MEASURES OF VISUAL ATTENTION IN CHILDREN WITH AND WITHOUT VISUAL EFFICIENCY PROBLEMS

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ABSTRACT

Research has shown a relationship between improvements in accommodative functioning and certain visual perceptual skills. One explanation for these results is that accommodative dysfunction interferes with the development of visual attention. This study compared three components of attentional ability: coming to attention, decision making, and sustaining attention in children with and without non-strabismic dysfunctions of accommodation and/or vergence. Twenty children, ages 8 to 11 years (10 boys and 10 girls) of normal intelligence participated in the study. The group with inefficient visual skills performed significantly poorer compared to the visually normal functioning group on coming to attention and sustaining attention but not on decision making. This implies that a relationship exists between dysfunctions in accommodation and/or vergence and dysfunctions of certain attentional skills.

KEY WORDS

accommodation, vergence, attention, visual perception

Certain vision therapy regimens have been found to be effective for alleviating the signs and symptoms of non-strabismic dysfunctions in the accommodative and/or vergence systems.[1-4] Cooper et al.[1] used operant conditioning and automated fusional vergence training with random dot stereograms to improve convergence. An increase in vergence ability, as measured by standard optometric procedures and by fixation disparity curves, was associated with a reduction in asthenopia. In a similar vein, Cooper et al.[2] used automated accommodative facility training for patients who exhibited accommodation dysfunction. An increase in the amplitude of accommodation was associated with a reduction in asthenopia. Lieu et al.[5] objectively measured reductions in time constants and response latencies of accommodation following standard vision therapy. Improved functioning of the accommodative and vergence systems were associated with a reduction in symptomatology.

Vision therapy for the enhancement of accommodation has also been associated with an improvement in visual perceptual skills. Weisz[6] reported a significant reduction in the number of errors on a perceptual-motor nearpoint paper and pencil task in children who completed vision therapy for accommodative dysfunction when compared to a control group. Hofffman[7] reported that improving accommodative skills with vision therapy in the 5-year to 7- years-11-month age group led to improvements in four categories of perceptual motor skills: a. gross motor and bilateral integration; b. visual perceptual, discrimination, and attention skills; c. visual motor integration and organization; d. auditory perceptual discrimination, integration and attention skills. These studies suggest that improving accommodative functioning through vision therapy results in improved perceptual motor skills. While we can only speculate as to the mechanism for this relationship at this time, one possibility is that compromised accommodative functioning interferes with the efficiency of certain components of visual information processing such as attentional skills.

For the purposes of this paper, attention is considered as one aspect of information processing and is defined as the ability to focus consciousness on a particular task.[8] However, no single definition of attention exists.[9]

Investigators have identified a relationship between poor attentional skills and learning difficulties.[10,11,12] These deficient attentional skills manifest themselves as distractibility, poorly sustained attention and poor selective attention. Additionally, Attention Deficit Hyperactivity Disorder is a recognized diagnostic classification.[13] The signs for this disorder include poor impulse control, inattention and distractibility.

Several methods of evaluating attention in children exist.[11,14] We used a model proposed by Keogh and Margolis[15] which evaluates three distinct components of attention: coming to attention, decision making and sustaining attention. Coming to attention refers to the child's ability to focus his attention on the requirements of the task. This is the ability to analyze, organize and determine salience of the stimulus field. Decision making refers to the cognitive style of the child. This represents a continuum from the child who is impulsive (a fast and inaccurate decision maker) to the one who is reflective (a thoughtful problem solver). Finally, sustaining attention is the ability to maintain attention for the duration of the task. This is the ability to not be distracted from a task over a period of time. This model was chosen because each measure of attention evaluates skills needed for effective classroom performance.[15] Furthermore, using a model which measures separately defined components of attention may reveal the effects of visual dysfunction on different aspects of attentional ability.

Brown and Wynne[16] used this model to measure attentional ability in two age groups of hyperactive and non-hyperactive boys. The Children's Embedded Figures Test (CEFT)[17] was used to measure coming to attention. The Matching Familiar Figures Test (MFFT)[18] was used to measure decision making. The Children's Checking Test (CCT)[19] was used for measuring sustained attention. Brown and Wynne found significantly poorer performance for 10-year-old hyperactive boys on all measures of attention. Fourteen-year-old hyperactive boys showed significantly poorer performance on the MFFT and the CCT but not on the CEFT. It was concluded that hyperactive boys continue to experience difficulty with concentration and sustaining effort when compared to normally achieving boys as they mature. However, the fact that coming to attention was normal in both groups of 14-year-old boys was interpreted as evidence that the capacity for perceptual analysis does improve in hyperactive boys.

There is sufficient evidence to state that vision therapy for binocular dysfunction is effective for improving such skills and will also reduce associated symptomatology.[1,2,4] A separate issue is whether improving functioning in accommodation and vergence will improve visual attention skills. However, the purpose of this study is to investigate the relationship between deficits in visual skills and various measures of attention. Each of the three components of attention were measured in children with normal and abnormal functioning in the accommodative and/or vergence systems. It was hypothesized that children with visual skills deficits would also be deficient on one or more components or measures of visual attention.

METHODS

Subjects

Subjects were chosen from the clinic population at the Southern California College of Optometry. To be eligible the subject had to meet the following criteria: aged 8-11 years, verbal IQ of 90 or above as measured by the Slossen Intelligence Test or the verbal IQ of the WISC-R, best corrected Snellen VA of 20/30 or better in each eye at 6 meters and 40 centimeters, no unilateral or alternating strabismus, no significant ocular pathology, and stereoacuity of 50 seconds or less. A total of 20 subjects participated in the study (10 males and 10 females). The experimental group was defined as children with an anomaly in the accommodation and/or vergence system referred to as "visually inefficient." The control group were children with "normal functioning" in both systems.

Procedures

All subjects first received a visual examination which included evaluation of ocular health and refractive status. Standard optometric tests for the evaluation of the accommodative and vergence systems were also performed. The protocols for clinical tests of accommodation and vergence were the standard procedures used at the Southern California College of Optometry teaching clinic.[20] For testing of accommodation, vergence and attention the subjects wore their habitual spectacle lenses, no spectacle correction, or the lens prescription for correction of significant refractive errors determined at the initial examination. The guidelines for correcting refractive errors were as follows: All hyperopia above +1.25 diopters, all myopia greater than -1.00 diopters and astigmatism greater than 0.75 diopters were corrected with lenses. The experimenter or the original optometrist seeing the patient determined the need for corrections for refractive errors between these parameters. The results of standard clinical diagnostic tests determined whether the subject was in the experimental or control group. Criteria for defining a dysfunction in the accommodative and/or vergence systems were as follows:

1. Accommodative Insufficiency (A.Ins.): A monocular push up amplitude of less than 10 diopters, or a 2 diopter difference between the eyes, and a Positive Relative Accommodation (PRA) finding of less than 1.50 diopters. A cutoff value below Hofstetter's minimum expected for amplitude of accommodation[21] was used to eliminate possible variations in test results arising from different examiners. However, none of the subjects participating in the study met the criteria for this diagnosis.
2. Accommodative Infacility (A.Inf.): A monocular finding of 6 or fewer cycles per minute (c/m) and 3 or fewer c/m in the binocular phase of the +/-2.00 D Flipper Test. These values are one standard deviation below the mean. Previous research indicates that these cutoff values are good predictors of patients who have asthenopic symptoms and have test-retest reliability (K = .477 for monocular facility and K = .655 for binocular facility).[22,23]
3. Convergence Insufficiency (C.I.): The patient must fail to meet Sheard's criterion for the phoria and vergence ranges relationship. Sheard's criterion states that the blur point on the base-out vergence range should be twice the phoria.[24] Discriminant analysis has shown this to be a statistically significant discriminator between asymptomatic and symptomatic patients.[25]
4. Convergence Excess (C.E.): An esophoria of greater than 2 prism diopters at 40 centimeters and a reduced base in vergence range at that distance. A reduced base in range was defined as more than one standard deviation below the mean of Morgan's norms.[21] Discriminant analysis has shown that the amount of esophoria and base-in vergence ranges are a statistically significant discriminator between symptomatic and asymptomatic patients.[25]
5. Binocular Dysfunction: The patient has a near phoria in the normal range (2 esophoria to 8 exophoria) with limited base-in and/or base-out ranges.[21] A restricted vergence range was defined by evaluating the blur, break

TABLE 1.
CRITERIA FOR ASSESSING VISUAL EFFICIENCY

(All testing done at 40 centimeters.)

TECHNIQUE	PASS	FAIL
ACCOMMODATIVE SKILLS:		
Accommodative amplitude	≥10 diopters	<10 diopters
Monocular facility	>6 cycles/min.	≤6 cycles/min.
Binocular facility	>3 cycles/min.	≤3 cycles/min
NRA/PRA	≥+1.50/-1.50	<1.50/-1.50
Monocular Estimate Retinoscopy (MEM)	Plano to +1.00	Against motion or >+1.00
VERGENCE SKILLS		
Base-In	>9/16/8 PD	≤9/16/8 PD
Base-Out	>12/15/4 PD	≤12/15/4 PD
Sensory aspect of vergence: Stereoacuity	≤50 sec.	>50 sec.

***Table 1.** Criteria for assessing visual efficiency. This table lists individual test criteria for determining the visual efficiency status of the patient (see methods sections for description).*

TABLE 2.
DIAGNOSTIC SUMMARY OF VISUALLY INEFFICIENT SUBJECTS

SUBJECTS PATIENT AGE (MONTHS)	
97	A.Inf.:10/9/0 c/m; C.E.: B.I. X/4/0, 3 EP
102	A.Inf.: 10/9/2 c/m
106	A.Inf.: 4/4.5/1 c/m
106	A.Inf.: 0/0/0 c/m; C.E.: B.I. X/10/-6, 12 EP
107	A.Inf.: 4/4/2 cm; C.I.: B.O. 22/34/18, 12 XP
110	A.Inf.:5/4/2 c/m
113	B.D.: B.I. X/10/4
114	A.Inf.:8/7/3 c/m; C.I.: B.O. 8/20/24, 6 XP
116	A.Inf.: 7.5/7.5/2.5 c/m
132	A.Inf.: 8/9/0 c/m; C.I.: B.O. 4/30/16, 10 XP
133	A.Inf.: 4/8/8 c/m; B.D.: B.I. 8/14/8, B.O. X/9/4

***Table 2.** This table lists the diagnoses for subjects in the visual inefficiency group along with the diagnostic test findings supporting each diagnosis. A.Inf.= Accommodative Infacility; A.Ins.= Accommodative Insufficiency; C.I.= Convergence Insufficiency; C.E.= Convergence Excess; B.D.= Binocular Dysfunction; numerical values preceding c/m are for right eye, left eye and binocular performances in the +/-2.00 D Flipper Test; EP = Esophoria; XP = Exophoria; B.O.= base-out vergence range; B.I.= base-in vergence range.*

and recovery findings. Both a limited blur or break and recovery were required for the diagnosis. The prism diopter vergence ranges used as the cutoffs were one or more standard deviations below the normal, as determined by Morgan.[21]

Table 1 indicates the relevant numerical test findings used to make these diagnoses.

Criteria for the control group were as follows:

To be considered "visually efficient" the subject had to meet the pass criteria for both accommodation and vergence (see Table 1). However, clinical judgment was used if an isolated finding was deficient. If a single finding was deficient but the subject did not meet the criteria for a diagnostic syndrome described above, he was considered visually efficient. Thus a patient would be classified as visually efficient if he showed a low recovery on one vergence range but all other findings were normal.

Eleven subjects (five males and six females) were diagnosed with an anomaly of accommodation and/or vergence systems. Nine subjects (five males and four females) met the passing criteria for these functions. The mean age of the visually inefficient group was 9.36 years (SD 0.94 year) and for the normal group was 9.58 (SD 1.0 year). Two subjects in the control group did not receive all tests but results on other tests clearly indicated that they would not have been defined as visually inefficient according to the criteria listed above. For the one subject, the MEM finding was not taken but all other findings were normal. For the second subject, accommodative facility was done only binocularly but this finding (9 c/m) was well above the cutoff criteria for either the monocular or binocular facility finding (see Table 2). The diagnoses of anomalies in accommodative and vergence for the visually inefficient group are listed in Table 1. Subjects in the experimental group could have more than one clinical diagnosis, as indeed six of the 11 did.

The Children's Embedded Figures Test (CEFT)[17] was used to measure coming to attention. The test requires the subject to disembed a target figure from a stimulus field in a given amount of time (see Appendix A and Figure 1). The test requires the subject to focus, organize and determine salience within the stimulus field.

The Matching Familiar Figures Test (MFFT)[18] was used to measure decision making (see Appendix B and Figures 2a and 2b). The test requires the subject to determine a match between a target figure and six choices. The latency to first response and total number of errors are recorded. These measures reflect the problem- solving style of the subject. The Children's Checking Test, used to measure sustained attention in previous studies, was replaced by a visual search task because the former includes an auditory component.[19] The primary interest in the current study was to determine the effects of visual functioning on visual attention. Thus, it became important to select a task that required visual attention and would not be contaminated by an auditory component. Both the MFFT and

***Figure 1.** This is one of the practice trials from the Children's Embedded Figure Tests. The child is instructed to find the triangle embedded within the picture and indicate where the triangle is (actual test plates are in color).*

the CEFT are solely visual tasks. However, attentional deficits can affect the auditory system.[10] This could represent a confounding variable when assessing visual attention. Furthermore, a previous study[6] indicated that accommodative training improved performance on a paper and pencil task. Consequently, a similar paper and pencil visual search task, derived from a procedure developed by Ruff[26] for measuring controlled and automated attention in brain-injured

Figure 2a.

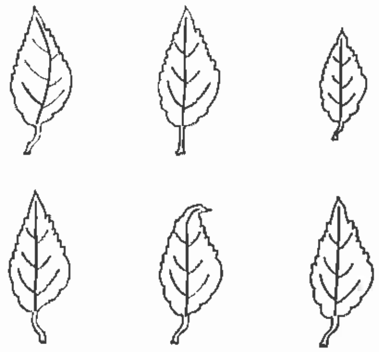

Figure 2b. *This is from the Matching Familiar Figures Test. The child is instructed to find the form in Figure 2b that exactly matches the target picture (Figure 2a) and indicate the correct response.*

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1 3 9 2 8 6 8 7 5 4 6 9 0 3 1 2 4 3 7 5 4 6 8 9 7
2 5 1 3 7 5 4 3 3 4 5 1 2 3 4 6 7 8 9 6 5 5 4 2 3
4 5 7 6 5 8 9 7 3 4 1 6 8 5 9 0 2 3 4 5 4 8 2 6 0
7 6 5 4 3 2 1 6 7 8 4 5 9 0 7 3 4 1 5 3 9 0 6 2 1
8 9 7 6 5 6 2 3 4 6 8 9 7 5 4 7 6 5 4 8 9 2 6 5 7
3 1 4 2 3 4 5 2 1 9 0 8 7 0 9 7 8 9 6 5 8 9 2 3 4
2 3 4 2 5 6 0 1 3 6 5 4 7 0 1 3 9 8 0 6 4 5 1 2 3
5 6 5 1 7 8 9 0 2 3 4 8 6 9 0 7 3 1 7 6 5 2 3 1 5
8 6 5 9 0 2 4 5 2 3 4 1 6 8 9 7 0 6 5 4 7 6 5 4 9
0 6 8 2 1 4 7 0 9 2 6 5 8 7 8 2 0 6 5 4 6 7 9 6 5

7 6 5 5 2 3 4 5 6 1 3 2 0 9 2 3 7 8 6 5 9 0 2 3 4
1 7 6 5 8 9 0 5 1 2 3 4 1 5 6 7 8 0 4 5 0 1 7 3 8
9 8 2 6 5 6 5 6 4 3 2 1 3 4 7 8 9 0 7 6 5 7 1 3 4
2 3 9 0 6 1 3 4 3 6 8 7 5 2 1 3 5 4 3 8 9 0 6 7 4
3 7 5 4 2 6 9 0 8 7 6 5 4 5 7 6 8 9 2 3 1 5 6 9 0
3 1 4 5 6 7 5 9 0 8 9 5 7 6 4 1 2 3 2 3 4 1 5 5 7
9 0 2 6 8 5 6 4 3 1 2 3 4 2 6 5 7 8 5 6 7 8 9 0 3
2 3 1 4 3 2 6 4 7 8 9 0 6 5 6 7 4 5 7 8 6 5 7 5 6
2 1 3 4 3 7 4 6 5 7 6 5 4 8 9 0 9 8 7 4 5 3 2 1 3
5 4 6 0 5 7 8 7 8 9 2 3 4 1 4 5 2 3 6 5 8 9 6 7 0
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Figure 3. *This is part of the 2 and 7 test. The child is instructed to cross out all the 2's and 7's randomly embedded in the array of numbers.*

patients, was used for measuring sustained attention (see Appendix C and Figure 3). The task requires the subject to cross out the numbers 2 and 7 each time either one occurred. These numbers are each embedded randomly between other numbers. The repetitive nature of the task requires the subject to sustain attention for the duration of the task. Performance was measured by the number of 2's and 7's crossed out in five minutes.

The three tests of visual attention were administered individually to the two groups. This testing usually was completed in one session. However, because of time constraints a number of subjects received testing in two sessions. The order of administration of the tests of attention to each subject was randomized. All testing of attention was done before any subsequent vision therapy intervention. While efforts were made to mask the experimenter's knowledge of the subject's group, logistical constraints made complete control impossible. Additionally, to avoid experimenter bias, the procedures for test administration and instructions were standardized (see Appendices A, B, C). Scoring for the CEFT was the total number correct. On the MFFT, two scores were derived: the average response time for all 12 trials and the total number of errors. For the visual search, the score was the total number of 2's and 7's that were crossed out.

RESULTS

Table 3 shows the means and standard deviations for the Children's Embedded Figure Test (CEFT), the Matching Familiar Figures Test (MFFT), and the 2 and 7 Test for the normal children and those who were visually inefficient. Additionally the data for each subject is shown in Table 3.

A t-test (two-tailed) was run for each measure of attention between the two groups. The Mann-Whitney U Test was used to validate the results of the t-test because of the small sample size and the possibility that the subject pool selected from a clinical population was not representative of the general population. On the CEFT, the t-test showed significantly more correct responses in the normal group than in the visually inefficient group ($t = -5.57$, $df = 18$, $p < .0001$). The Mann-Whitney U Test confirmed this result ($W = 42.0$, $p < .0006$). No significant differences between groups were seen for MFFT latency ($t = -0.21$, $df = 18$, p .838) or MFFT errors ($t = .28$, $df = 18$ p .783). The 2 and 7 test showed significantly more correct responses for the normal group than the visually inefficient group ($t = -2.46$, $df = 18$, $p < .02$). This was supported by the Mann-Whitney U Test ($W = 21.0$, $p < .03$).

TABLE 3.
SUMMARY OF DATA

	CEFT		MFFT				2 and 7 Test	
	Number Correct		Latency		Errors		Total Score	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Normal	17.11	4.14	17.03	8.63	8.67	4.36	139.0	28.48
Visually Inefficient	8.36	2.87	16.18	9.55	9.27	5.18	105.9	31.03

INDIVIDUAL DATA

Age (mos)	CEFT (correct responses)	MFFT (seconds)	MFFT (errors)	2 and 7 (total correct)
Normal				
97	17	25.0	17	105
101	11	35.9	2	104
104	22	18.1	10	159
114	21	7.7	13	126
115	14	9.9	9	157
121	12	13.5	8	111
122	22	15.5	6	142
127	21	12.8	6	169
134	17	14.9	7	178
Visually Inefficient				
97	7	14.0	12	27
102	14	19.6	15	98
106	8	14.1	17	121
106	7	8.9	10	142
107	8	28.7	1	94
110	6	17.0	5	104
113	6	11.0	11	109
114	7	8.7	8	110
116	10	33.6	1	106
132	12	9.3	12	146
133	15	7.6	10	106

Table 3. *Summary of data. Means and standard deviations for each test are given along with individual data.*

DISCUSSION

The results indicate that children defined as being visually inefficient performed significantly poorer on the CEFT and on the 2 and 7 Test than did normal children. This suggests that the two indices of information processing, coming to attention and sustaining attention, were different between the two groups. No significant difference was found between the groups on the MFFT.

Interpretations of the current results are limited by the small sample size since the possibility of a group bias exists particularly when analyzing a complex function like attention. Further, although subjects diagnosed with Attention Deficit Hyperactivity Disorder were excluded from this study, the experimental group could have contained subjects who had this condition but were not so diagnosed.

The finding that only coming to attention and sustaining attention was different between the groups is in contrast to the results of previous work. As previously discussed (p. 152), Brown and Wynne[16] found that decision making on the MFFT was more impulsive for hyperactive boys of both age levels, but coming to attention was significantly worse only for the 10-year-old boys. This suggests that the visually impaired group with attentional deficits in this experiment were indeed different from the hyperactive subjects in the Brown and Wynne study.[16]

A cause and effect relationship between binocular dysfunction and attentional measures cannot be made with certainty from the results of this pilot study; the groups were not matched for intelligence, academic achievement, educational opportunities and culturation. However, in view of the statistically significant relationship between two aspects of attention and visual dysfunction, the possibility should not be ignored. A plausible reason is that deficits in visual functional skills, such as accommodation and vergence, which are mediated by lower levels of the brain, provide interference when performing certain near-point visual perceptual tasks. These lower order visual functional skills normally act as essential background in the organization of the visual percept. When dysfunctional, they act as a displacement stimulus which impairs visual attention and results in the disorganization of the visual cognitive process.[27] A study by Ball and Pollack[28] indicated that degrading the visual image using neutral density and/or yellow filters significantly affected performance of adults on the Embedded Figures Test. This supports the hypothesis that low level functional deficits can affect higher level cognitive performance.

It is interesting that the MFFT did not yield significantly different performance between the two groups. This test was originally designed to define a dichotomy of cognitive style between impulsivity and reflectivity. Therefore, as a test of cognitive style it does not appear to be sensitive to dysfunctions in lower level visual functional skills.

Additional research is needed to see if these results can be replicated on a larger sample. Further, a controlled study of the effect of vision therapy on attentional ability would more fully define the relationship between visual skills and attentional ability. An improvement in visual functioning with vision therapy may result in improved attentional ability. If improvements in visual functioning are then isolated as the only difference between an experimental and control group then a cause and effect relationship has been established.

APPENDIX A
CHILDREN'S EMBEDDED FIGURES TEST
(Description and procedures)

Children's Embedded Figures Test (see Figure 1) is designed to measure the ability to perceptually disembed a defined target within a structured perceptual stimulus: "What it assesses most of all is the ability to break up an organized visual field in order to keep part of it separate from that field."[17]

The test administration starts with a training procedure where the subject is shown a triangle and told that it looks like a tent. Four triangles are presented to the subject on a separate sheet and he is told to point to the one that looks just like the triangle he was shown. There are four practice sheets and the child just correctly identifies two consecutive presentations before proceeding to the next phase.

The next part of the training phase requires the child to accurately disembed the tent from two separate pictures (see example in Figure 1). The test sequence then begins with 11 trials. If the subject answers correctly on any of the items 7-11, then the next phase of testing is started.

The second phase of testing is similar to the previous section except the triangle is replaced by a picture of a house. The subject now disembeds the house from the target picture. The subject again receives practice trials and then 14 test trials are started.

Testing is stopped if the subject has four errors in a row.

APPENDIX B
MATCHING FAMILIAR FIGURES TEST
(Description and procedures)

Matching Familiar Figures Test is designed to measure the problem-solving style of the patient.[18] The degree to which the subject is an impulsive or reflective problem solver is determined by the test. The test measures two parameters: the latency for the first response and the accuracy of the responses.

The administration of the test begins with two practice trials. A target figure is presented on one page and six figures are presented on another page (see Figures 2a and 2b). The subject is told to find the figure that exactly matches the target figure. The child must be able to complete the practice trials correctly before proceeding to the 12 test items. The time to the first response on each item is measured. The number of errors is recorded.

APPENDIX C
THE 2 AND 7 TEST
(Description and procedures)

The test was developed to measure controlled and automated attention skills in brain- injured patients.[25]

The subject is asked to use a pencil to cross out all the 2's and 7's embedded in an array of numbers (see Figure 3). The examiner crosses out the first 2 and 7 on a practice trial and then the subject crosses out the remaining 2's and 7's on the first line. If the subject randomly crosses out other numbers he is not given the test.

The subject is given five minutes to cross out the 2's and 7's on the remainder of the page. The score is the total number of 2's and 7's that were crossed out within that time. If the subject inadvertently crosses out a number other than a 2 or a 7 no credit is given for the response.

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