A NEW DYNAMIC VISUAL ACUITY TEST TO ASSESS PERIPHERAL VESTIBULAR FUNCTION

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ABSTRACT

Objective. To describe a newly developed dynamic visual acuity (DVA) test and report a study of the test in otologically healthy subjects and patients with peripheral vestibular loss.

Design. Prospective, clinical study.

Setting. Tertiary academic center.

Participants. One hundred otologically healthy subjects (age range, 19-80 years) and 15 patients with bilateral (n=5) or unilateral (n=10) peripheral vestibular loss (age range, 27-72 years).

Interventions. Testing of dynamic visual acuity and quantitative head impulse with scleral search coils.

Main Outcome Measure. Measurement of the difference (DVA loss) between static visual acuity and dynamic visual acuity during active and passive head rotations with velocities higher than 100°/s and 150°/s.

Results. The DVA loss was significantly higher in normal subjects with velocity limits of 150°/s and during passive head rotations compared to 100°/s and active head rotation ($p<0.0005$ resp. $p=0.006$). Dynamic Visual Acuity loss increased significantly with age ($p<0.0005$, $R^2=0.04$). Using passive head thrusts and velocities >150°/s, the DVA test discriminated highly significantly ($p<0.0005$) between subjects with bilateral vestibulopathy, with unilateral vestibulopathy, and normal subjects. Test sensitivity was 100 %, specificity 94 %, and accuracy 95 %.

Conclusions. Using optimized test parameters, the DVA test procedure as described in this report enables detection of peripheral vestibular dysfunction in a fast and simple way with high accuracy.

INTRODUCTION

Gaze stabilisation during high-velocity head movements is enabled by the vestibulo-ocular reflex (VOR), which induces compensatory eye movements and stabilizes images on the retina within 10 ms[1, 2]. The VOR-induced gaze stabilization can be evaluated qualitatively by the head impulse test[3]. However, the invasive test methods of scleral search coil recording are required for a quantitative assessment of the VOR function. This technique allows calculation of the VOR gain and can be regarded as a standard in the three-dimensional analysis of oculomotor function. The main disadvantages of the search coil technique include its semi-invasive nature, the rather complex procedure and high costs.

The measurement of visual acuity during head thrusts, called dynamic visual acuity (DVA) testing, offers a relatively simple alternative. This technique is based on the findings that peripheral vestibular lesions decrease the gain of the VOR and consequently increase retinal image slip[2, 4-6]. If retinal image slip velocity exceeds 2–4°/s, then visual acuity is consequently reduced[7, 8]. Therefore, measurement of dynamic visual acuity (DVA) can give information about the VOR performance and semicircular canal function, provided that non-vestibular oculomotor mechanisms have been excluded.

Several DVA testing systems have been described[2, 4-6, 8-11]. All of these systems have in common that visual acuity was tested using the Snellen optotype “E” during head movements of different velocities. In general, the tests were based on a rather high number of short head thrusts because the algorithms of visual acuity testing were non-adaptive and varied in 0.1 logMAR steps. Only Schubert et al.[2] introduced an adaptive algorithm, which started near the middle acuity level and continued in

accordance to the patient's performance. However, about 100 head thrusts were still necessary to test the DVA.

Our aim was to design an improved DVA test, which could be used efficiently in a clinical routine and applicable as an office procedure. With a low number of head thrusts and in a short time, this DVA test should be able to screen global VOR function.

We describe the newly developed DVA test in this study and report test results in a large number of otologically healthy subjects with a wide age range. Patients with uni- and bilateral vestibular loss were also studied to evaluate and optimize the test parameters.

METHODS

Subjects

One hundred subjects (mean age 45±16 years, range 19-80 years) without otological and neurological disorders were included in the study. They were recruited from among hospital personnel, students, people who attended public lectures at the university and family members of these persons. Normal peripheral vestibular function was assured by a normal VOR gain in quantitative head impulse testing. Fifteen patients (mean age 54±13 years, range 27-72 years) with uni- or bilateral peripheral vestibular loss were recruited through the clinical practice of the otologists and neuro-otologists of the department. Criterion for a complete unilateral vestibular loss were a history of labyrinthectomy or vestibular neurectomy and/or a VOR gain of <0.30 on the affected side in search coil head impulse testing; criterion for a complete bilateral vestibular loss were VOR gains of <0.20 on both sides. All subjects

were investigated on a volunteer basis and gave written informed consent to participate in a protocol approved by the local ethics committee.

DVA instrumentation

The equipment of our DVA testing system consisted of an IBM PC-compatible computer with an external keyboard, a 19-inch LCD monitor (1280x1024 pixels, 75 Hz) and a Sparkfun velocity sensor (Sparkfun Electronics, Boulder, USA), which was fixed on a headset to the subject's head. The monitor was placed at a distance of 5 meters in front of the patient, who was sitting on a chair.

Both static visual acuity (SVA) and DVA were measured. Visual acuity assessment was performed using the standard optotype "Landolt ring" as a visual target with eight different orientations instead of the Snellen optotype "E" with only four possible orientations[12], reducing the chance performance level by a factor of two. Visual acuity was expressed as the decadic logarithm of the minimum angle of resolution (logMAR), which represents an appropriate term for statistical analysis[12]. The subjects were asked to recognize the orientation of the Landolt rings, which are displayed randomly on the monitor, and to type in the correct answer on an external keyboard representing the eight possible orientations. If the subject did not recognize the orientation, then a forced choice paradigm was required. A series of five Landolt rings was presented at a given acuity level. A positive answer was counted if at least three of five orientations were correct. Only three optotypes were displayed if the first three were recognized correctly.

During DVA testing, Landolt rings were displayed for a time period of 100 ms if head velocity exceeded a preset limit. To improve fixation during the head thrust, a small dot was placed in the center of the monitor. This dot was extinguished immediately

before the Landolt ring occurred. In the SVA test, the next optotype was displayed automatically after the patient made his or her choice. Static visual acuity testing started at a level of 0.4 logMAR, DVA testing at a level of 0.4 logMAR above SVA. With each incorrect series of Landolt rings, acuity level increased by 0.4 logMAR. If a series was correct, then the size of the optotypes decreased by 0.1 logMAR until the series was no longer recognized correctly (incorrect detection of 3 or more Landolt rings), and the test was stopped. Visual acuity was determined by the value of the second last (correctly identified) series of Landolt rings minus 0.02 or 0.04 logMAR, respectively, if one or two answers on the last (incorrect) series were correct. By subtracting SVA from DVA, the term ”DVA loss” was calculated, which is a measure of the decrement of visual acuity during motion.

DVA test protocol

Because SVA was determined first using our system, DVA testing was independent from the patient’s visus. Subjects were allowed to wear their own glasses or contact lenses during both SVA and DVA testing. Visual acuity was measured binocularly with the better eye normally taking the lead.

Dynamic visual acuity testing consisted of an active and a passive part. In the active part, the subject self generated horizontal head rotations by active movements. In the passive part, head thrusts were delivered manually by the examiner with random timing. The head thrusts consisted of brisk rotations towards the tested labyrinth and the center with a starting position of a 20 to 30° turn to the contralateral side. This kind of thrust has the advantage that it is easy to perform for both the patient and the examiner, and patients are always able to view the monitor through the lenses of

their eyeglasses. Two different blocks of velocity limits were tested, one with 150°/s and one with 100°/s.

Before starting the actual DVA test, subjects were familiarized with the DVA test and they were provided with ample opportunity to practice active and passive DVA testing to both sides.

Quantitative head impulse testing

Quantitative head impulse testing (qHIT) with search coils was performed as previously described by members of the vestibulo-oculomotor laboratory of our institution[13, 14]. Briefly, eye and head movements were analysed during head impulse testing in a magnetic coil frame using a search coil around the cornea of the right eye applied following anaesthesia with oxybuprocaine 0.4 %, and a second coil fixed to the forehead with adhesive tape. Digitized signals were computed and the VOR gain defined by VOR=1-(∆gaze/∆head), where gaze (eye-in-space) and head were evaluated when the head had turned from 3 to 7°. If the median gain was below the mean minus 2 standard deviations of results from a reference population (n = 37, 47±16 years) of the vestibulo-oculomotor laboratory of our hospital, then head impulses were graded as pathological[13, 14].

Data analysis

Data were analysed by analysis of variance (ANOVA). Post hoc statistics were performed using Tukey's test if a statistically significant main effect or interaction was found ($p<0.05$). Additionally, age effects on the DVA loss and the correlation of DVA loss and VOR gain were studied by regression analysis. Discrimination of patients from healthy subjects was examined by analysis of the z-scores for the different test

parameters. Sensitivity was calculated as the ratio of true positive and the sum of true positive and false negative test results; specificity calculated as the ratio of true negative and the sum of true negative and false positive test results. Accuracy was calculated by the sum of true positive and true negative results, divided by the sum of true positive, true negative, false positive and false negative results.

RESULTS

DVA of normal subjects

Even though the DVA loss in normal subjects during rightward head rotations showed a significantly poorer value for the overall effect than during leftward rotations ($F=7.02$, $p=0.008$), the difference corresponded to a single optotype missed for head rotations to the right compared to the rotations to the left. More significant effects on the DVA loss were attributed to the type and the velocity of the head rotations: Active head thrusts led to a lower DVA loss than passive ($F=7.480$, $p=0.006$), just as the DVA loss was lower using a velocity limit of 100°/s than one of 150°/s ($F=126.46$, $p<0.0005$). The DVA loss was significantly higher with increasing age ($F=15.37$, $p<0.0005$). However, the linear correlation in the regression analysis was low with only 4 % of the variance of DVA loss accounted by age (figure 1, p. 10).

Comparison with DVA of patients with peripheral vestibular loss

Passive head rotations (z-score=2.27) showed clearer discrimination of patients from normal subjects than active movements (z=1.24). Furthermore, discrimination was better during head thrusts of >150°/s (z=2.08) than during those of >100°/s (z=1.43).

Thus, the highest z-score (z=2.72) was yielded with passive head rotations of a velocity higher than 150°/s (figure 2, p. 10). Using these parameters, comparisons between normal subjects and bilateral or ipsi- and contralateral side of the unilateral vestibulopathic patients were highly significant ($p<0.0005$).

Healthy subjects had a mean decrement of visual acuity of 0.38±0.10 logMAR under dynamic conditions. This DVA loss was 1.40±0.29 logMAR in bilateral vestibulopathic subjects. Data of right- and leftward rotation of the heads of normal subjects and bilateral vestibulopathic subjects were pooled as there was no significant difference for the test parameters of passive rotation and velocity limits of 150°/s ($p=0.11$ resp. $p=0.98$). Unilaterally vestibulopathic subjects had a mean DVA loss of 1.07±0.19 logMAR during ipsilesional and of 0.59±0.15 logMAR during contralesional head rotation. No significant difference was present between the numbers of correct answers for any of the eight possible directions of the Landolt rings, neither for normal nor for vestibulopathic subjects ($F=2.03$, $p=0.12$ resp. $F=0.98$, $p=0.47$).

The test performance of the patients was analysed using VOR gain as measured by quantitative head impulse testing as the gold standard, age-matched norm values (mean + 2 standard deviations), and test parameters of passive rotation and velocity limits of 150°/s. Sensitivity was 100 % for both unilateral and bilateral vestibular loss. Specificity was calculated to be 94 %. The accuracy of the DVA test was 95 %.

Number of head rotations

The mean number of head rotations needed to test both horizontal semicircular canals was 39±15 for the parameters of passive rotation and velocity limits of 150°/s. Subjects without peripheral vestibulopathy needed fewer head thrusts (34±13) than patients with peripheral vestibular loss (50±14).

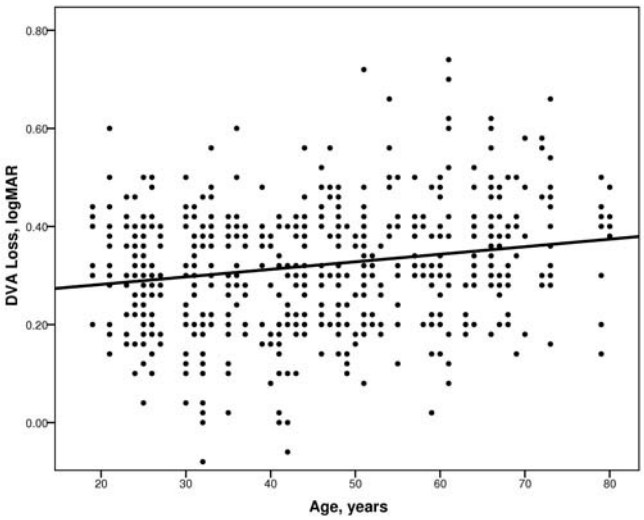

Figure 1

Dependency of the DVA loss on age. The dependency was highly significant ($p<0.0005$). The overall variance of DVA loss was high and linear regression analysis determined that age accounted for only 4 %.

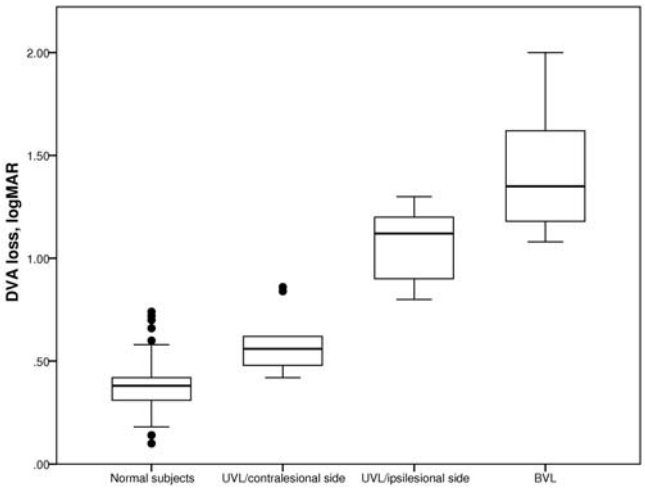

Figure 2

Boxplots of DVA loss for the normal subjects, of the contralesional and ipsilesional side of patients with unilateral vestibular loss (UVL) and of patients with bilateral vestibular loss (BVL). T-bars: 1.5 interquartile distances; dots: outliers.

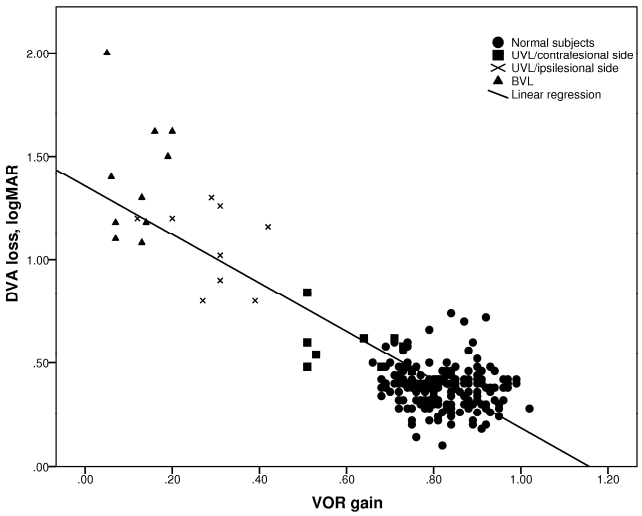

Figure 3

Correlation of DVA loss as measured with passive head thrusts >150°/s and VOR gain as measured by qHIT for normal subjects and patients with unilateral (UVL) or bilateral vestibular loss (BVL). The linear regression was significant ($p<0.0005$, $R^2=0.72$).

Correlation of DVA loss and VOR gain

The correlation of the DVA loss and the VOR gain, as measured by quantitative head impulse testing (qHIT) was significant ($p<0.0005$). Regression analysis showed a linear correlation with a R^2 of 0.72 (figure 3, p. 10).

COMMENT

We developed a new test procedure to measure DVA by optimizing several test parameters. In particular, the use of the optotype Landolt ring with eight orientations instead of the optotype E with only four, passive instead of active head rotation, and velocity limits of 150°/s lead to a DVA test with high efficiency compared to other DVA tests described in the literature. A test algorithm was designed with the aim of reducing the number of head thrusts compared to previous studies[2, 6, 10]. A peripheral vestibular loss was detected in a fast and simple way with high sensitivity, specificity and accuracy.

The reduction of visual acuity under dynamic conditions was age dependent. An age-related decrement of the VOR gain is well known, having been observed in sinusoidal rotation[15] and head impulse testing[16]. Because subjects were allowed to wear their habitual glasses or contact lenses, and the DVA loss was calculated as the difference of DVA and SVA, the age-related changes in DVA loss are unlikely to be related to a reduction of the static visual acuity with increasing age. Moreover, Herdman et al.[6, 10] also observed an even larger age dependency of the results of their DVA tests but tested fewer subjects.

Besides reducing test time, DVA testing during passive (unpredictable) head thrusts with a velocity higher than 150°/s enabled the best discrimination of healthy and vestibulopathic subjects compared to our other parameters.

During predictable active head rotations, non-vestibular oculomotor mechanisms may augment the VOR gain. Such non-vestibular contributions to gaze stabilisation mainly consist of anticipatory slow eye movements and preprogrammed catch-up saccades with short latencies[4, 5, 10]. Catch-up saccades during unpredictable head thrusts have latencies of 100-180 ms[5, 17] and prevent the recognition of Landolt rings within the display period of 100 ms in case of a deficient VOR gain. In contrast, latencies during predictable head movements are shorter (30-100 ms)[5] and might contribute to gaze stabilization within the stimulus presentation period. Even though DVA testing during active head rotations was a less sensitive screening of VOR function than passive rotations, it might have potential for measuring central adaptation following vestibulopathy.

One reason for the lower DVA loss in healthy subjects and the poorer discrimination of normal and vestibulopathic subjects using the velocity limit of 100°/s may be the push-pull mechanism of the semicircular canal function. Both horizontal semicircular canals contribute to the VOR function during head rotations of lower velocities. The contralateral afferents are inhibited with increasing velocity and are gradually driven into inhibitory cutoff[17]. The effect of the contralateral semicircular canal is decreased significantly during velocities higher than 150°/s compared to the lower velocity limit of 100°/s.

Neither the detection of a peripheral vestibular hypofunction nor the possibility of measuring the adaptation on a peripheral vestibulopathy by active DVA testing have been studied adequately yet. This will be the aim of further work, together with

improvements of our test algorithm and its adaptation to also test the anterior and posterior semicircular canals.

CONCLUSION

Our new DVA test procedure enables detection of a peripheral vestibular loss with high accuracy in a fast and simple way in any hospital or office. The sensitivity and specificity were comparable to quantitative VOR measurements with search coil head impulse testing. The accuracy of the test was dependent on the use of specific test parameters. Passive head thrusts with a velocity higher than 150°/s were found to provide high accuracy. Our new test algorithm reduced the number of head thrusts and made DVA testing fast and simple for both the patient and the examiner.

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CURRICULUM VITAE

Domenic Gian Vital

von Scuol GR

28.05.1983	geboren in Luzern
1990 – 1996	Primarschule, Stadtschulen Luzern
1996 – 2002	Gymnasium, Kantonsschule Alpenquai Luzern
06.2002	Matura, Kantonsschule Alpenquai Luzern
	Schwerpunktfach Physik & Anwendungen der Mathematik
	Ergänzungsfach Biologie
2002 – 2008	Studium der Humanmedizin, Universität Zürich
10.2008	Staatsexamen, Universität Zürich
11.2008 – 05.2009	Forschungsaufenthalt
	Klinik für Ohren-, Nasen-, Hals- und Gesichtschirurgie
	Universitätsspital Zürich
	(Klinikdirektor: Prof. Dr. med. Rudolf Probst)