Objective measurement of visual acuity by optokinetic nystagmus suppression in children and adult patients

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PURPOSE To investigate the correlation between subjective and objective visual acuity as elicited with a new computerized optokinetic nystagmus (OKN) suppression test ("SpeedWheel") in adults and school-aged children.

METHODS Fifteen children (6-12 years) and 27 adults with refractive errors, amblyopia, cataract, age-related macular degeneration, and thyroid-associated orbitopathy underwent testing of subjective visual acuity with E- and Landolt-C symbols (Freiburg Acuity and Contrast Test [FrACT]) and visual acuity as estimated with the SpeedWheel on an LCD screen. Statistical analysis: linear regression, Spearman correlation, and Bland-Altman plots.

RESULTS Mean difference against the mean was −0.01 when SpeedWheel was compared to Landolt C, but −0.15 when compared to E-symbols. Overall, SpeedWheel correlated very strongly to FrACT ("E": $r = 0.85$; $P < 0.001$; Landolt-C: $r = 0.81$; $P < 0.001$). This also held true in children ("E": $r = 0.74$; $P < 0.003$; Landolt-C: $r = 0.69$; $P < 0.005$).

CONCLUSIONS SpeedWheel enables estimation of visual acuity in a variety of conditions in both adults and school-aged children. (J AAPOS 2019;23:272.e1-6)

Visual acuity tests in school-aged children are typically performed with standard optotypes also used in adults. These tests are subjective; they rely on the ability and motivation of the individual to communicate. In uncooperative subjects or in the case of a language barrier, testing becomes difficult,[1] and objective estimates of visual acuity can be helpful. Objective estimates of visual acuity may be obtained through recording visual evoked potentials (VEPs) to successively smaller stimuli from the visual cortex or by eliciting the optokinetic nystagmus (OKN) to moving targets of different sizes or suppression of the OKN by fixation-targets of varying sizes.

The first method has several limitations. VEP generally requires specialized equipment, time to fix electrodes to the head, and expert technicians to perform the test. Additionally, it can be difficult to obtain a measurable response from children with ocular motility disorders (eg, nystagmus) and neuromotor function abnormalities (eg, cerebral palsy), which may lead to muscle artifacts obscuring the visual signal. Infants >9 months of age may resist placement of electrodes. VEP is therefore not often used in clinical practice but remains an important research tool.[2]

The OKN consists of a series of physiologic reflexive eye movements: first a smooth pursuit movement when the eye follows a moving target, then a fast catch-up saccade to refocus on a new target. The reflex is almost impossible to inhibit. Therefore, an OKN-inducing stimulus with increasing spatial resolution can be used to objectively estimate visual acuity, as can suppression of the OKN. Suppression of the OKN is achieved by superimposing fixation targets of successively increasing size over the moving grating pattern, leading to the inhibition of the OKN once fixation occurs.[3] Both OKN elicitation and suppression correlate with subjective visual acuity in adults.[4-7] However, we found only one study with a separate analysis of the OKN response in school-aged children, and the authors reported no correlation between subjective and objective assessment of visual acuity.[8]

The current study aimed to test the applicability of our previously developed computerized OKN suppression test (SpeedWheel) in the clinical setting with both visually impaired adults and children.

Subjects and Methods

This study was a prospective, single-center observational study approved by the Ethikkommission Nordwest- und Zentralschweiz (EKNZ), Basel, Switzerland, and adhered to the tenets of the Declaration of Helsinki. Written informed consent was obtained after explaining the nature and purpose of the study and

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possible consequences to the subjects and, in case of children, also to parents before children were tested.

Subjects were prospectively recruited from the University Eye Hospital Basel, Switzerland between July 2018 and August 2018. To be eligible for inclusion, adult participants had to be otherwise healthy individuals with a reduction in visual acuity due to either age-related macular degeneration (AMD), amblyopia, cataract, thyroid-associated orbitopathy (TAO), or reduced visual acuity of unknown origin (possible malingering); children had to be between 6-12 years of age and otherwise healthy except for a reduction in visual acuity due to amblyopia or refractive errors. Primary exclusion criteria were lack of written informed individual/parental consent, physical or psychological disability preventing completion of the test, ocular motility disorders (eg, nystagmus), and epilepsy.

Adults and children were divided into five different subgroups according to their eye pathology. The refractive group consisted only of children and was measured without correction. Reference testing of subjective visual acuity was made with Landolt-C and E symbols presented in the Freiburg visual acuity and Contrast Test (FrACT)[9,10] at a distance of 1 m presented on a 28-inch LED screen (Samsung UHD Monitor U28E590D LED, 3840 × 2160 resolution; refresh rate 60 Hz). FrACT measured visual acuity between 1.6 and 0.1, equivalent to −0.2 and 1.0 logMAR. Two subjective visual acuity tests were chosen because in the beginning it was not clear whether every child would be able to identify the direction of opening of the Landolt-C symbols, because this required differentiation between horizontal, vertical, and oblique directions. In contrast, the E symbols were only presented in horizontal or vertical orientations. Objective estimation of visual acuity using the SpeedWheel test was performed as follows: an optokinetic stimulus pattern was presented on the same screen located 1 m in front of the subject in a dark room. Filling the entire screen, alternating vertical black and white stripes moved at a velocity of 10°/s from left to right to ensure triggering of an OKN. Spatial resolution of the stripes was 1° (1.75 cm width, maximum luminance of 0.4 cd/m^2 (black) and 362 cd/m^2 (white); Michelson contrast, 97%), After 10 seconds, 90 stable dark gray dots arranged in a cross across the screen were superimposed to suppress OKN. These dots remained in a stable position on the screen and started out at a very small size, continuously increasing every 10 seconds in 7 steps (from 0.29 mm to 2.91 mm). The diameter of the dots was calculated according to the following formula:

$$\text{OS (object size)} = \frac{\pi}{10800} \times \frac{d\ (distance)}{v\ (VA\ in\ decimal)}$$

Suppression of the OKN through detection of these dots at a viewing distance of 1 m corresponds to a visual acuity range equivalent to 0.05-1.0 logMAR. This estimate was termed *log SpeedWheelAcuity* (logSWA).

To disguise the true intention of the test and to maintain the subject's attention, the subject was asked to look at the center of the screen and to report whether something other than the stripes was seen and if so, what exactly. The smallest size of the suppression stimulus that stopped the OKN was defined as the SpeedWheel acuity (SWA). Then, both the suppression stimulus for one acuity value above and below the measured result was tested to ensure stability of the result. Suppression of the OKN was noted through direct observation of the eye movements magnified onto a smartphone by the SMI vision mobile eye tracking glasses (Sensory Motor Instruments Inc/ Boston, MA).

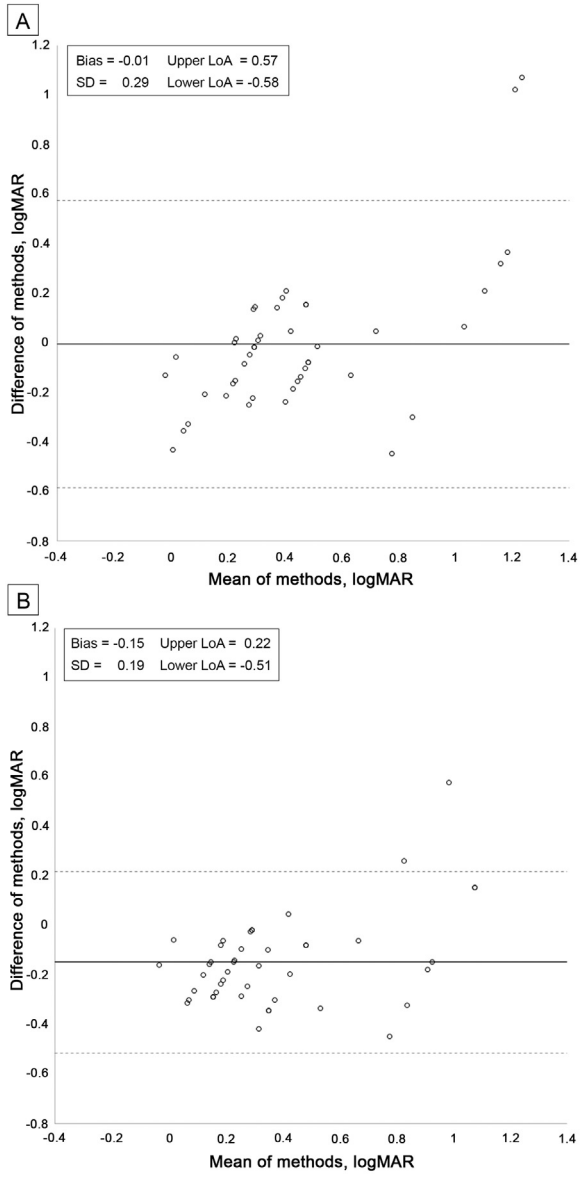

FIG 1. Bland-Altman plots comparing the difference between FrACT-E and -C and SpeedWheel test with the mean of the two tests. A, Landolt-C test compared with the SpeedWheel test. B, E-test compared with the SpeedWheel test. The dashed line depicts lower and upper limits corresponding to the mean of the differences ±1.96*SD.

Subjective visual acuities were compared to SWA. For statistical analysis, linear regression analysis, Spearman correlation and Bland-Altman Plots were performed using the statistical software R version 3.1.1 (2015; R Foundation for Statistical Computing, Vienna, Austria, https://www.R-project.org/) and Microsoft Excel 2016 (Microsoft, WA). Results are presented as lower and

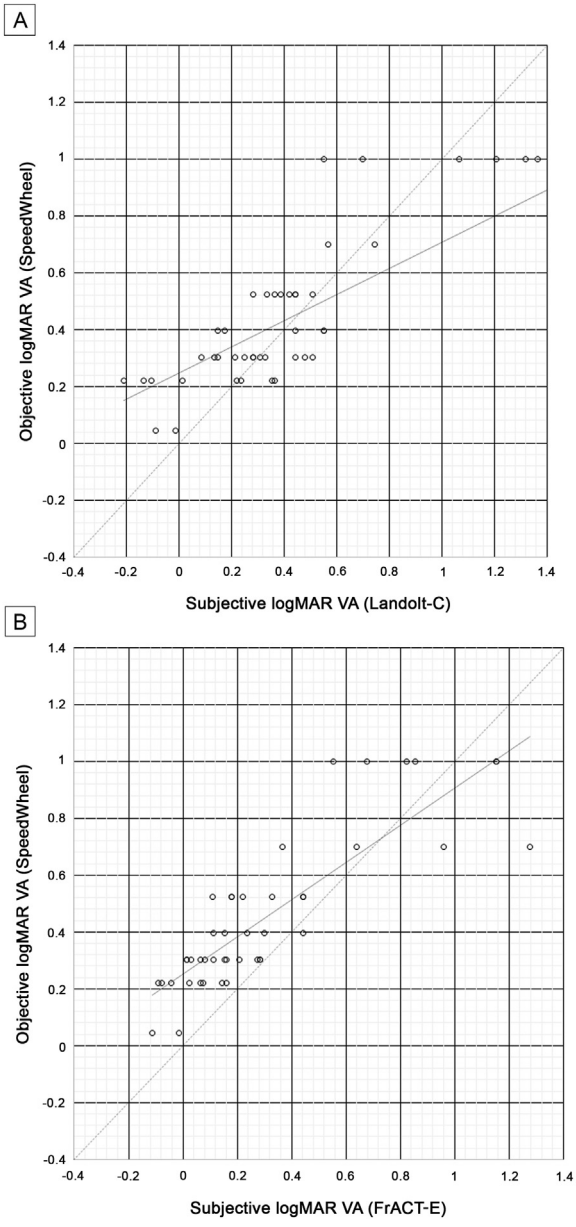

FIG 2. Linear regression correlating FrACT-E and -C to SpeedWheel values for all subjects. A, SpeedWheel compared with Landolt C. B, E chart compared with SpeedWheel.

upper 5%-95% limits and mean differences. Lower and upper limits correspond to the mean of the differences ±1.96*SD (standard deviation). A P value of <0.05 was considered significant.

Results

A total of 45 eyes of 42 individuals were measured: 27 adults (mean age, 46.7 ± 31.3 [SD] years; range, 22-90) and 15 children (mean age, 8.76 ± 2.03 years; range, 6-12). Distribution of eye pathologies was as follows: AMD, 10 eyes; amblyopia (either strabismic and/or refractive), 10 eyes); cataract, 8 eyes; TAO, 2 eyes; refractive error, 11 eyes; unknown causes, 4 eyes (2 patients). The three different visual acuity estimation tests could be performed on all subjects with the exception of 1 subject in the amblyopic group, who had time to complete only the C symbol and the SpeedWheel tests. This data was included, because correlation to SpeedWheel was of prime importance.

Visual acuities obtained with the different methods were comparable with each other except in the patients with reduction of visual acuity of unknown origin (eg, fictitious loss of vision).

Figure 1 shows Bland-Altman plots comparing the difference against the mean of the logSWA to both subjective methods. Subjective and objective visual acuity compared well, with a mean difference between Landolt-C symbols and logSWA of −0.01 (Figure 1A) and −0.15 between E symbols and SpeedWheel (Figure 1B).

Figure 2 depicts the very strong correlation between SpeedWheel and either Landolt-C (r 0.81; $P < 0.001$) or E symbols ($r = 0.85$; $P < 0.001$). Overall, both subjective visual acuity tests, E and Landolt-C symbols, also correlated very strongly ($r = 0.85$; $P < 0.001$). Patients with low visual acuity tended to have better estimates with the SpeedWheel test, whereas patients with high visual acuities had lower SWA estimates than FrACT estimates (difference, ≥0.1 logMAR).

Table 1 summarizes the mean visual acuity estimates for SpeedWheel and each subjective visual acuiyt test in each group. Overall, mean subjective logMAR was 0.38 ± 41. Mean subjective logMAR measured with E symbols was 0.31 ± 0.35; with Landolt-C symbols, 0.45 ± 0.44. Mean logSWA was 0.46 ± 0.26.

SpeedWheel was then compared to subjective visual acuity measurements in the different pathologies. SpeedWheel correlated strongly with both subjective acuity tests in amblyopia and refractive errors. For amblyopia, E symbols: $P < 0.001$ and $r = 0.92$; Landolt-C symbols: $P < 0.001$ and $r = 0.9$. For children with refractive errors, E symbols: $P < 0.005$ and $r = 0.79$; Landolt C-symbols: $P < 0.006$ and $r = 0.77$.

SpeedWheel showed a strong correlation with Landolt-C but not with E symbols in AMD and in cataract. For AMD, SpeedWheel to Landolt C-symbols: $P < 0.04$, $r = 0.67$; and to E-symbols: p: 0.1; r: 0.55. For cataract: SpeedWheel to Landolt C-symbols: $P < 0.03$ and $r = 0.78$; and to E symbols: $P = 0.29$ and $r = 0.43$.

Patients with unknown causes for low vision (possible malingering) had significantly lower visual acuity estimates in subjective testing than with SpeedWheel. Since only 4 eyes of 2 patients were investigated in this group, and no statistical analysis was performed. In the group with thyroid-associated orbitopathy, there were also too few people to calculate a correlation.

In children (the refractive group + 2 subjects from the amblyopia group), mean subjective logMAR was 0.23 ± 0.18. Mean logSWA was 0.38 ± 0.23. SpeedWheel also correlated significantly to E symbols ($P < 0.003$;

Table 1. VA estimates obtained with the SpeedWheel test and the subjective VA tests using E and C symbols[a]

	AMD	Amblyopia	Cataract	TAO	Refractive	Unknown
E-Chart	0.27 ± 0.24	0.28 ± 0.29	0.37 ± 0.22	0.3 ± 0.2	0.15 ± 0.22	1.14 ± 0.13
Landolt-C	0.35 ± 0.2	0.45 ± 0.37	0.37 ± 0.22	0.24 ± 0.1	0.24 ± 0.36	1.52 ± 0.27
SpeedWheel	0.45 ± 0.22	0.49 ± 0.31	0.38 ± 0.20	0.35 ± 0.07	0.36 ± 0.25	0.85 ± 0.17

AMD, age-related macular degeneration; *TAO*, thyroid-associated orbitopathy; *VA*, visual acuity.
[a]Mean logMAR values (with standard deviation) provided for the different clinical subgroups.

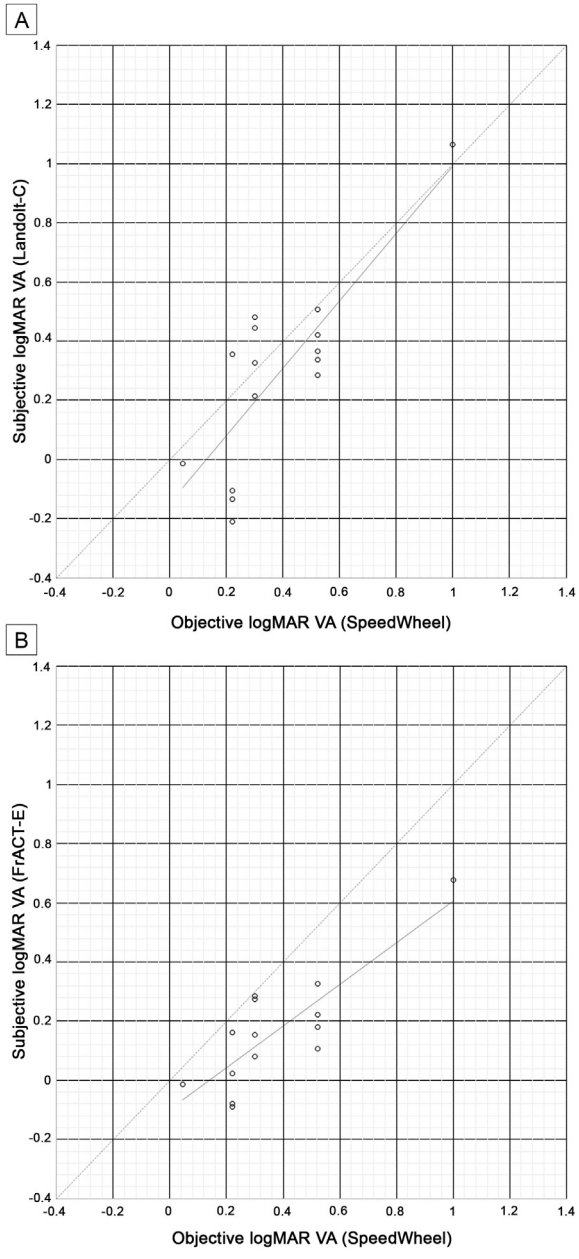

FIG 3. Linear regression correlating FrACT-E and -C to SpeedWheel values in children. A, SpeedWheel compared with Landolt-C. B, SpeedWheel compared with E-chart.

$r = 0.74$) as well as to Landolt-C symbols ($P < 0.005$; $r = 0.69$). See Figure 3.

P and r values are summarized in Table 2.

Discussion

We developed a computer program (SpeedWheel) displaying the OKN pattern on an LCD screen and indirectly observed suppression of the OKN eye movements when the fixation target was perceived. Eye movements were magnified onto a smartphone via eye tracking glasses to facilitate recognition of OKN suppression. Here we tested clinical applicability in visually impaired adults and school-age children.

Assessment of visual acuity through suppression of the OKN using the SpeedWheel test compared well with the subjective measurement of visual acuity in adults as well as in children. This is in agreement with previous studies conducted in adults that have shown good correlation between subjectively and objectively measured visual acuity using induction and/or suppression of the OKN.[4,5,7,11-13] We also found a strong correlation between SpeedWheel and the FrACT assessments of visual acuity in children and in amblyopic eyes.

Most of the studies investigating the OKN response in the assessment of visual acuity in children are conducted in infants or newborns.[14-19] We found only a single study that analyzed school-age children separately: Çetinkaya and colleagues[8] studied the OKN induction in a group of 52 children 3-11 years of age and found no relation between spatial frequency threshold for OKN and real visual acuity in children. Our results showed SpeedWheel to correlate strongly to subjective visual acuity in children, which suggests that in children, suppression of the OKN may be a better objective acuity estimate than induction of the OKN.

In amblyopia, OKN differs from healthy eyes.[20] Suppression of OKN is said to estimate a higher visual acuity in amblyopia, especially in strabismic amblyopia, than subjective measurements, thus overestimating visual acuity.[12,21,22] In contrast, we found SpeedWheel to correlate very strongly to E and Landolt-C symbols in our group of amblyopic patients. A difference in our study that might explain this finding is that the SpeedWheel incorporates not one but multiple suppression markers arranged in a cross across the screen. This may facilitate perception, especially in cases with an unsteady fixation. Also, patients avoiding central fixation, for unknown reasons, will invariably be exposed to a fixation target falling onto the fovea and thus suppress OKN if the resolution is good enough.

Suppression of the OKN through superimposed fixation relies on an intact central vision,[23-25] which is impaired in

Table 2. *R* and *P* values obtained when comparing E and C symbols to SpeedWheel

Compared to SpeedWheel	AMD	Amblyopia	Cataract	Refractive errors	Unknown and TAO
E Chart	$P = 0.1$ $r = 0.55$	$P < 0.001$ $r = 0.92$	$P = 0.29$ $r = 0.43$	$P < 0.005$ $r = 0.79$	No statistical analysis could be performed (n = too small)
Landolt-C	$P < 0.04$ $r = 0.67$	$P < 0.001$ $r = 0.9$	$P < 0.03$ $r = 0.78$	$P < 0.006$ $r = 0.77$	

AMD, age-related macular degeneration; *TAO*, thyroid-associated orbitopathy.

AMD and also cataracts.[26] In AMD, there is conflicting information on the correlation between the OKN response and subjective visual acuity: whereas OKN induction correlated positively,[27] OKN suppression did not.[4,5] In cataract patients, induction[27] as well as suppression of the OKN correlated well with subjective visual acuity.[5]

In our patients with either AMD or cataract, SpeedWheel correlated well to Landolt-C but not to E symbols. Both subjective tests rely on forced choice: subjects had to name the direction of the opening in the symbol. The E-symbols only offer 4 possible directions, but Landolt-C symbols include the diagonals (8 possible directions). Thus, E symbols are easier and have a better "guessing rate." Indeed, except for patients with loss of vision of unknown origin, subjective visual acuity measured with Landolt-C and especially E symbols tended to be better than values obtained by SpeedWheel. This has also been described by Reinecke and colleagues,[28] who compared 100 measurements of Snellen visual acuity to the that assessed by OKN induction. Thus, SpeedWheel appears to underestimate visual acuity measured with Landolt-C or E symbols.

This may also partly be because the best possible visual acuity measurement in the SpeedWheel was 0.1 logSWA, whereas both subjective tests could measure higher visual acuities. In addition, in patients with possible malingering, a better objective test result might be expected.

In patients with loss of vision of unknown origin, subjective visual acuity tended to be much lower compared to SWA. This agrees with the findings of Fukai and colleagues[29] and could indicate possible malingering.

In conclusion, our exploratory study supports measurement of OKN suppression as a valid means to objectively assess visual acuity in various ocular diseases and also in school-age children. In cases of malingering or noncollaborative subjects, it can be used to assess visual acuity. A larger sample size will be necessary to refine our findings, and sensitivity might be improved further by adding induction of the OKN as suggested in previous studies.[6,7]

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