

EFFECTS OF LEARNING AND ATTENTION ON THE DEVELOPMENTAL EYE
MOVEMENT (DEM) TEST

by

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ABSTRACT

This review investigates the influence of learning effects and attention on the repeatability of the Developmental Eye Movement (DEM) Test. The DEM test is a widely administered test for evaluation of saccadic eye movements and visual-verbal automaticity. Review of pertinent literature suggests that the DEM Test has been found to have poor repeatability characterized by improvement of scores in subjects. These improvements were commonly suggested to result from learning effects and/or attention levels. The overall conclusion from this review is that the DEM Test, like some of its predecessors, has poor repeatability due to influences from factors such as attention and the effects of learning. However proper environment and instruction can negate the influence of these factors on test performance.

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The DEM test is a widely administered test for evaluation of saccadic function and visual-verbal automaticity. The combination of eye movements, visual input, attention, and memory are required for the function of reading. Eye movements required during reading include short saccades, fixations, and regressions.¹ Saccades are fast horizontal eye movements that align the eyes with visual targets. Saccadic eye movements must be precise for proper derivation of visual information, such as letters and numbers, when reading.² Examination of individuals with poor reading ability frequently reveals abnormal eye movements, or oculomotor dysfunction (OMD). These erroneous movements include increased normal and regressive saccadic movements, and a longer time spent at each fixation. There is literature confirming that poor saccadic oculomotor control is associated with poor reading. However, the extent to which this degrades an individual's reading ability is still debated.³ The process of oculomotor control development is slow, and the detection of any delay is necessary for the prevention of reading and associated academic problems.⁴

The correlation between oculomotor function and reading ability led to the need for tests to evaluate a patient's eye movements to allow for intervention and treatment of individuals found to be developing abnormally. Of the many formats of testing developed to address the need for this evaluation, the standardized timed visual-verbal oculomotor tests simulate normal reading conditions while allowing for quantitative measuring of eye movements. These tests also have the benefits of being relatively inexpensive, and can be easily administered regardless of location. Early visual-verbal oculomotor tests included the Pierce Saccadic test (1972), the King-Devick test (1976), and the NYSOA King-Devick test (1983). These saccadic eye movement tests assess oculomotor function by

quantifying the speed and accuracy with which an individual can locate, recognize, and recite a series of targets.⁵ They were developed during a time when it was assumed that reduced reading speed is directly linked to OMD.

Rapid Automatized Naming (RAN) skill, also known as visual-verbal automatic calling skills (automaticity) develops as an individual is introduced to and memorizes a larger amount of symbols. RAN is the performing of mental actions such as symbol recognition and recital with minimal attention.^{4, 6} With improved RAN skill, more attention is available for processes such as comprehension. RAN deficiency is commonly found among those with poor reading performance. RAN deficiency can inhibit the ability to perform well on visual-verbal oculomotor tests due to the extended time it takes for a patient to name presented numbers. Early tests did not assess the subjects' RAN skills.⁷ It was determined that the cause of poor test results could not be differentiated between saccadic OMD and deficient RAN skills by these early tests.^{3, 4, 7} Oride, Marutani, Rouse, & DeLand (1986)⁸ investigated the repeatability of these tests and found significant variation of an individual's performance between separate administrations.⁷ This poor repeatability was determined, in part, to result from learning effects.¹⁰

Garzia, Richman, Nicholson, and Gaines (1990)¹ introduced the Developmental Eye Movement (DEM) Test as a new saccadic eye movement test in 1987. The DEM also requires the patient's visual system to use fast saccadic eye movements to process information about positioning and detail of test images while providing the ability to rate an individual's performance.⁹ The DEM Test was designed to diagnose saccadic OMD by measuring and controlling for RAN and removing its effect on the measured visual-

verbal oculomotor function.⁶ Thus, patients with OMD could now be separated from those with RAN deficiencies.^{5,9} This was accomplished by incorporating an additional vertical test to assess a patient's RAN skill.³

The DEM consists of a pre-test and three sub-tests (Test A, B, and C) displayed on four individual test cards. The patient is instructed to read each test aloud, as fast as possible. The numbers are read aloud to replicate the motor activity of reading. The examiner times the individual on each section to induce any sense of pressure felt during reading.¹⁰ The pre-test consists of ten equally spaced single digits. This test allows the examiner to determine if the child both understands the instructions and can verbally name the presented digits without difficulty. Tests A and B are vertical tests and are comprised of forty numbers each. Each tests' numbers are presented in two separate vertical columns of twenty numbers with equal spacing between individual digits. This vertical presentation does not require patient's to perform horizontal eye movements, and determines RAN ability. The third subtest consists of the same eighty numbers as Tests A and B displayed over sixteen rows of five numbers each. The first and last digits in each row are aligned vertically. The internal three number of each row have variable spacing between them. This horizontal presentation requires both control of horizontal eye movements and efficient RAN skill. In addition to the examiner recording the time required to complete Test C, the amount and type of errors made are also recorded. Errors include; omissions, additions, transpositions, and substitutions. The DEM test is scored in four ways upon completion. The vertical time score is the addition of the total time taken to complete Tests A and B. This score represents the subject's baseline RAN skill by determining the time required to recite all eighty numbers without the use of horizontal

eye movements.⁴ A low vertical time score is representative of a RAN deficiency.⁶ The horizontal time score is the time required to complete Test C and has been determined to correlate with reading ability. Poor saccadic eye movements yield a longer horizontal time.³ This score is then adjusted by the amount of omission and addition errors made in Test C. The error score is the total amount of errors in Test C. The ratio score is derived by dividing the horizontal adjusted score by the vertical score. The resulting ratio is the comparison between oculomotor and RAN skills, and it assists in differentiating between OMD and a RAN deficiency by eliminating the RAN ability.^{7, 9, 10} Ideally, calculating this ratio should yield a value of 1.0.^{2,4} A ratio score of 1.0 is found when Tests A and B are read in the same amount of time as Test C. This ratio score would suggest that horizontal saccadic eye movements did not impede the patient's test performance. High ratio scores are representative of saccadic OMD.^{3,4,6,9} A normal ratio found in the presence of increased vertical and horizontal test times is indicative of deficient RAN skill.³ Tables of norms were provided to determine the percentile rank of each score among appropriate age groups.¹¹

The DEM test was designed as an improved visual-verbal measure of saccadic function over its predecessors by controlling for automaticity. While this goal was accomplished by the incorporation of a vertical test component, it was the only problematic criteria addressed by its developers. The first paper regarding factors affecting reliability of early tests such as the Pierrce and King Devick available in the databases was published only one year before Garzia, et al.'s (1990)¹ work. There were no additional components identified by the developers of the DEM intended to negate the effects of task learning, or other factors, on test performance. Due to the poor

repeatability and reliability from effects such as task learning and attention of the early visual-verbal tests, it is hypothesized that the same effects will cause poor repeatability of DEM test results as well. This paper will review the available literature on factors affecting the repeatability of the Developmental Eye Movement Test.

Garzia, et al. (1990) evaluated the repeatability and validity of the DEM Test results. Their study sample included forty children between the ages of six and eleven. To determine repeatability, the authors employed Pearson product moment correlation coefficients (r). The authors found the test-retest repeatability to be good for both the vertical ($r = 0.86$) and horizontal ($r = 0.86$) time scores. The error score's repeatability ($r = 0.07$) was found to be poor. The consistency of the ratio score ($r = 0.57$) was determined to be fair to good (Garzia, et al. 1990). This fair to good rating was a marked improvement over early forms of visual verbal oculomotor tests. These findings suggested the DEM Test could assess oculomotor function with consistent results among individuals. Overall, the researchers found good repeatability of results, suggesting that external factors had no influence resulting in variation of scores. However, one of the limitations of their study was a small sample size.

Rouse, Nestor, Parot, and Deland (2004) also investigated the DEM Test's repeatability on thirty third grade students and then repeated the test once more after two weeks. In analyzing their gathered data, the authors used the Pearson correlation coefficients to allow for a direct comparison of Garzia et al.'s, (1990) findings. They also measured the repeatability of the DEM Test by calculating intraclass correlation coefficients (ICC). ICCs range from 0 to 1 with 1 indicating perfect reliability. Intrasubject repeatability was determined by deriving Bland-Altman 95% limits of

agreement (Loa). The Loa provides an estimate of the differences between an individual's scores from test to retest. The Pearson correlation coefficient results were found to be much lower for horizontal ($r = 0.65$), vertical ($r = 0.56$), and ratio ($r = 0.26$) scores. The results of the test-retest repeatability with the use of ICCs were found to be fair to good for both the vertical (ICC = 0.60) and horizontal (ICC = 0.55) time scores. However, the consistency of the ratio score (ICC = 0.27) was determined to be fair to poor. The variability of individuals scores was found to be large for horizontal (loa = -4.2 ± 16.5 s), vertical (loa = -8.3 ± 17.4 s), and ratio (loa = -0.08 ± 0.39) scores. A clinically and statistically significant number of participants were found to have better vertical, horizontal, and ratio scores on the follow-up test. Specifically, the improvement of vertical and horizontal scores at retest led to the poor reliability of the ratio score. The authors determined from the developer's normative data that a change in ratio score of magnitude 0.39 for their study population would move an individual from the 15th to the 90th percentile resulting in a failing score first, then a passing score, or vice versa. They suggested that any variation in ratio score cannot be attributed to therapy unless it is larger than the maximum normal variation of 0.39. Their findings led them to question the value of the DEM Test as a clinical diagnostic test of OMD and/or RAN deficiency or monitoring tool of oculomotor function due to the poor repeatability of the ratio score. The authors proposed these large variations could be secondary to learning effects as Oride, et al. (1986) had found with earlier tests, or from the patient's level of visual attention as proposed by Coulter and Shallo-Hoffmann (2001). While comparing the results of both studies, these authors were aware that differences in population demographics allowed for some variance in the analyzed data. The intrasubject variability

between their study and Garzia et al.'s (1990) study was comparable and the authors concluded that Garzia, et al.'s (1990) high correlation test-retest results were possibly masking this variability (Rouse, et al., 2004). Overall, the findings of Rouse et al. support the hypothesis that the DEM Test results have poor repeatability owing to factors such as the effects of task learning and attention. However, this study only mentioned these factors as a possibility and did not directly assess or quantify the specific effects of each factor.

Tassinari and DeLand (2005) investigated the test-retest reliability of the DEM Test when given both in an office setting, and as a school screening. The authors were aware that the ratio score repeatability of $r = 0.57$ found by Garzia was below the recommendation of Solan and Suchoff ($r = 0.80$) for tests of optometric function. Their research involved administering the DEM Test to sixty-six children between the ages of seven and fourteen on two separate occasions. The time between tests ranged from one to four weeks for individuals. Fifty-three children tested in-office, while thirteen performed the testing at their school. For the in-office group, the results of the test-retest repeatability were found to be good to excellent for vertical (ICC = 0.96), horizontal (ICC = 0.92), and ratio (ICC = 0.76) scores. The variability of individuals scores was found to be large for horizontal (loa = -11.8 ± 10.1 s), vertical (loa = -45.3 ± 34.5 s), and ratio (loa = -0.55 ± 0.45) scores. For the school group, the results of the test-retest repeatability were found to be good to excellent for vertical (ICC = 0.85) and horizontal (ICC = 0.89) time score, and fair to good for the ratio (ICC = 0.59) score. The variability of individuals' scores was found to be large for horizontal (loa = -10.87 ± 5.49 s), vertical (loa = -13.00 ± 3.77 s), and ratio (loa = -0.18 ± 0.11) scores. From the

gathered data, the authors determined that up to five percent of patients may be misdiagnosed as having OMD when using the ratio score based on the DEM Tests repeatability. The author's pointed out that these large variations between test administrations may not change a patient's diagnostic classification between pass and fail, and stated that up to 5% of individuals can improve from a fail to pass rating without therapeutic intervention. Analysis of the data found an improvement of ratio score would have to be greater than 0.55 before it could be attributed to therapy. The authors surmised that as many as 23% of individuals found to have deficient RAN may be incorrectly diagnosed. The results of these authors' school based research agreed with the poor ratio repeatability findings of the previously reviewed studies. They addressed the possibility of data interference from test delivery and examiner/examinee interactions as possible explanations for this poor repeatability. However, in a clinical setting, the ratio repeatability was found to be good to excellent. The authors stated that the more thorough interactions between the examiner and patients may have prompted a better effort on initial testing, lessening the improvement on retest and the subsequent poor repeatability findings. They also mentioned that clinical settings do provide the required quiet setting recommended for testing and may have been the reason for these findings. The authors concluded their study by supporting the DEM Test as an in office diagnostic test, but reminded the reader that the use of the ratio score for monitoring therapeutic intervention is limited by the large variation in scores due simply to chance (Tassinari & DeLand, 2005). This research article did address attention as a possible deterring factor of DEM Test repeatability, but focused primarily on testing environment. There was no mention of any improvement of scores resulting from a learning effect. The high ICC of ratio

score in an office setting contradicts the hypothesis that the DEM Test would show poor repeatability, yet the poor ICC found in the school sample supports it. This is an important finding as the DEM Test is typically administered in office when intended to diagnose OMD or monitor progress from therapy. Overall, this article offered mild support of this paper's hypothesis. One limitation of the study was the small sample size of the school based students. Also, the clinical based population of the study was not randomized.

Orlansky, Hopkins, Mitchell, Huang, Frazier, Heyman and Scheiman (2011), undertook the task of evaluating the repeatability of the DEM Test through the use of a large sample size. To control for memorization/learning effects, the authors developed three separate versions of the DEM Test. 181 subjects between the ages of 6 and 11 were administered the three versions in a randomized order at an initial presentation, then again once more at the follow up presentation. Data was analyzed for each individual age. Within session repeatability of vertical time was found to be good to excellent with ICC ranging between 0.75 and 0.93 among the age groups, horizontal time was good to excellent with ICC between 0.69 and 0.91, and ratio score was poor to good with ICC varying from 0.18-0.52 among the age groups. The authors concluded that the improved ratio scores found between tests administered on the same day is suggestive of a possible learning effect decreasing the repeatability of the DEM Test. They also determined that normal variance ranging between 0.32 and 0.58 of the ratio score can lead to misdiagnoses of OMD, stating as many as 53% of their subjects switched between pass and fail classifications. Between session repeatability of vertical time was found to be fair to good with ICC = 0.67-0.89, horizontal time was fair to excellent between 0.61 -

0.89, and ratio score was poor varying from 0.34-0.61 among the age groups. The author's determined that the use of the ratio score for progress monitoring of patients undergoing OMD therapy could yield as many as 44% of individuals showing false improvements, and was advised against. Included in the data analysis was the appropriate normal variation of each score for individual age groups that must be surpassed before the change could be attributed to therapy. This article concluded with recommending the DEM Test not be used alone when diagnosing OMD, and for clinicians to be aware of the large normal variations in scores when monitoring for improvements after therapy (Orlansky, et al., 2011). The results of these authors' research were fairly consistent with both Rouse, et al.'s, and Tassanari, et al.'s research. These findings were supportive of the hypothesis proposed in this paper. The suggestion of learning effects specifically causing this poor repeatability offers additional support, yet it was only a suggestion and concrete evidence was not obtained. A potential limitation of this study was the administration of all testing in a screening setting.

The literature reviewed prior to this point focused on determining the repeatability of the Developmental Eye Movement Test through the utilization of various methods and population demographics. Though each study was unique and the resulting data generally correlated between the studies, there were some key differences in the interpretation of the gathered data. A brief summarization and comparison of each reliability study (Table 1) is offered. In partial agreement to the hypothesis of this paper, the repeatability of the DEM Test's ratio score was found to be poor except by the developers of the test and when the test was used in an office setting. The general consensus gathered from

Table 1.

Summarization and Comparison of Reliability Studies									
		Demographics:		Repeatability of Ratio Score:			Repeatability of Ratio Score Interpretation:	Suggested Use of DEM Test:	Ratio Score Improvement Attributable to Therapy:
Authors:	Research Setting:	Population Size:	Age Range:	(r):	(ICC):	(Loa):			
Garzia, et al. (1990)	School Screening	40	6-11	0.57			Good	reliable	
Rouse, et al. (2004)	School Screening	30	3 rd Graders	0.26	0.27	-0.08 +/- - 0.39	Poor	Caution as diagnostic monitoring and	> 0.39
Tassanari and Deland (2005)	School Screening	13	7-14		0.59	-0.18 +/- - 0.11	Poor	Caution as diagnostic monitoring and	
	Office Screening	53			0.76	-0.55 +/- - 0.45	Good	Reliable as diagnostic/Caution as monitoring	> 0.55
Orlansky, et al. (2011)	School Screening	181	6-11		0.34-0.61		Poor	Caution as diagnostic monitoring and	>0.41-0.60

reviewing these articles is that the DEM Test has little value for diagnosing OMD as a stand alone screening. The research performed in an office setting contradicts this belief. However, there was only one study found performing research in this environment. Caution should be used when using the DEM test to monitor improvements of oculomotor control by all researchers other than the developers. In all instances where poor repeatability was found individual test subjects had performed better on retest administrations. Reasoning for this measured improvement on retakes included the following hypotheses; results of learning effects, variance in level of visual attention, testing environment, interactions between tester and patient, and delivery of test instructions. Support for this papers hypothesis was found in reviewing the preceding literature from the suggestion of influence from the hypothesized factors of task learning and attention. However, the prior works focused primarily on if the test was repeatable and not what affected the repeatability. Further searching through available databases

uncovered a very low number of articles with the intention of studying the specific effects of single influences on the DEM Test. The following reviewed literature aimed to evaluate the effects of attention on the Developmental Eye Movement Test.

Coulter and Shallo-Hoffmann (2001) assessed the effect attention has on performing the DEM Test by measuring the accuracy, or errors made, over time. This research was developed on the premise that visual attention and saccadic eye movements are interrelated processes. Inadequate attention was expected, by the authors, to result in slow times and high levels of errors for all sub-tests. This study had 22 participants ranging in age from 6 to 11 years old. For this study, the authors recorded the errors made in the first and second halves of the horizontal test (Test C) separately. For patients with normal results, the amount of errors made in each half were found to be equal. The results of the study found individuals with poor test results made significantly more errors during the second half of Test C. The authors deduced that this pattern of errors resulted from decreases of patient attention during test performance after eliminating other potential factors, such as fatigue and OMD. Fatigue would lead to an increase in the number of errors between the two halves by both those with normal and abnormal test results, which was not the case. OMD alone should yield equal amount of errors between the two halves of Test C, which was not found. They also concluded that inadequate attention creates deficits of high order processing that control oculomotor function. A suggestion of decreasing attention resulting in increasing errors over time in individuals with poor scores was the final proposition. The authors stated that further research is required to elicit the effects of vision on attention, and the levels of visual attention

between patients with normal and abnormal DEM Test results (Coulter and Shallo-Hoffmann, 2001). One limitation of this study was its small sample size.

Adler, Vershner, Oushomirsky, and Millodot (2004), further assessed the effect attention has on performing the DEM Test in a different way. The authors had eighteen ten to eleven year olds perform either a normal (ABC) or reversed (CAB) form of the DEM Test, then perform the remaining format one week later to eliminate any learning effect. The difference in performance on the same format between the two groups was not significant. The authors interpreted this as suggesting that one week between administrations most likely negated any learning effect. The overall ratio scores and total errors between the two formats were found to be significantly different, with the reversed format yielding a ratio score closer to one and less errors than the normal format. OMD would have affected scores of either format equally and was also eliminated from consideration. The authors concluded that attention was the reason for their research results. They believed the reversed format aroused their patients' visual attention for Test C, leading to better performance. They stated that if attention continued at the same level, vertical time scores would have been better leading to higher ratios than were observed (Adler, et al. 2004). By showing that attention does factor into the performance of DEM Test scores, this research supported the current hypothesis. This research also contradicts the hypothesis that a learning effect had no impact on test scores. This study did not assess the affect of fatigue. The results of this research were limited by the small sample size, and by an all female population.

Unlike the repeatability studies, Adler, et al. (2004) did not find an improvement of DEM Test ratio scores on retest and from this determined a learning effect was

insignificant. The authors came to this conclusion by comparing the average ratio score of the test taken at one point in time by a group of individuals to the average ratio score of the test taken at a different point in time by a group consisting of different individuals. The repeatability studies evaluated the performance by the same individuals on separate administrations, finding significant improvement, and suggesting a learning effect as a possible reason for their findings. This variation in the interpretation of results is noteworthy.

Only one other article measuring the factors affecting DEM Test results was found. Pang, Lam, and Woo (2010) studied the effects of the examiner interpretation of data, concluding that experience in administering the DEM Test can yield more accurate results. This article is worth mentioning as previously reviewed studies did suggest the examiner as a potential source for error.

In summary, a review of available literature revealed higher support than contradiction to this paper's hypothesis that factors such as effects of learning and attention cause poor repeatability of the Developmental Eye Movement Test. The addition of a vertical time component did nothing to overcome these influences. This same literature also identifies the widespread use of the DEM Test's ratio score in diagnosing OMD and monitoring the progression of improvement after therapeutic intervention, and warns against the potential invalid representation of a patient's status. Altering components identified included the hypothesized factors of learning effects and attention, as well as fatigue, exam presentation, environment, delivery of instructions, etc. The most recent DEM Test Instruction Manual includes tips for avoiding erroneous testing and also identifies possible factors leading to these errors. Factors identified

include; examiner competency, visual attention, motivation, testing environment, fatigue, health, anxiety, and attitude. The manual holds the examiner responsible for controlling external environmental conditions and also states one must be aware of the presence of internal complications, making note of any deemed to be present and affecting test performance. Furthermore, the manual suggests multiple administrations of the DEM Test for more accurate measurement of a patient's oculomotor function. The manual cited the work of Kohl, Rosenow, and Clary (1994), stating that improved performance was noted between the first and second administrations of the DEM Test to individuals, but not between the second and third administrations. It went on to state that these findings likely resulted from familiarity, attention, and anxiety. This is an interesting approach as the current manual declares the potential adverse effects that task learning may have on the test, yet advises multiple administrations. This may be due to the exhaustion of improvements from task learning after only a few administrations.

From the limited literature on the topic of specific factors affecting the DEM Test, one can easily surmise that additional research is needed. Future research should be explorative for new factors, and accurately quantify the effects of influences already identified. Perhaps the limited research of the influencing factors is due to the inability to quantify the effects of such internal factors as motivation, anxiety, and attitude. If this is in fact the case, then research is needed to determine the proper approach to eliminating the presence of these influences prior to test administration.

It has been documented that both learning effects and attention influence DEM Test performance. However, there is also documentation that the effects of learning are not significant after multiple administrations. This theory should be reconfirmed. It is

proposed that a study of attention on the DEM Test in a clinical setting be researched. This study should have a large sample size, be administered by examiners experienced in giving the DEM Test to patients, and take place in a clinical setting free of external distractions. The wide spread use of this oculomotor test in optometric clinical settings warrants this further research. The DEM Test was a proper improvement over its predecessors. An observation of minimal effects from attention on the DEM Test by the proposed study would aid in solidifying the Developmental Eye Movement Tests place in the optometric clinic.

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