79–0.85), and on the high test–retest reliability (K 0.82), we concluded that the oktotype is effective in predicting Snellen visual acuity in normal and poorly collaborative subjects with no ophthalmological alterations. It remains to state whether the technique is equally valid in the presence of pathological ocular conditions.

Therefore, this study intends to investigate the efficacy of the oktotype in a sample of patients affected by two different ophthalmological diseases, namely age-related macular degeneration and cataract. These conditions, indeed, are representative of two main clinical patterns in ophthalmology, as the first case is characterized by selective impairment of high-spatial-frequency channels located in the central part of the retina, whereas cataract is expected to affect to the same extent the entire visual field.

Materials and methods

The technique has been explained in details in a recent paper [20]. In brief, 13 sequences of dark symbols moving from left to right at a constant rate are displayed on a 15″ LCD screen. Symbols within the sequence are different from each other. A field of random dots (density 400 dots/cm^2) with luminance decreasing from 60 to 160 cd/m^2 is superimposed on the first five presentations (Fig. 1); in fact, partially masking the sequence with white noise proved to be effective in minimizing the overestimate, we found at the lower half of the subjective acuity range (see Aleci et al. [20]).

In order to help patients with low visual acuity maintain their fixation on the target, the movement of each symbol is made slower for the first three presentations compared to the following eight stimulations (1.43 vs. 2.86 °/s).

The screen is placed 14 feet far from the observer, in a dim environment. A small infrared camera (Kadymay Kdm-6406G, horizontal spatial resolution

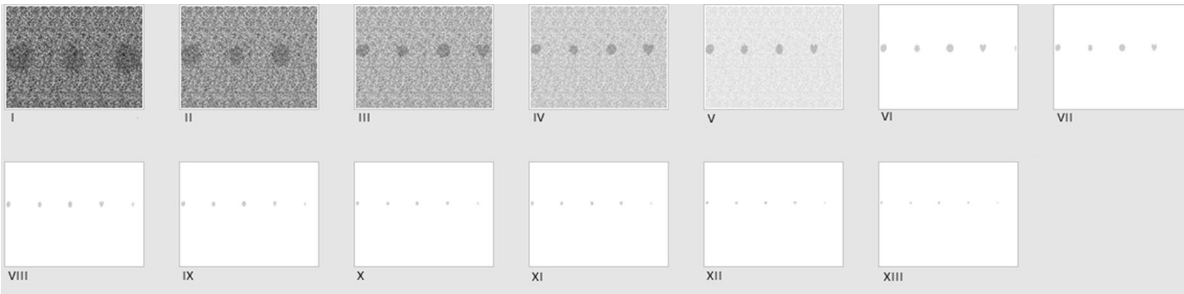

Fig. 1 Serial stimulations employed in the experiment. A field of random dots (density 400 dots/cm^2) with decreasing luminance masks the first five presentations from Aleci et al. [20]

700 TVL) mounted on a frame lens is aimed at the eye not under examination and connected to a second screen positioned in front of the operator (Fig. 2).

As soon as each presentation is displayed, the operator confirms the occurrence of the OKR, inspecting the monitor connected to the camera. The OKR is considered as evoked if uninterrupted nystagmus is observed for at least 3 s.

After the optokinetic response is observed, the size of the stimuli is reduced, starting from 45.12 min arc (first sequence) up to 3.84 min arc (last sequence). At the first "null" presentation (i.e., OKR not observed), the run is reversed until a positive response occurs (i.e., OKR observed). If the minimum angular size evoking the optokinetic reflex (MAER) is different at the ascending and descending run during the same session, the test is repeated after a few minutes.

Sample

Fifteen patients suffering from corticonuclear cataract (CAT group: 14 males, one female, median 70 years, range 67–82 years) and 14 patients with age-related macular degeneration (AMD group: two males, 12 females, median 78 years, range 63–85 years) have been recruited from the outpatient clinic of ophthalmology of the University of Turin. Except for nine patients (64.2%) in the AMD group, who were pseudophakic, all subjects did not show any other ophthalmological condition. In all cases, the best corrected visual acuity (BCVA) was equal or higher than 6/60.

Patients underwent a preliminary ophthalmological and orthoptic examination, and then, BCVA as logMAR was measured with the ETDRS tables and objective visual acuity as logMAER was assessed with the oktotype in each group. ETDRS and oktotype were

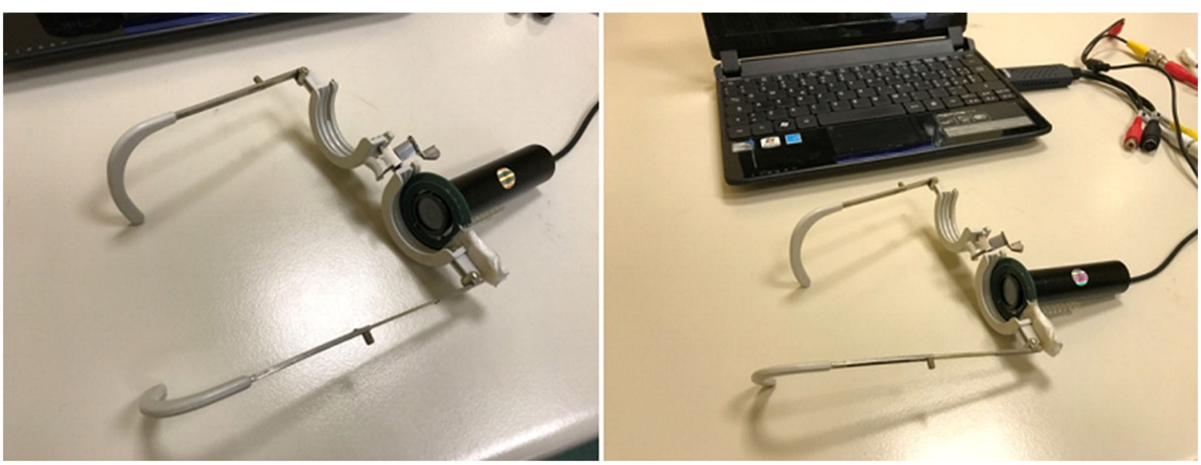

Fig. 2 Oktotype: The small infrared camera mounted on a frame lens aiming at the eye not under examination and connected to a second screen placed in front of the operator

administered by two different operators skilled in psychophysical and behavioral testing (FC and GC) in a randomized manner. The operators were masked as to the estimates obtained at the other test. To evaluate test–retest reliability, the oktotype was repeated by two different operators (CM and LC) some minutes later. The examination took about 15 min to be performed.

Correspondence between subjective logMAR and objective logMAER has been investigated in the two groups by performing linear regression analysis.

All experiments were approved by the ethics committee and therefore performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Informed consent was obtained from each participant to the study.

Results

As shown in Fig. 3, logMAER–logMAR linear regression was significant both in the CAT and in the AMD group ($R^2_{cat} = 0.70$, $p < .0001$; $R^2_{AMD} = 0.63$, $p < .0007$).

Each presentation (labeled as I–XIII in decreasing order of MAER) has been assigned an arbitrary decimal notation (objective visual acuity). Based on the equation describing the linear regression, the relationship between objective and subjective visual acuity (in decimal units or Snellen fraction) is obtained across the whole subjective range of acuity in the two clinical conditions (Table 1).

Concordance correlation coefficient (CCC) between subjective and objective acuity in the CAT group was 0.59 (CI 0.37–0.74) with quasiperfect precision ($r = 0.99$) but low accuracy (bias correction factor $C_b = 0.59$). After scaling by − 0.2 arbitrary units, the objective acuities, accuracy improved markedly ($C_b = 0.91$), and the CCC rose up to 0.91 (CI 0.82–0.95, Fig. 4, upper panels).

Similarly, concordance correlation coefficient in the AMD group was 0.41 (CI 0.20–0.58) with quasiperfect precision ($r = 0.99$) but low accuracy (bias correction factor $C_b = 0.41$). After scaling by − 0.3 arbitrary units, the objective visual acuities, accuracy improved consistently ($C_b = 0.95$), and the CCC rose up to 0.94 (CI 0.85–0.97, Fig. 4, lower panels).

Test–retest reliability of the oktotype was good for the cataract group and moderate for the AMD sample (K 0.81 and 0.59, respectively, according to the classification of Altman [21]). The degree of consistency among single measures expressed as intraclass correlation coefficient (ICC [22]) was lower at the oktotype ($ICC_{cat} = 0.94$, CI 0.84–0.98; $ICC_{AMD} = 0.85$, CI 0.60–0.95) compared to the EDTRS ($ICC_{cat} = 0.98$, CI 0.95–0.99; $ICC_{AMD} = 0.97$, CI 0.92–0.99 Fig. 5).

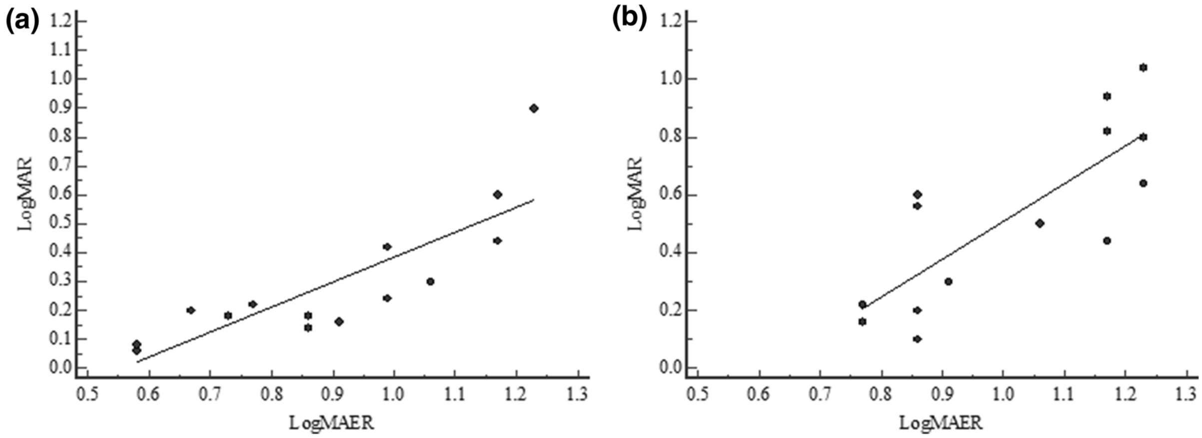

Fig. 3 Correlation between logMAR and logMAER; **a** CAT group, **b** AMD group. In both samples, the linear regression model seems able to predict the logMAR of the patient at each minimum angle able to evoke the OKR, as deduced in the experimental condition and after MAER has been converted to logarithm

Table 1 Relationship between objective and subjective visual acuity across the whole subjective acuity range in the two clinical conditions

logMAER	Presentation	Objective VA (arbitrary decimal units)	Subjective VA (decimal units)	logMAR
1.23	IV	0.4	0.2	0.7
1.17	V	0.5	0.3	0.52
1.06–0.99	VI–VII	0.65	0.4	0.4
0.91	VIII	0.8	0.5	0.3
0.86	IX	0.9	0.6	0.22
0.77	X	1.0	0.7	0.14
0.73–0.67	XI–XII	1.15	0.8	0.1
0.67–0.58	XII–XIII	1.25	0.9	0.05
0.58	XIII	1.3	1.0	0.00
1.23	V	0.5	0.1	1.0
1.17–1.06	V–VI	0.55	0.2	0.7
1.06–0.99	VI–VII	0.65	0.3	0.52
0.99	VII	0.7	0.4	0.4
0.91	VIII	0.8	0.5	0.3
0.91–0.86	VIII–IX	0.85	0.6	0.22
0.86–0.77	IX–X	0.95	0.7	0.14
0.77	X	1.0	0.8	0.1
0.73	XI	1.1	0.9	0.05
0.67	XII	1.2	1.0	0.00

Top: CAT; bottom: AMD

Discussion

The relationship between subjective (Snellen) and objective (optokinetic response based) visual acuity is well established [13, 15, 17], and the use of the latter to estimate the former is a procedure worth to be further investigated as a promising tool to assess the visual function in noncooperative patients within the clinical setting. As a proof of this, by combining the suppression and the induction method, Han et al. [16] found that the objective method was sensitive and specific enough to detect patients with Snellen visual acuity $< 20/200$, that is, a criterion for legal blindness in the USA and European countries. Yet, to date, the optokinetic paradigm described in the literature proved not to be effective in measuring acuities beyond 0.3 [13], and even below this level, it is flawed by low accuracy [17]. Evidently, its introduction in the clinical practice requires improved precision, so as to make less ambiguous the correspondence between the subjective and OKR-derived estimates of acuity.

Indeed, a cheap, simple, user-friendly and fast OKR-based visual estimator, the *oktotype*, has been developed in our laboratory for clinical purpose, as reported in our previous paper [20]. The technique, not coupled to eye tracker systems, differs from those adopted so far [13, 15–17] both in the paradigm and in the characteristic of the serial stimulation.

To summarize:

(1) the procedure makes use of the induction method rather than the suppression method, or their combination, as the correlation between objective and subjective acuity is found stronger with the induction method [13, 17]; moreover, the induction method would better reflect the overall integrity of the visual system [13, 15];

(2) in order to help the observer keep focused on the moving pattern, black-and-white stripes are replaced with different symbols displaced horizontally. The serial configuration shifts from left to right at a lower speed compared to the

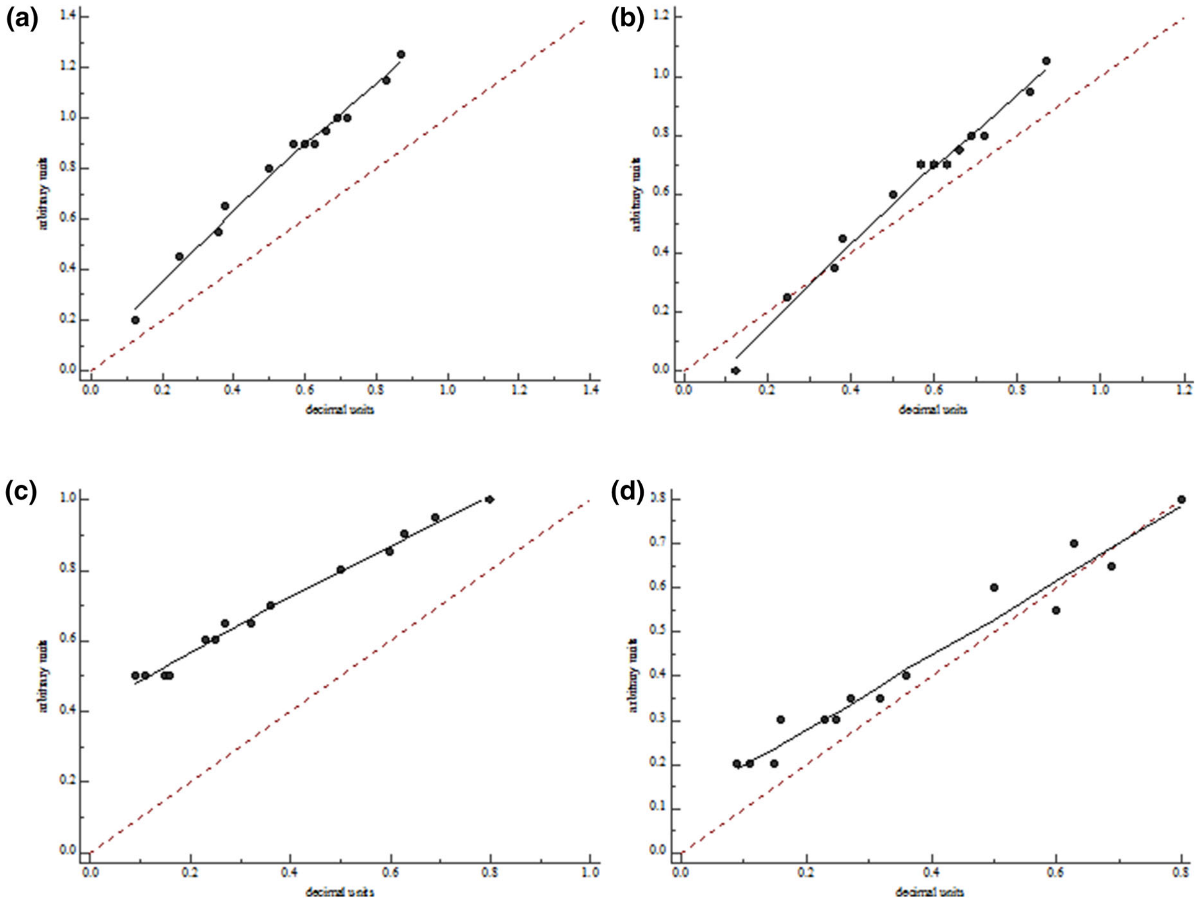

Fig. 4 Correlation between objective and subjective acuity, before (left) and after scaling the objective visual acuities (right); **a**, **b** CAT sample; **c**, **d** AMD sample

procedures employed so far (1.43–2.86 °/s vs. 10 °/s adopted in the previous investigations [13, 15–17]). As a matter of fact, detecting the periodic movements of the eyes in the absence of an eye tracker is much easier with slow shifting rates. This is not trivial, considering that our procedure does not make use of ocular movement recording devices. A further factor to be borne in mind is that the velocity of the stimulation causes restrictions on spatial resolution. For example, at 10 °/s the spatial resolution is limited to 6 cycles/°, corresponding to a Snellen acuity of 20/100 [17]. Evidently, this issue undermines the estimate based on the correlation between the subjective and the objective data. Finally, it has been reported that the use of dynamic targets increases the acuity threshold [23, 24]: As the intention is to derive Teller acuity for clinical purpose, that is, to say in stationary conditions, slow moving patterns should be adopted. Considering that low velocity is preferable for low visual acuities, whereas higher speed is more indicated to test subjects with relatively better visual function [14], the shift rate is made slower in the first three presentations and faster the fourth stimulation onwards.

The objective acuity provided by the oktotype is found to be consistent with the subjective ETDRS estimate. In fact, logMAER–logMAR correlation is satisfying and higher compared to the induction method used by Han et al. (R^2 = 0.70 and R^2 = 0.66 in the cataract and AMD group vs. R^2 = 0.65 and R^2 = 0.31) [17] and by Shin et al. (R^2 = 0.88 and R^2 = 0.36) [13]. In this respect, it is noteworthy that in the two pathological samples the oktotype provided a

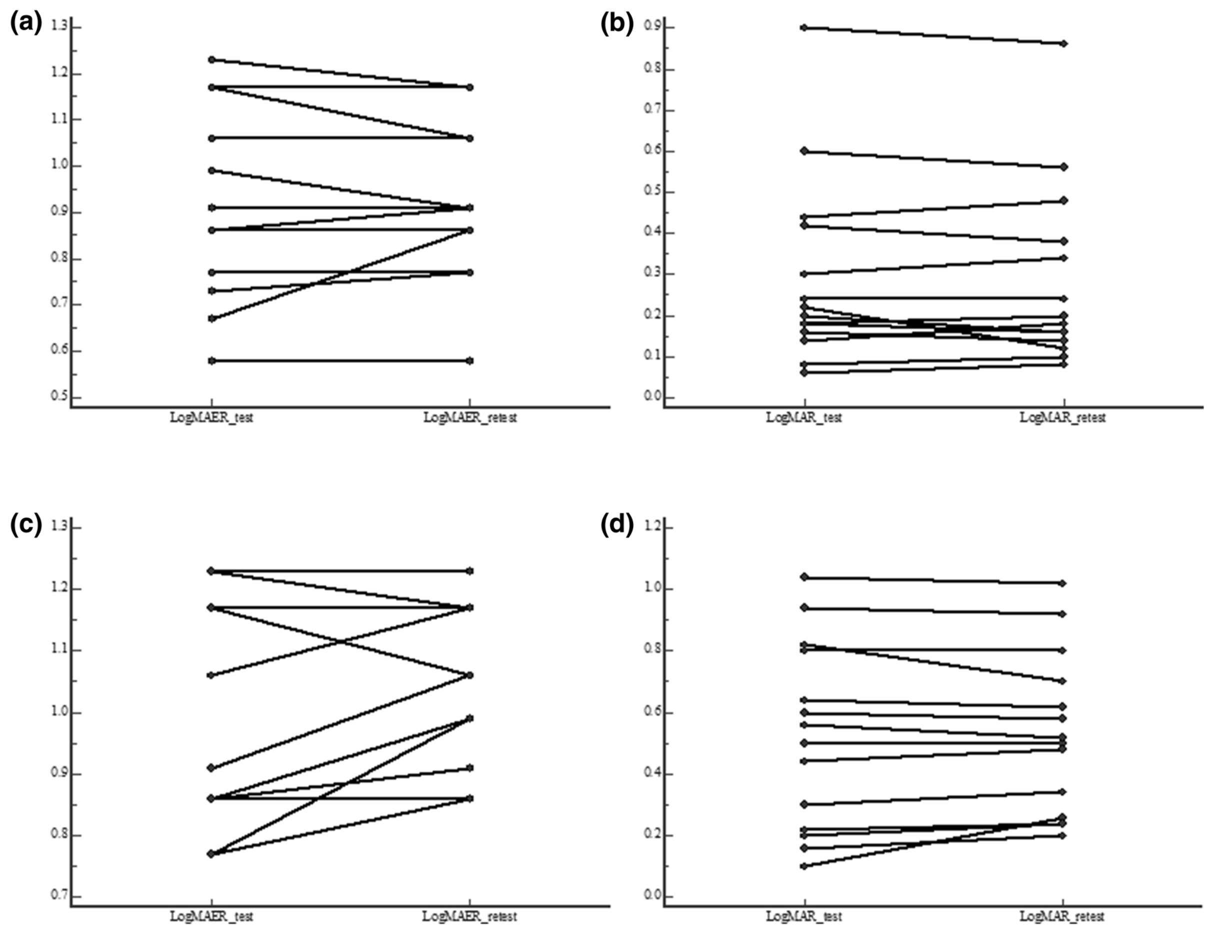

Fig. 5 Intraclass correlation coefficient (ICC) at the Oktotype and ETDRS in the CAT sample (**a**, **b**) and AMD group (**c**, **d**)

determination coefficient higher than that reported by Hyon in a group of normal subjects ($R^2 = 0.56$). Indeed, the procedure adopted by Hyon [15] was not sensitive enough to assess the subjective acuity when objective acuity was 0.4, 0.5 and 0.6 arbitrary units.

After the measures have been scaled by a correction factor, high concordance correlation coefficient computed in the two classes of patients confirms the strict correspondence between the acuity measures provided by the subjective and objective method.

Finally, test–retest reliability of the oktotype is good (ICC = 0.85–0.94) and in line with the ICC computed by Hyon (ICC = 0.94) [15] and by Han (ICC = 0.90) [17], as well as with the value we have reported in our previous investigation in noncooperating subjects (ICC: 0.92) [20]. Indeed, it is high enough to make this procedure potentially suitable for the clinical setting.

According to the so-called central dominance theory, most of the optokinetic response stems from the macular region, though it encompasses a restricted central portion of visual field [25, 26]. In support of this hypothesis, we found no difference in the MAR–MAER log correlation between the group affected by macular degeneration, where the signal reduction is limited to the central region of the retina, and by the sample with cataract, where the signal is reduced across the whole visual field ($r = 0.81$ and 0.83). This finding is in line with the correlation coefficients reported by Shin et al. [13] in generalized retinal diseases and macular degeneration ($r = 0.60$ and 0.62, respectively).

Interestingly, we found in both samples that the minimum angle evoking the nystagmus is markedly higher than the minimum angle of resolution (Table 2).

Table 2 Log–log correspondence between MAR and MAER in the two samples

logMAR	$logMAER_{CAT}$	$logMAER_{AMD}$	$logMAER^{a}_{norm}$
1	–	1.23	1.73
0.7	1.23	1.06–1.17	1.58
0.52	1.17	0.99–1.06	1.40
0.39	0.99–1.06	0.99	1.31
0.30	0.91	0.91	1.25
0.22	0.86	0.86–0.91	1.13
0.15	0.77	0.77–0.86	1.07
0.09	0.67–0.73	0.77	0.98
0.04	0.58–0.67	0.73	0.93
0	0.58	0.67	0.85
− 0.04	–	–	0.80

[a]As comparison, data from normal (no ophthalmological diseases) noncooperative subjects from Aleci et al. [20]

This discrepancy has been reported even since 1969 by Millodot and Harper [11] and confirmed in our previous paper, where a tentative explanation has been formulated [20]. In brief, the reason could rely on the dynamic vs. static modality of stimulation: The measurement of Snellen acuity is a static procedure that requires to identify steady-state optotypes; on the contrary, the acuity estimate by means of the optokinetic response implies moving stimuli. Indeed, more than 60 years ago Ludvigh and Miller [27] reported that "the acuteness of vision is markedly reduced from its static value when a "relative" angular velocity exists between the object viewed and the eye." In addition, it cannot be excluded that the visual threshold needed for triggering the eye movements is well above the discrimination or recognition threshold. In other terms, additional amount of information could be necessary to evoke the optokinetic response other than discriminating the spatial intervals of the serial configuration: This "surplus," indeed, would make MAER wider than MAR. This rule, indeed, does not seem to be affected by pathological conditions like cataract or maculopathy. A more straightforward explanation relies on the contrast level of the targets, which, as reported in the methods section of our previous paper [20], is lower compared to that used in the ETDRS or Snellen optotypes. As a matter of fact, this discrepancy is expected to affect more the higher than the lower spatial frequencies, in line with the poorer correspondence found at the higher acuities (i.e., at the lower MAER).[1]

The lack of an eye movement control system can be regarded as the technical limitation of the procedure; even if the operator-dependent criterion is accepted when testing children with the Teller Acuity Cards and in other types of experiments (see for example, the study of Towle and Harter) [28], coupling the oktotype with an eye tracking system like video-oculography, electro-oculography or scleral search coils would make the detection of the OKR more precise and reliable.

Indeed, assessing the difference in precision and reliability with and without an eye tracker is fundamental to better understand the potential of the oktotype in the class of patients considered in this study, even if it should be borne in mind that our purpose was to devise an acuity estimator as simple and inexpensive as possible, so as to make it suitable for the clinical practice.

For the moment, even if intra- and inter-observer agreement seems satisfying, estimates should be confirmed by testing repetition, and the comparison between subsequent evaluations performed by different operators requires caution. In addition, in this study, subjects with visual acuities lower than 6/60 have not been considered. Evidently, to fully determine the potential of the technique sensitivity, specificity and repeatability should be assessed also in this class of patients.

The small samples and the limited classes of ophthalmological conditions are the methodological limitation of this investigation: It is advisable to study predictive power and reliability of the oktotype in patients suffering from pathologies other than cataract and AMD, like amblyopia, central origin visual disorders and those conditions that preserve the central visual field at the early stage like glaucoma and retinitis pigmentosa, in order to validate the technique across a broad spectrum of clinical conditions, as well as to help clarify the contribution of the peripheral and central visual field on the genesis of the optokinetic reflex.

[1] We are grateful to the anonymous reviewer for this valuable suggestion.

Conclusion

The oktotype seems a promising method to assess the visual acuity in non-communicative or non-collaborative subjects suffering from cataract and age-related macular degeneration.

Further studies with large samples and a greater variety of clinical conditions are required to better define the precision and accuracy of the procedure, thereby its suitability for the clinical practice.

Compliance with ethical standards

Conflict of interest All authors certify that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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