TITLE: **A NOVEL COMPUTER SOFWARE FOR THE EVALUATION OF DYNAMIC VISUAL ACUITY**

Running title: Evaluation of dynamic visual acuity

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ABSTRACT

Purpose: Dynamic visual acuity (DVA) is defined as the ability to discriminate fine details in a moving target. Albeit a growing interest in DVA, there is a lack of standardized, validated instrumentation and procedures for the assessment of this visual function parameter. The aim of the present study was to analyze qualitative construct validity and test-retest reliability of a novel, computer-assisted instrument (DinVA 3.0) for the measurement of DVA.

Methods: Two different experiments are presented, involving the participation of 33 subjects. The first experiment aimed at testing qualitative construct validity of the DinVA 3.0 by comparing the outcome of a series of trials consisting in different speeds, contrasts and trajectories of the target stimuli with those reported in the literature. The second experiment assessed test-retest reliability by repeating a series of trials at three different time intervals, at maximum target stimuli contrast and either high or low speed configurations.

Results: The results of the first experiment gave support to the qualitative construct validity of DinVA 3.0, as the DVA scores were found to be modulated by the speed of the moving target (high speeds yielded lower DVA), contrast (high contrast resulted in better DVA) and trajectory (DVA was better at horizontal rather than oblique trajectories). Test-retest reliability was found to be good, with a small insignificant trend towards improvement with learning.

Conclusion: The DinVA 3.0 proved to be a valid and reliable instrument for the assessment of DVA and may be considered a promising tool for both clinicians and researchers.

KEY WORDS

Dynamic Visual Acuity; Ocular Movements; Sports Vision; Visual Function

I. INTRODUCTION

Given the dynamic environment in which we live, our ability to resolve moving targets determines our performance in a wide variety of real-world tasks such as driving, flying or sports activities[1]. This visual ability is formally referred to as dynamic visual acuity (DVA), and defined as a very complex visual function that requires the observer to detect a moving target, to visually acquire it by eye movements, and to resolve critical details contained within it, all in a relatively brief time exposure[2]. As early as 1985, the Committee on Vision of the National Research Council described DVA assessment as an "emergent technique" with impressive evidence of being more predictive of performance in life than are static measures[1].

Reviews of DVA literature have been offered by several authors[3-7]. Some of most frequent findings relating external factors that influence DVA can be summarized as follows: DVA deteriorates with increasing target angular velocities[8-11]; longer exposure times lead to higher levels of DVA[12,13]; scores are better for horizontal than diagonal target trajectories[14] (a manifestation of the well-documented "oblique effect" which seems to point to a cortical origin of this anisotropy[15]); performance is enhanced by increasing target contrast[8,16-18]; and DVA is only modestly related to traditional static-acuity measures[19], even though a good SVA is a necessary condition for a good DVA[20].

Sports practice has witnessed an increased interest in DVA. Indeed, some authors have shown indicative evidence of significantly superior DVA in athletes participating in fast paced sports involving resolution of detail at high speed[21-25]. Higher DVA scores have also been associated with lower driving crash rates[26,27], and been found to improve with training[28,29]. However, notwithstanding these efforts in basic research, the generalization of DVA evaluation is not devoid of practical difficulties, with many researchers referring to the lack of an effective, standard and accepted equipment or procedure to ensure the formal and more exhaustive assessment of this visual function parameter[30,31,1].

Several research groups have attempted to develop a suitable method for the evaluation of DVA[4,19,30,32]. However, not only the standardization, but also the availability of these tests is limited as a result of the mechanical and intrinsic nature of the adopted instrumental designs[3,33]. Historically, DVA measurements have relied on instruments mostly consisting in the movement (especially rotation) of high contrast targets at a given velocity, which was gradually slowed until the subject could correctly identify the target[4,19,30]. This type of testing, however, bears little resemblance to the typical DVA stimulus encountered in daily life[3,24,34].

Modern computer-based methods have recently been developed to address this issue[33,35,36]. Among these, we developed the DinVA 3.0 software to clinically measure DVA, and we employed it in the context of elite sports performance evaluation, as well in other research studies[24,37], some of which are still unpublished.

The purpose of this article is to describe the DinVA 3.0 software, which relies on moving stimuli presented on a computer display, and to discuss its suitability for clinical and laboratory use. Contrasts, speeds and trajectories of the target stimuli are user configurable variables within a set of possible fixed values (10 speeds and 3 contrasts). The stimulus may be drawn with any image editor and the relative colour of the target versus background may be configured, by using the chromaticity coordinates in the CIE-XYZ, to simulate several visual tasks in daily life (for example a water polo ball on a swimming pool). Besides, in its displacement through the screen, the target can describe lateral, vertical and oblique, lineal or parabolic trajectories. Also, with the goal of emulating real life situations, tests can be presented at a greater distance that the 50 cm commonly used for computer work.

Additionally, and taking into account that the concept of DVA implies the union of visual acuity (VA) and speed, the DinVA 3.0 software allows for two different ways of measuring DVA, either by maintaining the same target size while progressively slowing its movement (size series) or by starting with the smallest target and, while keeping speed constant, progressively increasing its size until the lower limit for orientation discrimination is determined (speed series). Whereas for the speed series the DVA may be expressed in visual acuity units (decimal, logMAR, etc.), with indication of the employed speed (and contrast) configuration, size series requires DVA to be expressed in terms of size and maximum speed at which the orientation of the target is correctly observed. The present paper, which studied only the speed series, describes two different and complementary experiments aiming at investigating the qualitative construct validity and the test-retest reliability of this instrument.

2. EXPERIMENT I: CONSTRUCT VALIDITY

The validity of an instrument describes the degree to which measurements represent the construct proposed by the authors of the test. In order to gather empirical evidence to assess validity, the measurements of the instrument under evaluation need to be compared to those obtained with other instruments, in terms of the concepts under study, that is, construct validity of an instrument seeks agreement between a theoretical concept and a specific measuring device or procedure[38,39].

Dynamic visual acuity refers to the ability to discriminate detail in an object when there is relative movement between the observer and the object. The main factors influencing our construct validity are related to the movement of the stimulus (speed and trajectory), the spatial resolution at a given contrast and the temporal resolution (duration of each frame-stimulus and interval between two successive frames). Consequently, the appropriate optotype was selected to provide a valid measurement of static visual acuity (SVA) in different conditions of discriminability (contrast), whereupon this optotype was presented in a dynamic environment, with variations in speed and trajectory.

The validity of the DinVA 3.0 software was determined by the qualitative agreement of its measurements with those previously described in the literature regarding DVA. Thus, we hypothesized that: 1) DVA results decrease with contrast, with a direct relationship between both variables[8,16-18]; 2) DVA scores are inversely related to the speed of the moving target stimulus[8-11]; and 3) DVA is superior in the horizontal than in oblique trajectories[14].

Methods

Participants

A total of 33 optometry students (16 female and 17 male) from the Faculty of Optics and Optometry of Terrassa were recruited (mean age = 23.4 years; SD = 3.92 years). Participants had good ocular health and no recent history of medication or systemic diseases, as well as good distance SVA of 20/20 or better. None of the participants had any corrected myopic or hyperopic refractive error superior to 4.00 D. All participants had normal contrast sensitivity function (CSF) curves, as measured with the CSV 1000 (Vectorvision Inc, 1988) and eye movements, both saccades and pursuits (standard Hart charts) (SCCO 4 + criteria)[40].

All participants provided written informed consent and the Declaration of Helsinki tenets of 1975 (as revised in Tokyo in 2004) were followed throughout the study.

Instrumentation

Participants were tested with the Palomar Universal Optotype[41] as stimulus for spatial resolution. This optotype (see **Figure 1**) presents a broken ring similar to the Landolt C, which can adopt 8 different orientations (right, left, up, down and four diagonal) to challenge observers to choose from. The same optotype was used to measure distance SVA and DVA. A PC (3000 MHz) with a wireless keyboard served to control the experimental sequence and to receive inputs from participants. The stimulus was displayed on a 17 inch phosphor-based CRT-type computer monitor providing a spatial resolution of 1024 x768 pixels, a frame refresh rate of 100 Hz. Colour calibration of the display was managed through the Windows Color System, which aims to achieve color consistency across various software and hardware.

Procedure

DVA was binocularly measured by instructing participants to indicate the perceived orientation of the Palomar stimulus with the arrow keys of their numeric keyboard. A forced choice task with eight different alternatives (orientation of the target) was implemented, as well as a modified (only ascending) psychophysics limits method in which the size of the stimulus increased until the lower limit for orientation discrimination was determined, that is, an adaptive staircase psychometric procedure.

All participants remained sitting at 2 meters in front of the screen and had to manipulate the keyboard with their dominant hand. Every participant completed a training and familiarization exercise which consisted of a series of 10 presentations or trials in which the different conditions of the stimulus (contrast, trajectory and speed) appeared at random. No participant was excluded at this stage due to failure to complete the training exercise.

As commanded by the examiner, each speed series of DinVA 3.0 trials began with the stimulus (either in high, medium or low contrast) moving across the screen at a given speed (slow, medium or fast) and in any of the three possible trajectories. The stimulus was initially set to its smallest angular presentation (2 pixels of target gap size, or 10 pixels in total diameter, equivalent to a SVA of 0.964) and it progressively increased in size, in steps of 1 pixel every 2.3 seconds. Once the stimulus reached the edge of the screen, it reversed its trajectory. Observers pressed the corresponding key as soon as the target was large enough for them to determine the orientation of the gap in the optotype.

Each series ended when the number of correct responses reached 10, with a maximum of 13 trials in total, beyond which the score for that particular series would be zero. All participants completed the series within this limit. DVA was expressed in visual acuity units (decimal), and with indication of the experimental settings (speed and contrast configurations for each series).

As mentioned above, the experiment was conducted at three different speeds (14.1, 8.58 and 1.14 degrees/s) and three randomly presented trajectories (horizontal and oblique at 45 and 135 degrees). Additionally, three different levels of contrast against the white background of the screen (black, grey and clear grey, equivalent to 0.997, 0.54 and 0.13 respectively[42]) were examined. Thus, each series consisted of 10 correct trials and a total of 270 measures (3 speeds x 3 contrasts x 3 trajectories) were necessary for each observer, which were completed in approximately 25 minutes. Room illumination and other ambient conditions remained constant throughout the study.

Results

In order to verify the influence of the three factors (speed, contrast and trajectory) on DVA, an ANOVA for repeated measures was conducted. The results of the ANOVA (3 x 3 x 3), with intra-subjects factors being speed, contrast and trajectory, revealed a significant first order interaction between contrast and speed [$F(4,128) = 2.54$; $p = 0.043$], indicating that in every condition of speed, DVA scores are influenced by the level of contrast. In addition, significant effects for contrast [$F(2,64) = 266.27$; $p < 0.001$], speed [$F(2,64) = 172.87$; $p < 0.001$] and trajectory [$F(2,64) = 9.7$; $p < 0.001$] were encountered. Thus, DVA was better at maximum contrast (DVA = 0.588; SD = 0.016) and decreased at medium (DVA = 0.521; SD = 0.017) and lowest contrasts of the target stimuli (DVA = 0.348; SD = 0.012) (see **Figure 2**). Similarly, an inverse association was evinced between DVA and speed, with lowest DVA scores at the highest speed (DVA = 0.377; SD = 0.015), and improving outcomes at medium (DVA = 0.496; SD = 0.014) and slowest speeds (DVA = 0.584; SD = 0.017) (see **Figure 3**). Finally, DVA outcomes were found to be better at horizontal (DVA = 0.603; SD = 0.1) than at any of the oblique trajectories (DVA = 0.582; SD = 0.098 and DVA = 0.579; SD = 0.094) (see **Figure 4**). No statistically significant differences were found between oblique trajectories [$t(32) = 0.27$; $p = 0.787$].

3. EXPERIMENT II: TEST-RETEST RELIABILITY

Reliability refers to the accuracy or consistency in the measure, that is, to the degree that a measurement procedure can be reproduced under the same conditions[43]. Among the various methods commonly used to assess the reliability of a test, we opted for test-retest reliability, or temporal consistency. Temporal consistency is influenced by the selection of the appropriate wash-out period to ensure that the results obtained at the retest are not partially affected by learning. Therefore, it is essential to design a preliminary test to train observers by allowing them to gain familiarity with the instrument and procedure. In the optometric context, previous literature on the reliability of dynamic eye-hand coordination evaluation dictated a minimum wash-out period of 2 weeks between test and retest[44].

In order to assess the temporal consistency of the DinVA 3.0 software and to reduce learning effects between trials the same procedure described in Experiment I was repeated on three separate occasions with a wash-out interval of between 7 and 15 days between the first (t1) and second (t2) sessions and between 16 and 36 days between the second and third sessions (t3).

Method

Participants and *Instrumentation* are coincident with those described in Experiment I.

Procedures

A forced choice task with eight different alternatives (orientation of the target stimuli) was implemented by using the modified psychophysics limits method and the experimental procedure described previously.

Two different speed configurations were presented at random (14.1 and 1.14 degrees/s). The stimuli described a horizontal trajectory on the screen and the contrast remained at its maximum value (0.997). Observers were not informed of their performance at any time during the study.

Results

Temporal consistency was assessed with the Pearson correlation coefficient. Statistically significant correlations in the DVA scores were found between any pair of temporal intervals for high ($r_{t1/t2} = 0.78$; $r_{t1/t3} = 0.92$; $r_{t2/t3} = 0.77$; all $p < 0.01$) and low ($r_{t1/t2} = 0.72$; $r_{t1/t3} = 0.84$; $r_{t2/t3} = 0.85$; all $p < 0.01$) speed configurations, that is, subjects obtaining good DVA results for a given speed at t1 also offered a good performance at t2 and t3. The DVA outcomes as examined with the DinVA 3.0 software exhibited good temporal stability (see **Figure 5** and **Figure 6** for the Bland-Altman plots for high and low speed configurations, respectively).

Additionally, the Student t-test for related samples failed to reveal any statistically significant differences between DVA scores at t1, t2 and t3, neither for high nor for low speed experimental settings, albeit a certain trend towards better DVA values was observed at t2 and t3 for both speed configurations.

4. DISCUSSION

The aim of the present study, consisting of two different although complementary experimental designs, was to assess the construct validity and the test-retest reliability of a novel computer-assisted device to measure dynamic visual acuity. It must be noted that a direct comparison of the present findings with those reported in the literature is challenged by the wide range of apparatus, measurement techniques, contextual stimulus conditions, characteristics of the participants and psychophysical methods employed by previous investigators, only allowing for a qualitative construct validity assessment. The need for a standardized test or procedure, a “gold standard” for the measurement of DVA is self-evident.

The findings from the first experiment depict the DinVA 3.0 software as an efficient tool for the evaluation of dynamic visual acuity, as the obtained results are consistent with the concept underlying the notion of DVA described in the literature, thus supporting qualitative construct validity of the test. In agreement with previous results[4,8,9,17], an increase in target contrast was found to lead to better DVA scores, which, in turn, were negatively affected by an increase in target speed. Indeed, the effect of the speed of the target stimulus on DVA scores was found to be modulated by the contrast between it and the background over which it is presented. Previous authors, while investigating a different range of target velocities and contrasts, reported a degradation in DVA with increasing velocity of the target stimuli, and described this relationship as a positively accelerating function with little adverse impact at velocities up to 30°/s[10,16]. Other authors documented a decline in visual acuity with increasing velocity during vertical optotype motion, to a minimum of approximately 20/200 at 100°/s[11]. Similarly, reduced contrast was found to have little effect on eye movements (one of the two factors, together with static visual acuity, traditionally associated with DVA) for target velocities below 50°/s, except for the lowest contrast levels under investigation (23%)[18]. Besides, horizontal trajectories yielded superior DVA values than either of the oblique trajectories. This last finding is consistent with results reported by other studies[14], and would give support to the well-described oblique effect in which the discrimination of an object moving diagonally tends to be more difficult than if it follows a horizontal trajectory, given the increasing complexity of the required eye movements to follow an object moving diagonally and their later acquisition through life, as well as cortical considerations[15].

The outcomes from the second experiment advocate for the temporal consistency of the DinVA 3.0 software for the measurement of DVA. Although no statistically significant differences were encountered between the different measurement intervals, a certain trend towards better DVA scores at t2 and t3 was observed, which may have arisen from a small learning effect, an insufficient wash-out period of both. This result is of relevance, as it would suggest that DVA is prone to improve with proper training, as reported by Long and Riggs in 1991[28]. In view of this finding, particular consideration must be applied to refining the initial trial protocol to improve familiarization, such as by increasing the number of trial runs as advised by previous researchers[44]. Overall, the statistically significant high correlations encountered between the different time intervals give support to the temporal consistency of the instrument.

Finally, despite the obvious advantages offered by this novel instrument, a number of weaknesses to the measurement technique need to be acknowledged, mainly arising from present limitations in our software and hardware configurations, thus preventing the implementation of the higher stimulus speeds which would result in an improvement in the ecological validity of the test. Similarly, these limitations currently impede the extrapolation of the DinVA 3.0 software to modern flat screens, laptops and hand-held devices in order to generalize its application. We believe that, once these limitations have been overcome, the DinVA 3.0 software may become a good priced, highly flexible, portable, valid and reliable instrument for the assessment of DVA.

In conclusion, the DinVA 3.0 software may be considered a valid and reliable, easy to use objective tool for the assessment of DVA. Its particular configuration and versatility allows for the evaluation of DVA in a variety of experimental and clinical settings, while offering the possibility of training of this visual function parameter. Thus, taking into account the lack of specific instrumentation of proven validity and reliability for the measurement of DVA, our aim was to present and make available to clinicians and researchers a tool which may be implemented in different contexts of everyday life, such as in sports performance evaluation or in the assessment of driving competence and road safety, in the comparison of different risk groups (cataracts, glaucoma, retinopathy, low vision, etc.), as well as in the testing of experimental hypothesis regarding the basic processes of perception of motion and others.

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FIGURES

Figure 1: Palomar Universal Optotype[35] for three levels of contrast (black, grey and clear grey, equivalent to 0.997, 0.54 and 0.13 respectively).

Figure 2: Mean dynamic visual acuity (DVA) scores (Decimal) for three different contrast levels of the target stimuli (high: 0.997; medium: 0.54; low: 0.13). Error bars are SD.

Figure 3: Mean dynamic visual acuity (DVA) scores (Decimal) for three speed levels of the target stimuli (high: 14.1 deg/s; medium: 8.58 deg/s; low: 1.14 deg/s). Error bars are SD.

Figure 4: Mean dynamic visual acuity (DVA) scores (Decimal) for three trajectories of the target stimuli. Error bars are SD.

Figure 5: Bland-Altman plots comparing the DVA between the different temporal intervals (a: t1 versus t2; b: t1 versus t3; c: t2 versus t3) for target stimuli moving at high speed.

Figure 6: Bland-Altman plots comparing the DVA between the different temporal intervals (a: t1 versus t2; b: t1 versus t3; c: t2 versus t3) for target stimuli moving at low speed.