Article ▸ # Modified Direction of DEM Test Suggests Differences in Naming and Eye Movements

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ABSTRACT

Background: The Developmental Eye Movement Test (DEM) is a screening and clinical test used to evaluate ocular motility and naming skills with respect to developmental age. The DEM test combines a vertical condition to assess naming with a horizontal condition to assess naming and ocular movements. The aim of this study is to verify the assessments of naming and ocular movement in the vertical, horizontal, or combined directions.

Method: The participants were 157 children in the age range from six to 14 years. Standard DEM cards (A, B, C) were used, together with a modified version, in which stimuli could be presented manipulating the crowding (the space between letters; crowded or uncrowded) and the direction (horizontal or vertical).

Results: Results showed that the horizontal ocular movements are faster than the vertical, regardless of crowding between stimuli. We have also shown that the time required to execute the eye movements, which represents the best predictor of movement quality, is strongly related to the classical DEM ratio score.

Conclusion: These results confirm that horizontal eye movements are faster than vertical, independent of the crowding condition. Additional information about ocular motility could be obtained by using only one direction (horizontal or vertical) and a subtractive method. Independent of these evaluations, the DEM test remains valid for clinical use because normative data permits these limitations to be bypassed.

Keywords: crowding, eye movements, DEM test, developmental age

Introduction

The Developmental Eye Movement test (DEM) is a practical and easy method for assessing and quantifying ocular motor skills in children. The DEM allows clinicians to have quantitative measures of ocular movement skills. The task consists of naming numbers in a simulated reading-like condition. The test validity has been reported in the test manuals[1-3] and has also been retested and analyzed using new statistics and methodology,[4] confirming the validity of the test in the assessment of ocular motility according to developmental age.

The DEM comprises two conditions: (i) vertical naming and (ii) horizontal reading-like. The vertical condition, as reported in the manual, is used "to assess the patient's ability to automatically convert the visual stimuli into a verbal response in the absence of horizontal eye movement."[2] This condition is designed as a baseline assessment of naming speed. In fact, this test is different from the King-Devick test[5] in that it does not take into account the naming process and is therefore not able to differentiate naming problems from ocular movement issues.[6] In the DEM, the vertical subtest involves 76 vertical movements, separated onto two test plates, with a size of 1° (at 33 cm distance) and two large diagonal movements. The horizontal subtest has 16 rows composed of five numbers; the length of each row is 19.3°, and each row is separated vertically by 1°.[1] The five numbers in each row are positioned irregularly, with only the first and last number in a fixed position. The common element in the vertical and horizontal condition is the number naming that requires rapid and continuous naming speed. The horizontal subtest requires horizontal and irregular saccadic eye movements, whereas the vertical subtest does not. The ratio between the results of the horizontal and vertical subtests provides a measure of horizontal ocular movement. The DEM test appears to be a comparison between a pure naming condition (vertical) and a condition with the same naming plus (horizontal) ocular movements. On the other hand, as reported in the manual, the DEM test "assesses rapid naming in a format requiring horizontal saccadic eye movements, whereas the Vertical Test does not."[2] Vertical presentation of numbers is selected because it is standard practice in psycho-educational tests and also because there is significant correlation of performance with tachistoscopic presentation in which eye movements are excluded.[3] In the 2nd edition of the test manual,[2] it is reported that the DEM vertical subtest and the Rapid Naming Digit Subtest are significantly related to each other, as well as to other word-naming tests. It is reported that there is also a significant correlation between the DEM subtest and naming test of words and non-words in the Italian language.[4] One limitation from this point of view is that the correlation itself is not the best statistical method of determining whether the vertical subtest is a (pure) naming test. The naming process is the basis of all the aforementioned reading tests and research, but different kinds of stimuli (numbers, words, non-words) and different visuo-spatial demands give different results. For example, if we observe only correlations, we find significant correlations also within the DEM subtest. Vertical time and horizontal time are strongly related, due to the common naming component. The manual ($r=0.75$ $p<0.001$)[3] and independent research (0.85 $p<0.001$)[4] report a strong positive correlation and significance, but this relationship does not provide confirmation that these two subtests measure the naming process specifically. As previously demonstrated, in the DEM, the contribution of naming to the total time varies from 64% for six-year-old children to up 90% for 13-year-old adolescents.[4] Experimentally, in a study which aimed to find the relationship between a performance test of ocular movements and tachistoscopic naming presentation of the same stimuli, the results show a medium to high correlation. This confirms the role of naming in eye movement testing using a visuo-verbal format.[6]

To classify a naming test, it is necessary to take into account specific characteristics of the stimuli. One purpose common to all naming tests is to reduce visuo-spatial abilities (ocular movements and visuo-spatial attention) in order to maximize the naming process. In the word naming task, it is necessary to use a vertical arrangement of words to obtain the smallest ocular movements, otherwise it is similar to a normal reading task. In the single digit naming task, it is possible to use both horizontal and vertical arrangements, because with regular spacing a single digit can be positioned very close in order to reduce ocular movements. In this way, it is possible to minimize ocular movements.

The DEM consists of vertical ocular movements (subtests A and B) and horizontal movements (subtest C). It should be emphasized that the DEM is composed of small regular vertical ocular movements, in the first part, and large irregular horizontal ocular movements in the second part. These characteristics arise from the stimuli used and can be classified as two variables, crowding and direction.

Spacing between numbers can also be defined as crowding. Several pieces of evidence have demonstrated the specific relationship between reading speed and crowding,[7,8] highlighting that the interference of spatio-temporal proximity between letters causes a reduction in letter identification[9,10] because of massive competition for processing resources.[11-13] The relationship between crowding and reading speed is nonlinear, showing a specific profile (Figure 1). Starting from the uncrowded condition (large space between letters; x axis, left), reading speed (shown on the y axis) is slow. By increasing crowding, the reading speed increases. This part of the graph is labeled "Cliff." At a specific value of crowding, the speed does not improve further with increased crowding, and the "Cliff" disappears. This part of the graph is labeled "Plateau." At a still higher specific level of crowding, the reading speed starts to decrease.

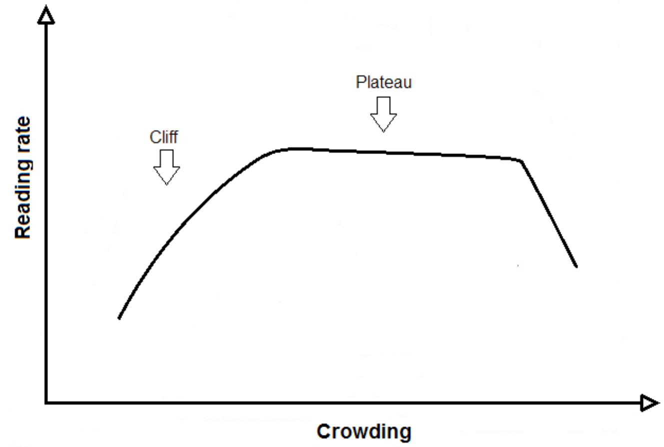

Figure 1: *Relationship between crowding and reading speed (retraced and modified from 5).*

These psychophysical observations are interesting for the following reasons:

- the results have been obtained only using the horizontal direction;
- in the Plateau zone, reading speed remains constant with increasing values of crowding
- in the Cliff zone, reading speed is related to crowding

With this theoretical scheme, a psychometric test of ocular movements such as the DEM would represent a comparison between two different conditions of crowding, one in the Plateau zone, used for assessing naming, and the other in the Cliff zone to evaluate naming and ocular movement. A basilar condition for comparison is to assess these two tasks in the same direction.

On consideration of direction, it is possible to derive different results for naming and/or ocular movement in the vertical and horizontal condition. There are several pieces of evidence that support this hypothesis. Using Rapid Serial Visual Presentation and Flashcard (two psychophysical tachistoscopic presentation methods), the naming process is faster in the horizontal direction than in the vertical.[14] Under some conditions, visuo-spatial attention appears to be equally distributed between the horizontal and vertical directions.[15] Therefore, the visual span is asymmetric to the left or right of the point of fixation[16] and smaller for vertical reading.[14] The neural control of horizontal and vertical eye movements is located in two specific and separate sites. Horizontal eye movements are generated by the paramedian pontine reticular formation, and vertical eye movements by the mesencephalic reticular formation.[17] The execution of horizontal eye

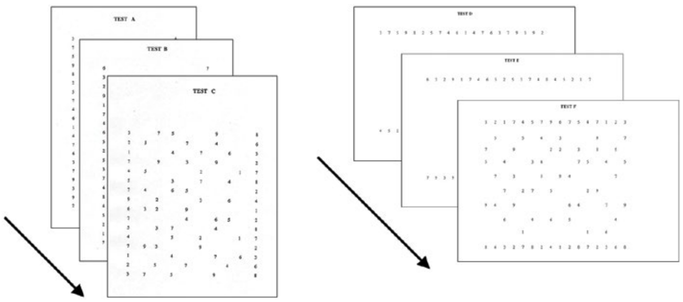

Figure 2: The 6 cards used in the experimental evaluation and their sequence of administration (ABC – DEF).

movement is performed principally by two muscles, whereas vertical movement is performed by four. Moreover, the process of acquisition of reading skills and the act of reading is itself intensive training in the horizontal direction compared with the vertical.

The authors are interested in determining whether there are differences in naming and ocular movements for different directions (i.e. only horizontal, only vertical, or mixed vertical and horizontal, such as are measured in the DEM test). In order to verify this hypothesis, the standard DEM test cards and other modified cards to assess naming horizontally and ocular movements vertically were used. These new cards are not intended for clinical use but only for this research related to the assessment of the influence of direction in ocular movement testing.

Materials and Methods

Participants

The participants were 157 children (83 male and 74 female) aged six to 14 years (mean 10.1; SD 2.4), recruited from two public schools in northern Italy. Participants were selected for the study according to the following criteria: (i) habitual use of lenses for testing (as indicated by parents; if a subject required correction but did not have one, the child was excluded), (ii) binocular visual acuity at near equal to or better than 0.8 decimal acuity, and (iii) ability to complete the battery of tests. Informed consent was obtained from the children and their parents.

Stimuli

The standard cards of the DEM (A, B, C) were used, together with a new modified version (D, E, F) in which all characteristics of the test were the same except that the direction was rotated by 90° (Figure 2). The numbers used for all cards, at the 33 cm viewing distance, represent a horizontal arc of 20.8 min and vertical arc of 31.2 min. The eighty numbers contained on each card or pair of cards are the same and are presented in the same order under all conditions. A description of the six cards is outlined below:

A and B cards

These are the standard two cards used in the DEM test. Each card is composed of two columns of 20 digits. The numbers in the column are separated by 1°. The two columns are separated by 11.5°.

Table 1: Correspondence between cards used and condition

Cards used	Condition
A and B	Crowded Vertical (CV)
C	Uncrowded Horizontal (UH)
D and E	Crowded Horizontal (CH)
F	Uncrowded Vertical (UV)

Table 2: Subdivision of conditions for spacing and direction

		Crowding	
		Crowded	Uncrowded
Direction	Vertical	Crowded Vertical (CV)	Uncrowded Vertical (UV)
	Horizontal	Crowded Horizontal (CH)	Uncrowded Horizontal (UH)

C card

This is the third standard card used in the DEM test. The card is composed of 16 rows, each of five numbers. The first and the last number of each row is in the same vertical position so that the length of the rows at 19.2° is the same. The five numbers of which each row is composed are spaced irregularly.

D and E cards

These two new cards are composed of two rows of 20 digits. The numbers in the row are separated by 1°. The two rows are separated by 11.5°.

F card

This card is composed of 16 columns, each of five numbers. The first and the last number for each column are in the same horizontal position, so that the length of the columns is equal at 19.2°. The five numbers which each column contains are spaced irregularly.

The difference between A-B and D-E cards is the direction. The numbers are highly crowded, and therefore we defined the conditions as Crowded Vertical (CV) and Crowded Horizontal (CH), respectively. The difference between the C and F cards is the directionality, and that the numbers are less crowded, and therefore we defined the conditions as Uncrowded Vertical (UV) and Uncrowded Horizontal (UH), respectively. Tables 1 and 2 summarize the characteristics of the four conditions represented in Figure 2.

Procedure

The experimental evaluation was carried out during a complete school visual screening program. Stimuli presentation was subdivided into two parts: one series of three cards was presented in the initial part of the visual screening and the

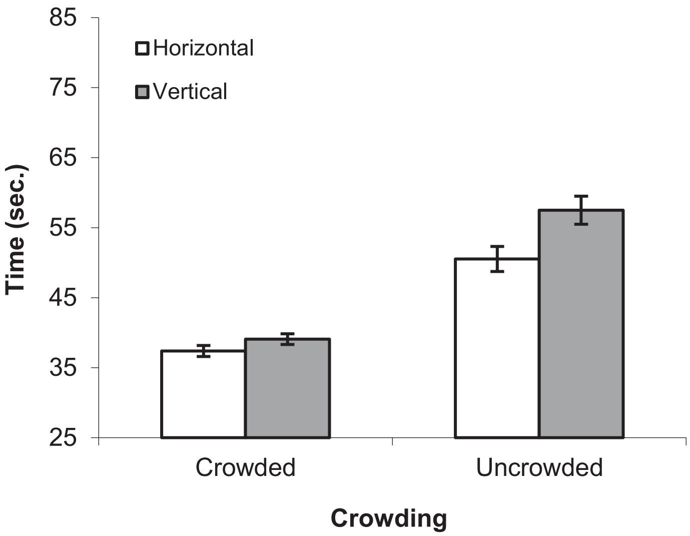

Figure 3: *Mean results for the four experimental conditions. Bars represent +/- 1 SEM.*

Table 3: Mean and standard deviation for each condition

Condition	Results
CV	39.08 (9.47) sec.
UH	50.53 (22.29) sec.
CH	37.39 (9.75) sec.
UV	57.50 (25.10) sec.

Table 4: Different type of ratio obtained from the fourth experimental condition (SD in parentheses)

UH/CV	1.26 (0.33)
UH/CH	1.33 (0.38)
UV/CV	1.43 (0.39)
UV/CH	1.50 (0.41)

second series in the final part, which took place about 30 minutes later. These two blocks of conditions were presented counterbalanced at the subjects: 82 participants performed the sequence ABC – DEF and 75 participants performed the sequence DEF – ABC. Before each sequence, a horizontal standard DEM pretest of 12 numbers was carried out.

Children were asked to read the numbers as quickly as possible. The time spent in reading each card was recorded to two decimals. For each condition, four types of error were recorded separately: additions, omissions, substitutions, and transpositions. All times recorded were corrected for errors of addition and omission using the formula for adjusted horizontal time of DEM:

$$CorrectedTime = RawTime x \frac{80}{80 - O + A}$$

where RawTime is the time measured for four conditions (A and B were summed; D and E were summed), O is the number of omission errors, and A the number of addition errors. In the analysis, we have taken into account the corrected time for errors for the four conditions (CH, UH, CV, UV).

Results

Time

The mean results of the time for the four conditions are listed in Table 3 and in Figure 3. To evaluate all conditions together, a MANOVA was used. Within factors were Direction (Horizontal and Vertical) and Crowding (Crowded and Uncrowded), and the between factor was the sequence of presentation (ABC-DEF and DEF-ABC).

The results show no differences with respect to the sequence of presentation. A significant main effect was found for Direction ($F(1,155)=49.27$ $p<0.0001$) and Crowding ($F(1,155)=154.59$ $p<0.0001$). In addition, significant interaction for Direction x Crowding ($F(1,155)=18.86$ $p<0.0001$) was found. A single comparison using the t-test showed that differences between all conditions were significant (all <0.0001).

The CH time was significantly shorter than CV time (mean CH=37.39; mean CV=39.08; $t(156)=5.03$ $p<0.0001$). This result suggests the role of direction in naming time: naming numbers horizontally is generally faster than vertically. The UH time was significantly shorter than UV time (mean UH=50.53; mean UV=57.5; $t(156)=5.86$ $p<0.0001$). Compared to the naming condition, we have found the same trend: performing an ocular movement in the vertical direction is slower than in the horizontal. The interaction between direction and spacing shows that the naming process itself is not the only cause of the slower time in the UV condition, but the ocular movement also seems to be slower.

Ratios

To demonstrate the role of ocular movements, we used the ratios between the crowded and uncrowded conditions. We tested ratios not only within the same direction, but also between different directions (similar to a DEM test). Ratios and the mean results were calculated individually, and the means are reported in Table 4 and in Figure 4.

The values of the Ratios confirm the previous results reported in studies of time evaluation. In the horizontal direction, the mean was 1.33 (SD 0.38), and in the vertical it was 1.43 (SD 0.39). Mixing the direction for the two conditions of crowding, the results appear lower (UH/CV = 1.26) or higher (UV/CH= 1.50), due to the vertical time generally being longer than the horizontal. To test the difference between the Ratios, a one-way ANOVA was performed. The results are significant ($F(3,468)=41.58$ $p<0.001$). A direct comparison between each single ratio using the t-test shows a difference between all ratios ($p<0.0001$). A comparison between the data for the same direction gives more uniform results than for when the two directions are mixed, where the results are higher or slower.

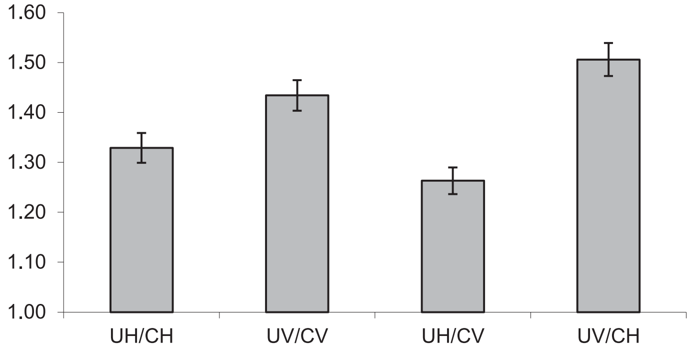

Figure 4: *Ratios between the two conditions of crowding. Bars represent +/- 1 SEM*

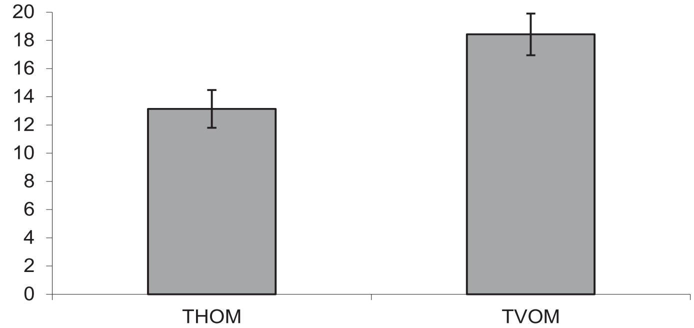

Figure 6: *Time to execute ocular movement in horizontal (THOM) and vertical condition (TVOM). The difference was significant (p<0.0001). Bars represent +/- 1 SEM.*

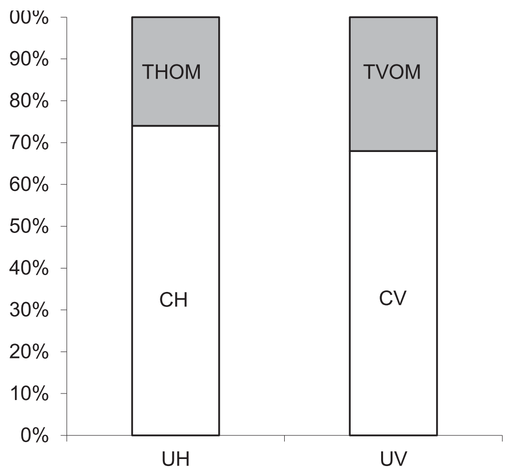

Figure 5: *Decomposition of the total time of uncrowded condition in naming and ocular movement time. Bar height does not represent the time and is not to scale.*

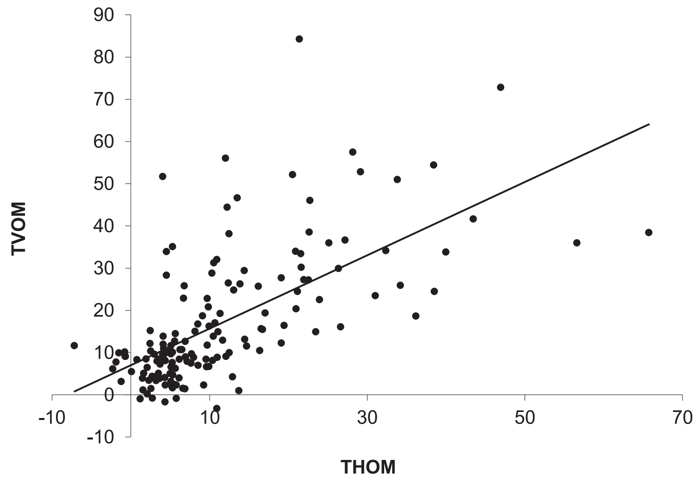

Figure 7: *Relationship between vertical and horizontal ocular movement evaluated by subtractive method.*

Subtractive Method

If we compare two conditions in the same direction, one with naming and the second composed of naming and ocular movements, it is easier to obtain an absolute value of ocular movement, subtracting the crowded from the uncrowded condition. On the other hand, with the subtractive method[16] it is possible to evaluate better the Time spent in executing the Horizontal Ocular Movements (THOM) and the Time for Vertical Ocular Movement (TVOM).

These times were calculated with the following formulae:

THOM = UH – CH

TVOM = UV – CV

The mean value for THOM is 13.13 sec. (SD 16.77) and represents 25.99% of the UH time. The mean value for TVOM is 18.42 sec. (SD 18.47) and represents 32.03% of the UV time (see Figure 5 for full comparisons).

A comparison between THOM and TVOM shows a significant difference between the two directions ($t(156)=4.25$ $p<0.0001$), highlighting that even with this specific method there is a difference in execution time between these two directions of ocular movement (Figure 6).

This analysis of the data for the two directions is useful in assessing whether they are related (Figure 7). The results show that the correlation between the two directions has a medium value ($r=0.61$ $p<0.0001$). To verify the power of this relationship, a partial correlation was performed to remove the common component due to age. The results show a significant correlation of $r=0.42$ $p<0.0001$.

Relationship between subtractive method and UH/CV ratio

To assess the relationship between the subtractive method and the UH/CV ratio (similar to the classical DEM evaluation), a correlation between the two variables was performed. The results show a correlation of $r= 0.95$ $p<0.001$ (Figure 8). To confirm this result and to exclude the influence of the covariation caused by age, a partial correlation corrected for age was performed ($r=0.93$ $p<0.001$).

Discussion

The aim of this study was to explore whether the DEM is significantly affected by the direction in naming and eye movement processes. For this purpose, we used traditional standardized DEM test stimuli, controlling crowding and direction as experimental variables. Crowding was subdivided into a crowded condition (used as baseline) and an uncrowded condition. Compared with the standard DEM test, we have added two other conditions to complete the paradigm and

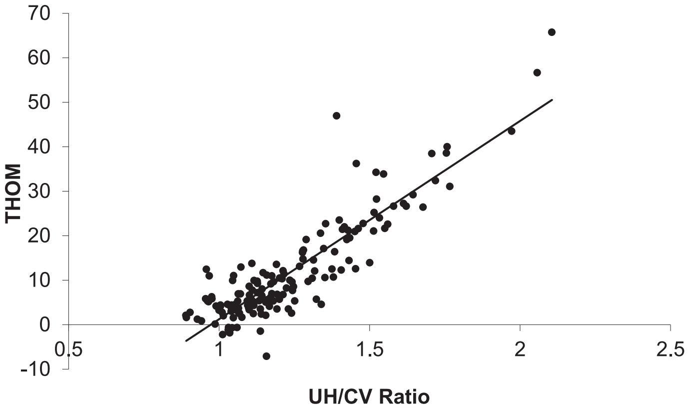

***Figure 8:** Relationship between subtractive method and standard DEM Ratio as UH/CV.*

to assess ocular movements in the horizontal and vertical directions. We have not used the term "naming" because the crowded conditions (H and V) are not pure naming conditions, obtainable only with a sophisticated technique known as Rapid Serial Visual Presentation, without ocular movements.[17,18] The crowded condition can be defined as a condition with minimal ocular motility demands. Conversely, the uncrowded condition has high ocular motility demands. In a graph that shows the relationship between crowding and reading speed, these two variables correspond to Cliff and Plateau zones (Figure 1). The comparison between these conditions provides us with a value of quality of ocular movements. This evaluation was assessed in both horizontal and vertical directions of ocular movement. Taking into account the crowded condition and comparing vertical and horizontal directions, we found that the horizontal time was significantly shorter than the vertical. This result leads to several considerations, arising from some parameters that differentiate vertical and horizontal eye movements. As discussed in the Introduction, there are many factors, but an important source may be the distribution of asymmetric visual span in the two directions considered.[18] Similar results have been obtained by comparing horizontal and vertical reading:[17] horizontal reading was faster than vertical by an average factor of 1.32. Using a very different method and different stimuli, we have obtained a lower factor of 1.05, but one which follows the same trend.

Therefore, the so-called naming condition applied in the DEM cannot be considered to be a pure naming condition, because as viewed, it would be known as "a condition with limited ocular movements" and moreover, in the vertical direction (the DEM A and B Cards), the time spent in naming crowded numbers is significantly longer than in the horizontal one. In the uncrowded condition, when large and irregular ocular movements are required, there is a similar behavior (i.e. vertical eye movements are slower than horizontal).

The ratio obtained from the four conditions shows that the comparison is better when it is made with the stimuli in the same direction. Mixing the conditions reduces (UH/CV) or increases (UV/CH) results. The DEM uses the mixed orientation condition UH/CV.

If we use a subtractive method, we can observe the ocular movements in the two directions in a better way than by using ratios. With this method, is possible to obtain the time spent in executing ocular movements in an uncrowded, compared with a crowded, condition. This procedure is possible only when the direction of eye movement is the same. The results obtained with this accurate methodology have shown that vertical ocular movements are always slower than horizontal. Although the two directions of ocular movements show different times to execute a similar task, there is a medium to high relationship between the two directions ($r=0.61$ $p<0.0001$).

To link these results to clinical use of the DEM, the comparison between THOM and classical evaluation of the DEM test (by ratio UH/CV) shows a very close relationship. The data have a common 90% variance, which is very high. This result and the proportionality shown by the relationship between THOM and TVOM provide confirmation of the validity of standard DEM evaluation. On the other hand, although the DEM test uses two different directions for crowded and uncrowded conditions, their specific norms (for both crowding and direction) can bypass these limitations.

In summary, because there are specific norms for each condition, the DEM test remains a valid tool in the assessment of ocular motility in a reading-like condition.[4] The use of one direction to assess ocular movements and the subtractive method permits better results to be obtained and a higher content validity.

Inconsistent results, a link to reliability?

A limitation that became evident during the course of this research, and which is clearly visible in the results from the subtractive method, is that we found the uncrowded time to be smaller than the crowded, and consequentially, the time spent in executing ocular movement becomes negative. This can also be demonstrated by a ratio where the value is less than 1. This result is aberrant and in theory not possible. If we consider the structure and the data of the DEM test, it is possible that the vertical time could be higher than the horizontal, and could give these aberrant results. Some published research also clearly shows this outcome.[19-21] However, in this experimental evaluation, using the same direction and the adjusted time for all conditions (the classical DEM evaluation needs correction only for horizontal time), we found the same inconsistent results (Figure 7 and 8, below zero for the two directions). The anomalous results may be due to the absence of a true pretest specific for all conditions that permits knowledge of a task to be acquired and the skill tested to be stabilized. The DEM has a pretest, but it is very aspecific and is used to assess the basic skills for the execution of the test, not to gain familiarity with specific visuo-spatial demands of subsequent tests. For example, in an Italian version of the Rapid Automated Naming test,[22] each table has a specific pretest and the instructions specify that only when the subject has learned the instruction and is able to execute the pretest without interruption is it possible to assess the test. This second type of pretest permits a subject to learn the specific task required and the performance to become regular before the test commences.

Because tests were always submitted in the same sequence (i.e. first crowded condition (A and B cards) and after uncrowded (C card) the incoherent results could be ascribed to a lower first crowded condition. It is clear that only a few subjects manifest this behavior, but it is necessary to understand why it happens.

The same effect could also be connected with the reliability of the test, because the second repetition of the naming task appears to produce better results.[23] If we consider the definition of reliability as a quality of test scores that suggests they are sufficiently consistent and free from measurement error to be useful,[24] the DEM shows good reliability,[1,25] but two specific studies have shown that the DEM test has a high reliability for Vertical Time and Adjusted Horizontal Time but poor reliability for Ratio and Errors.[25,26] For this reason the author of the DEM test in the last edition of the manual[2] and others[25,27] recommend multiple administrations to assess a definitive diagnosis.

Reliability (test-retest) can tell us that a subject who performs poorly the first time will also do so the second time. At the same time, subjects who perform well the first time will also do so the second time. A different type of correlation (ICC, Pearson r and partial) returns high results that are interpreted as a high degree of reliability.

Otherwise, with correlation it is impossible to assess whether during the second performance there are ameliorations, stabilizations, or worsening of performance. For this evaluation it is necessary to compare the mean results with a t-test or ANOVA. Experimentally, in the standard DEM, there are results of amelioration during the second execution of the test[6,26,28] at a different retesting time.

Conversely, it is possible to obtain stabilization of the results up to the second session, if the first appears to be a pretest, which is a useful method of stabilizing the results[5] when required. In fact, the authors,[2] in the case of inconsistent or pathological results, recommend that the test be run twice, which is a simple solution to this problem. However, the normative data acquired for all languages lose their diagnostic efficacy because they are specific to the first evaluation.

Similar results were obtained in research where the DEM test was performed in standard (ABC) and in reverse sequences (CAB). The results show a significant difference in the Ratio of results for the two sequences of presentation but not in test-retest. The limitation of the number of subjects (18), age groups, statistical method applied (only mean comparison), and only the report of Ratio limits the scope for drawing definitive conclusions from these results.[29]

The problem of inconsistent data, linked to stabilization of results, reliability, and the relationship to normative data, is an important question, shown in the literature and confirmed by this research. Clearly, further studies are necessary to confirm these hypotheses.

Conclusion

Stimuli and methodology used by the DEM test allowed us to confirm that horizontal ocular movements are faster than vertical. We found that the crowded condition is sensitive to direction, showing a short time for naming execution in a horizontal array. Moreover, using the same direction, it is possible by the subtractive method to assess ocular movement better. If we link these results to the standard DEM test, we find some limitations. Vertical naming is not the fastest naming condition, and better results are predicted if the test is performed by using the same direction and subtractive method. Since the vertical and horizontal eye movements are strongly related, and with precise normative data for each condition and language, the DEM test remains valid in the assessment of ocular movements according to developmental age.

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