Article ▸ # Visual Sequential Memory and the Effect of Luminance Contrast

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ABSTRACT

Background: Standard visual acuity using reverse contrast (white-on-black) has been shown to be significantly better than standard contrast (black-on-white). We examined whether differences in luminance contrast would have any effect on a visual sequential memory task.

Methods: Forty-two subjects (23 males, 19 females) performed two tests of visual sequential memory specifically designed for this study. Each test had 16 questions. One test was presented in standard contrast and another was presented in reverse contrast. All of the test stimuli were well above visual acuity thresholds. Subjects were free from ocular pathologies, had visual acuities of 0.1 logMAR or better, and the majority (81%) were completely naïve to the standard clinical test of visual sequential memory, which is given in standard contrast. The raw scores (number correct) of each test were compared using an unpaired t-test.

Results: A significant order effect was observed, and thus, subjects' scores on the first test performed was the outcome measure analyzed. The mean scores were 11.6 [95% CI: 10.8-12.4] and 12.9 [95% CI: 11.9-13.9] for the standard and reverse contrast tests, respectively. Subjects performed significantly ($p < 0.05$) better (8.3% improvement) when the test was presented in reverse contrast versus standard contrast.

Conclusions: Reverse contrast presentation of stimuli yields a statistically significant improvement in visual sequential memory. The findings could play an important clinical role in the determination of optimal print contrast for some patients.

Keywords: contrast, memory, polarity, visual memory, visual perceptual processing, visual sequential memory

Introduction

Visual sequential memory (VSM) is a visual analysis skill within the larger framework of visual information processing.[1] It has been shown to be associated with word recognition, oral reading, and reading comprehension.[2-4] There are various standardized visual analysis tests, but a common one is the Test of Visual Perceptual Skills (TVPS),[5] now in its third edition. The TVPS provides a valid assessment of visual perceptual skills.[6,7] The VSM subtest of the TVPS has been shown to be a primary factor in using the TVPS to discriminate between learning disabled and normal individuals.[2,6] The TVPS has also been shown to discriminate between those with and without visual processing impairment among adults who have had a cerebrovascular accident.[8] Deficits in VSM have been shown to occur after brain injury,[9] in addition to the whole spectrum of visual sequelae. Visual sequential memory can improve with practice by adopting various strategies.[3,10]

While VSM may improve somewhat with passive or active learning and adopting various strategies to improve the memory itself, enhanced visual efficiency may also have an impact. While most visual acuity tests and perceptual tests use standard (black-on-white) high contrast stimuli, reversed (white-on-black) contrast stimuli have been shown to be more efficient. Westheimer found that reverse contrast visual acuity was significantly better than standard contrast in a large clinic population sample[11] and provided the rationale, based on the line-spread function, that reverse contrast actually provides a higher level of retinal image contrast.[12] Miyajima also found that visual acuity with reverse contrast charts was better than standard contrast among patients with cataracts.[13] While improvements in static visual acuity have been shown, the more practical application of reading in reverse contrast has not been shown to improve significantly in normal patients.[14] However, reverse contrast has been shown by Legge to improve reading speed in patients with low vision.[15] This improvement in reading speed with reverse contrast text is thought to be due to decreased light scatter,[15] as increased light scatter would reduce the contrast of the retinal image.

Though the primary explanation of differences found between standard and reverse contrast is likely at the retinal level, there could also be differential processing of reverse contrast at cortical levels. For instance, vernier acuity thresholds, which are well-known to be processed at a fairly high cortical level, are found to differ when using reverse contrast for one of the offset bars.[16] The so-called crowding effect, a neural phenomenon, also differs when using reverse contrast.[17]

Visual sequential memory is most certainly a cortical phenomenon, likely involving multiple sites in the brain. In this investigation, relatively young and healthy control subjects (i.e. not likely to have light scatter issues) performed a visual sequential memory task that used stimuli well above visual acuity thresholds. If a difference was found between standard and reverse contrast stimuli for visual sequential memory, the possible clinical implication would be that patients with VSM deficits could benefit from utilizing reverse contrast material.

Methods

Subjects

Forty-two subjects completed the study, having been recruited from the general campus population at the Southern California College of Optometry. The inclusion criteria included being between 18 and 35 years of age, having normal ocular and systemic health, and being able to read 20/25 (0.1 logMAR) or better at the time of testing.

Subjects' age (mean ± SD) was 26.0 ± 3.2. Twenty-three males and nineteen females participated in the study. All subjects were tested to have near visual acuity of 20/25 or better before the start of any visual sequential memory testing. All subjects provided informed written consent, and the procedures were in compliance with the Declaration of Helsinki and were approved by the Southern California College of Optometry's Institutional Review Board.

Materials/Procedures

A computer-based visual sequential memory test was designed for this particular study. It was developed as a self-running and self-timed presentation within Microsoft PowerPoint. It was presented on a laptop with test symbols having a Michelson contrast of greater than 95%.

The test loosely followed the structure of the paper-based TVPS-3 that uses standard black-on-white contrast only.[5] While the TVPS-3 does not specify a test distance, the symbols used in the TVPS-3 were calculated to be equal to approximately a reduced Snellen equivalent of 20/480. The symbols used in this study were approximately equivalent to 20/300, both of these sizes being well above the threshold of the subjects. Both the TVPS-3 and the test used in this study ended with nine-symbol sequences. Testing began with four-symbol sequences instead of two-symbol sequences, as in the TVPS-3. This increased the difficulty level for our study subjects. The TVPS-3 is designed for, and has normative data for, younger subjects (i.e. 4-18 years of age). In this study, all participants were over 18 years of age and thus likely to achieve maximum or near-maximum scores on a standard TVPS-3 test. Two sets of 16 (32 total) sequences (sequence A and sequence B) were developed for the standard contrast version and the reverse contrast version of the test (i.e. one each). Subjects were given one of two tests (test X or test Y). The first test (test X) presented sequence A in standard contrast first and then sequence B in reverse contrast. The second test (test Y) presented sequence A in reverse contrast first and then sequence B in standard contrast (Figure 1). Subjects were randomly assigned to perform either test X or test Y. Subjects were allowed to adopt a habitual viewing posture within a viewing distance range of 40-75 cm, which allowed the symbols to remain well above threshold size and allowed the patient to be comfortably tested. Testing was conducted ensuring that no glare was present on the screen.

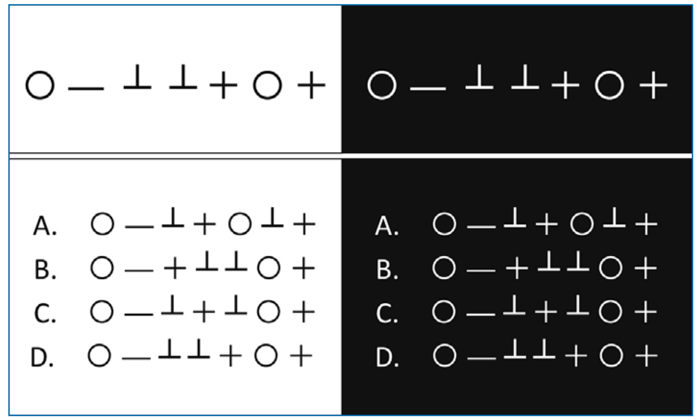

Figure 1. Example test sequences for illustrative purposes only in standard contrast (left) and reverse contrast (right) and subsequently shown answer choices.

For each sequence displayed on the screen, the subject silently viewed and memorized the sequence of shapes in the order presented. A viewing time of five seconds was allowed for each sequence (as in the TVPS-3). The presentation then automatically presented a screen for 15 seconds with four possible choices and the subject verbally indicated the correct answer, which the examiner recorded. No feedback was provided upon recording subject responses. While the TVPS-3 does not specify a time to respond, the test's instruction manual indicates that subjects will generally respond within 20 seconds. Subjects completed all 16 sequences for each test regardless of their real-time performance. Each sequence was presented in this manner until the subject finished the test, and then the opposite contrast test, using different sequences, was presented. In the TVPS-3 sequential memory test, the test is terminated if and when a patient has three consecutive incorrect answers or when they finish the test.

Data Analysis

Raw scores were determined for each test and compared. Initially, the study was designed as a paired test using both the standard and reverse contrast scores for all 42 subjects, but early data monitoring revealed a substantial order effect; whichever version of the test was presented second (standard contrast or reversed contrast) had a higher raw score. For example, of the first seven subjects who participated in the study, over 70% performed better on the second test, regardless of the contrast. Given this empirical observation, we continued to present both tests to the subjects and followed the same protocol, but made the *a priori* decision ultimately to compare only the data collected from whichever test the subject performed first in order to eliminate the confounding factor of order. Thus, we analyzed that data using a non-paired t-test assuming

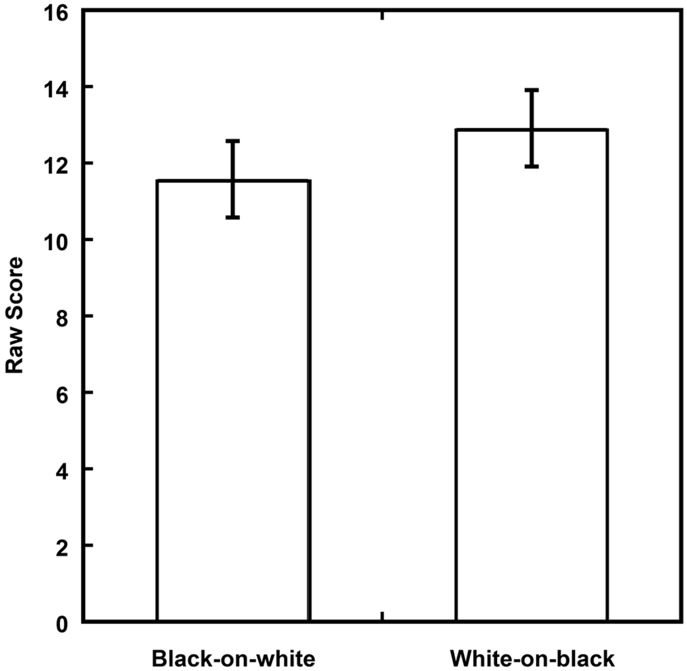

Figure 2. Standard contrast (left) and reverse contrast (right) bar graphs for mean data. Error bars represent 95% confidence intervals. The mean raw score for the reverse contrast testing was significantly higher.

unequal variance; 21 subjects' data for standard contrast and another 21 subjects' data for reverse contrast (i.e. sequence A in standard contrast versus sequence A in reverse contrast).

Results

Half of the subjects were given the standard contrast test first, and the other half were given the reverse contrast test first. While some of the subjects had prior exposure to the TVPS-3, the vast majority of the subjects (81%) were completely naïve to the test. The mean score, out of 16 possible, for the twenty-one subjects who performed the test under standard contrast conditions, was 11.57 [95% CI: 10.8 - 12.4]. Under reverse contrast conditions, the mean score was 12.90 [95% CI: 11.9-13.9]. The mean difference of 1.33 was statistically significant ($p = 0.04$), representing an average improvement of 8.3% in visual sequential memory using reverse contrast symbols versus standard contrast symbols (Figure 2).

Discussion

A computerized test of visual sequential memory was presented in standard and reverse contrast to 42 subjects. Subjects had significantly higher raw scores when the test was presented in reverse contrast. The raw median scores for standard (black-on-white) and reverse (white-on-black) contrast were 11 and 13, respectively. The normative, smoothed raw score median of the TVPS-3 sequential memory test, which is printed in standard contrast, is 13.47 out of 16 in patients 18 years of age, the highest age for which data is listed.[5] Thus, the test used in this study was somewhat harder, as it was designed to be, and only 3 of the 42 subjects achieved the maximum score, indicating that no substantial ceiling effect occurred.

A statistically significant difference was found ($p = 0.04$) between testing visual sequential memory using standard versus reverse contrast. This indicates that as a group, the first time the subjects took the test, they performed significantly better with reverse contrast (i.e. 8.3% better with reverse contrast). The test-retest reliability of the TVPS-3 has not been widely studied in an adult population of control subjects. The TVPS-3 manual that accompanies the test provides summary data from 42 control subjects (children) who took the VSM subtest twice with a mean time between tests of 21 days, and the results showed a test-retest difference of 0.7% for raw score means.[5] Several other studies have examined test-retest reliability in children, but used the TVPS-R, a test designed for children four to 12 years of age, which limits the applicability of the results to this study.[18-20] The studies that used the TVPS-R often showed that the VSM subtest had the highest test-retest reliability of all subtests, reporting intraclass correlation coefficients as high as 0.92 for test-retest periods of one to two weeks. Raw mean data was not available from these studies to determine a mean percentage change. One study using the TVPS-3 in adult subjects over 20 years of age retested subjects on average within two weeks of the first test.[7] It reported a Spearman correlation of only 0.42, but this was accompanied by a wide confidence interval. No raw data was provided to determine the mean percentage change.[7] Compared to the data provided with the TVPS-3, an 8.3% mean improvement in raw scores in this study is substantial.

An empirical order effect was observed in this study that perhaps should be studied more because the implication would be that immediate retesting of tests of visual sequential memory may show an improved score, and it would be interesting to study the time frame over which such an improvement could be sustained. Another study could be conducted such that subjects were repeatedly tested on visual sequential memory tasks until their raw scores reached a plateau (assuming they did). Subsequently, an examination of the effects of the reverse contrast could be done in a paired design.

For patients who need to perform tasks that may be critical, of short duration, and that do not allow for repeated practice (e.g. copying long words from a board in school or trying to memorize a phone number from a billboard that a patient is passing while driving their car), there may be benefit to having the print presented in a reverse contrast (white-on-black) fashion. Most research on standard and reversed contrast with respect to visual acuity and reading has attributed any differences simply to decreased amount of light scatter in the eye with reverse contrast.[11,12,21,22] All subjects in this study were young and free from ocular disease, and although not examined explicitly, likely did not have any issues of light scatter. The visual sequential memory task performed in this study was given using large, high contrast targets, and thus was different compared to measuring resolution thresholds (i.e. visual acuity) or characteristics of reading. If light scatter alone caused a difference in standard and reverse contrast measures, then no significant difference would likely have been observed in this study. Further work is needed to examine the possible mechanisms that could account for the results of this current study.

Patients with low vision have been found to read better with reverse contrast, and this improvement may not always be simply an optical issue (i.e. veiling glare or scatter). It may also be found that patients with visual processing deficits (e.g. traumatic brain injury), and not a decrease in visual acuity only, could benefit from variations in presented stimuli (reversing contrast in this case). Such studies would be interesting and perhaps would show a larger difference between standard and reverse contrast stimuli.

Conclusion

Overall, the type of contrast played a significant role in the memorization of sequential information in this study. These study results warrant further investigation of visual processing with reverse contrast stimuli. The results have potential applications to improving vision performance for some patients.

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