



ORIGINAL ARTICLE

Clinical reading-related oculomotor assessment in visual snow syndrome



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Abstract

Purpose: Visual snow syndrome (VSS) is a complex neurological condition presenting with an array of sensory, motor, and perceptual dysfunctions and related visual and non-visual symptoms. Recent laboratory studies have found subtle, basic, saccadic-based abnormalities in this population. The objective of the present investigation was to determine if saccadic-related problems could be confirmed and extended using three common clinical reading-related eye movement tests having well-developed protocols and normative databases.

Methods: This was a retrospective analysis of 32 patients (ages 16–56 years) diagnosed with VSS in the first author's optometric practice. There was a battery of three reading-related tests: the Visagraph Reading Eye Movement Test, the Developmental Eye Movement (DEM) Test, and the RightEye Dynamic Vision Assessment Test, all performed using their standard documented protocols and large normative databases.

Results: A high frequency of oculomotor deficits was found with all three tests. The greatest percentage was revealed with the Visagraph (56%) and the least with the RightEye (23%). A total of 77% of patients failed at least one of the three tests.

Conclusion: The present findings confirm and extend earlier investigations revealing a high frequency of saccadic-based oculomotor problems in the VSS population, now including reading-related tasks. This is consistent with the more general oculomotor/motor problems found in these individuals.

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Introduction

The clinical condition of Visual Snow Syndrome (VSS) has received considerable attention over the past two decades.¹⁻³ The primary visual symptom is the presence of "visual snow" (VS), that is a pixelated array of "dots" (i.e., dynamic visual

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noise similar to that produced on a detuned television) of either a chromatic or achromatic nature, and either transient or constant, superimposed upon the background visual scene. This produces a disturbing perceptual phenomenon: a foreground of moving dots with the critical visual scene in the background, thus creating two different depth planes of visual information. VS can occur for months or even years, typically being present for at least 3 months, and it is reported to be found in 2.2 % of the general population.⁴ In addition, for the diagnosis of VSS, one must report at least two of the following visual symptoms: palinopsia, photosensitivity, nyctalopia, and enhanced entoptic imagery. Individuals typically also report one of more of the following visual and non-visual symptoms: photopsia, migraine, phonophobia, hyperacusis, cutaneous allodynia, tremor, balance problems, and tinnitus. Successful neuro-optometric interventions have included chromatic/achromatic tints for the VS and photosensitivity, respectively, and saccadic-based vision therapy presumably to recalibrate the saccadic suppression mechanism to reduce the perceived intensity of the frequently occurring palinopsia.⁴

Over the past three years, there have been clinical⁴⁻⁵ and laboratory⁶⁻⁸ studies demonstrating an unusually high frequency of oculomotor deficits in VSS. In the clinical studies, up to 60% of the patients manifested common oculomotor diagnoses, such as convergence insufficiency, accommodative insufficiency, and general oculomotor dysfunction (OMD) (e.g., saccadic dysmetria).⁴ These oculomotor problems can be successfully remediated using conventional vision therapy.⁹ In contrast, in the three laboratory-based investigations which involved the saccadic system,⁶⁻⁸ the deficits were subtle when compared to normals: there was a shorter latency for a pro-saccade task, an increased error rate for an anti-saccade task, and a delayed onset of an inhibition response to a cued saccadic task. The authors suggested that the findings implicated an underlying attentional aspect to the saccadic deficits.

Hence, the *objective* of the present study was to determine if the aforementioned objectively-based saccadic deficits could be revealed in three common reading-related oculomotor-based clinical test batteries in those patients with VSS. These included the Visagraph Reading Eye Movement Test, the RightEye Dynamic Vision Assessment Test, both of which are objective, and the subjective Developmental Eye Movement Test (DEM), all of which provide quantifiable metrics with well-developed protocols and normative data. Our *hypothesis* is that the basic eye movement dysfunction would carry-over to the more complex reading domain, with resultant reading-related problems being manifested.

Methods

The present study was retrospective in nature. All records from consecutive patients with a diagnosis of "visual snow syndrome (VSS)" from 1/1/2021 to 5/1/2022 were reviewed from the first author's optometric practice. All thirty-two patient records were included in the analysis. The possibly inter-related conditions were as follows: the majority ($n = 17/32$, or 53 %) had a history of concussion/mTBI, 5/17 (29 %) had a history of VSS before the C/mTBI, 23/32 (72 %) had a history of migraine, 3/17 (18 %) had a history of migraine before their C/mTBI, and 10/23 (43 %) had a diagnosis of migraine but not C/mTBI.

The demographics included the following. Individuals ranged in age from 16 to 56 years (mean=27.3, SD=12.1). There were 15 males and 17 females.

All received a comprehensive vision examination (i.e., refractive, binocular, and ocular health status) in the first author's practice prior to testing. The corrected distance and near visual acuities were at least 20/20-. None had a of reading disability, nor any other ocular/neurological condition or use of medications, that would impact adversely on the findings. None received any prior vision therapy.⁹

There were three reading-related eye movement tests included in the battery. However, due to logistical constraints, not all were tested on each of the three tests. See [Table 1](#). During testing, they wore either their near reading or computer-based refractive correction. Either reading grade level or percentiles were used to assess performance per the criteria for each test system.

(1). Visagraph Reading Eye Movement Test.¹⁰ The test system measures binocular, horizontal eye movements during reading using the objective, infrared limbal approach, including calibration before and after each test completion. Its resolution is one degree. The reading material consisted of 100-word paragraphs over the full range of grade levels (grade 1 to college/adult). They read the initial 2 paragraphs, which were purposely set at one grade level below the subject's current grade level, to assure reasonable comprehension, followed by ten true/false questions with a comprehension pass level of 70 %. The first was a practice paragraph, with the second being the test paragraph used in the analysis. However, if 70 % comprehension were not attained, then a third paragraph at the same grade level was used. Only the test parameter metric of "mean expected grade level" was used in the analysis per the criteria used by this test system, and it was compared to the "expected grade level" per Talyor's established norms.¹¹ In addition, thirty of the individuals (93 %) were also tested at the fifth-grade level to determine if their performance primarily reflected an "oculomotor problem" or a "language problem".¹⁰ If reading at this lower level still resulted in a low grade level of performance, *then* it was mainly attributed to an "oculomotor problem".¹⁰

(2). Developmental Eye Movement (DEM) Test.¹² This test involved a language-free, global saccadic visual search tracking task incorporating number identification. It has three test components. Tests A and B are comprised of two columns of single digit numbers which are tracked vertically in sequence and read aloud, as rapidly as possible. Test C involves a similar task, but now with multiple, horizontally-arranged, single digit numbers to be tracked horizontally in sequence and read aloud, as rapidly as possible. The horizontal/vertical ratio and the time for completion of each test were used and compared to a their large normative database. If the horizontal test times are greater than the vertical ones, and the ratio is high, it suggests an oculomotor problem. The errors were also counted. The mean percentiles were the assessed metric for the test system per the system's criteria. There is no actual recording of eye movements during the DEM test.

(3) RightEye Dynamic Vision Assessment Test.¹³ This system involves binocular, video-based recording of both horizontal and vertical eye movements, with an accuracy of 0.4°, including calibration before and after each test set. There is no language-based aspect involved in the testing. There were two types of tasks. The first involved midline

Table 1 Summary of test results.		
A. Visagraph Reading Eye Movement Test Results		
Visagraph Reading Eye Movement Test-Lower Text Level Used (<i>n</i> = 27)		
Mean expected grade level	Mean number of grade levels VSS patients performed below expected	VSS patients performing 2 or more grade levels below expected (<i>n</i> = 27)
11.3 (range 4th grade to 12th grade)	5.6 (range 10.1 below to 2.9 above)	15 (56 %)
B. RightEye Dynamic Vision Assessment Test Results		
RightEye Dynamic Vision Assessment (<i>n</i> = 22)		
	Mean percentiles	VSS patients performing below the sixteenth percentile (<i>n</i> = 22)
Pursuit	54th%ile (range 19th% to 97th%)	1 (4.5 %)
Saccade	67th%ile (range 34th% to 99th%)	0 (0 %)
Fixation	59th%ile (range 4th% to 95th%)	4 (18 %)
	Mean values	VSS patients performing greater than one SD from the mean (<i>n</i> = 20)
Choice reaction time		
Latency	280.35 ms (std dev = 62.33 ms)	5 (25 %)
Accuracy	87 % (range 50th% to 100 %)	5 (25 %)
Discriminate reaction time		
Latency	263.45 ms (std dev = 43.47 ms)	4 (20 %)
Accuracy	94 % (58th to 100th%)	3 (15 %)
C. Developmental Eye Movement Test Results		
Developmental Eye Movement Test (<i>n</i> = 27)		
	Mean percentiles	VSS patients performing below the sixteenth percentile (<i>n</i> = 27)
Horizontal time (adjusted)	36.10 s (std dev=24.25 s)	9 (33 %)
Vertical time (adjusted)	32.57 s (std dev=11.97 s)	6 (22 %)
Ratio	1.12 (std dev=0.32)	7 (26 %)
Ratio	42nd%ile (range <1st% to 91st%)	9 (33 %)
Errors	67th%ile(range <1st% to 77th%)	3 (11 %)

fixation, horizontal and vertical saccades, and horizontal and vertical pursuit. The performance percentage for each oculomotor category was computed and compared with normative data, with performance below the 16th percentile considered to be abnormal for the criterion used by this test system. The second tests involved two reaction times tasks. These tests were used, as they were most similar to the tasks involved in the three laboratory-based saccadic studies.⁶⁻⁸ It included both saccadic choice and discriminate reaction times. In both cases, the individual had to saccade to the appropriate test target and rapidly depress the keypad for the selected choice and for the time to be recorded. The latency and error values were compared with normative data, with performance 1 standard deviation below the mean being considered abnormal for this test system.

Results

The summarized findings are presented in Table 1. This includes the oculomotor results, as well as the choice and discriminate reaction time findings with the RightEye system.

For the Visagraph system (Table 1A), 15 out of the 27 patients (56%) tested at a reduced text grade level, that is they performed at least two grade levels below the expected which

is considered to be abnormal for this test system. The mean expected grade level was 11.3, whereas those with VSS performed on average 5.6 grade levels being significantly below it.

For the RightEye system (Table 1B), 5 out of the 22 patients tested (23%) who completed the oculomotor component performed below the sixteenth percentile which is considered to be significantly abnormal for this test system, averaged across the saccade, pursuit, and fixation tasks. Performance was worst on the fixational task and best on the saccadic task. In addition, for the reaction time tasks, on average 25% failed the choice reaction time component, whereas on average 17.5% failed the discriminate reaction time component.

The Developmental Eye Movement test was performed on 27 of the patients (Table 1C). For the ratio metric, 9 (33%) performed below the sixteenth percentile, which is considered to be significantly abnormal for this test system/database, whereas for the error metric, 3 (11%) did. The ratio metric values are also included in Table 1C.

Discussion

The findings of the present retrospective study confirmed and extended those of earlier investigations⁴⁻⁸: individuals

with VSS manifest a wide range and high prevalence of oculomotor-based dysfunctions and related reading problems. For example, in a recent clinically-based, retrospective study,⁴ nearly all (96 %) of the 27 patients diagnosed with VSS exhibited a binocular vision/oculomotor problem: 59 % had a versional deficit (i.e., general oculomotor dysfunction, OMD), 53 % had convergence insufficiency, 33 % had convergence excess, and 54 % had accommodative insufficiency. This is consistent with the basic oculomotor findings of the present investigation. Furthermore, and importantly, these general findings were now extended in the present investigation using three conventional, saccadic, reading-related eye movement-based tests, two of which were objective in nature. Saccadic-based problems were again prevalent but now also for reading, which is a *new* finding. This was most dramatic with the Visagraph testing, where 56% performed below the criterion of expected grade level. Furthermore, and importantly, with the protocol used,¹⁰ this poor performance could be attributed primarily to the oculomotor system, namely basic versional/saccadic in nature. This high failure rate of 56% in the present study with the Visagraph was similar to that reported in an earlier clinical investigation (e.g., 60 % with OMD).⁴ Of the patients who completed all three tests in the present study, 17/22 (77%) failed at least one test.

A high prevalence of oculomotor deficits was also revealed in the two other tests, which did not include reading per se, but rather involved simple saccadic tracking tasks related and critical to reading. For the RightEye system, on average, nearly 7.5 % exhibited poor versional performance. With the DEM test, it was 33 % for the important "ratio metric", which is most closely tied to abnormal saccadic tracking.¹¹ This DEM horizontal/vertical ratio is an important clinical metric. Since the horizontal times were greater, on average, than the vertical ones, it was suggestive of an oculomotor problem.¹⁰⁻¹¹ This is consistent with the high frequency of abnormal basic eye movements found in these patients with respect to related clinical findings (e.g., saccadic dysmetria), and now extended for more complex reading and reading-related tasks.

Interestingly, this was also true for the two saccadic-based reaction times tests assessed with the RightEye system. On average, 21 % performed in the abnormal range for the criterion used by this test system. These tests are most similar to the more complex, laboratory-based, saccadic tracking tasks, which also involved a considerable attentional component.⁶⁻⁸

This is fertile territory for future clinical and laboratory studies. For example, these patients could be assessed using the aforementioned paradigms before and after global versional, vergence, and accommodative vision therapy to determine presence of any changes in basic tracking and reading-related performance. Similarly, one could administer either only basic saccadic therapy or only attentional therapy¹⁴ to isolate, and thus disambiguate, their relative contributions. One other strategy would be to test the saccadic system and assess parameters that are not attentionally affected, such as peak velocity and peak acceleration,¹⁵ for example being controlled in the rostral region of the superior colliculus¹⁶ for the versional system and the mid-brain¹⁵ for convergence. If these parameters are abnormal (e.g., slowed, variable), then it would suggest a basic

neurological control problem.¹⁵ If not, then it suggests at least in part an attentional component.^{6-8,14}

Thus, individuals with VSS have two major areas of concern. The first is their VS and VSS-related abnormalities. Fortunately, some of these can be remediated with saccadic therapy⁴ and tints.⁵ The second is their range of binocular vision/oculomotor problems, such as convergence insufficiency and saccadic dysmetria, and these too can be successfully remediated with conventional, oculomotor-based vision therapy.⁹ Furthermore, and fortunately, recent neuro-optometrically-based, detailed diagnostic and therapeutic protocols for VSS have been developed,¹⁷⁻¹⁸ and the application of these should lead to more consistent and efficacious vision care.

The DEM test has been used successfully for decades in the clinical testing of saccadic eye movements and their potential relation to the general symptom of "reading problems" found in many patients.^{12, 15} It has the ability to differentiate between a verbal naming deficit and a saccadic tracking problem. However, there has been discussion and debate over the usefulness and predictive value of the DEM test. These concerns reflect the complexity of the reading process, and perhaps the need for multiple tests to ascertain the proper and complete diagnosis and potential related functional ramifications (e.g., on reading). For example, in one study,¹⁹ the data revealed that in patients with either ocular or cerebral visual impairment, the additional presence of nystagmus in many of them did not affect the test parameters. This may not be unexpected, as the overall visual quality (e.g., visual acuity, contrast sensitivity) and underlying basic versional eye movements (with or without the superimposed nystagmus) were likely already of sufficiently poor quality to result in a *floor-based, saturation effect* on test performance. Thus, there would be no difference. Also, it is well-established that the sole presence of nystagmus in otherwise normal patients (i.e., idiopathic nystagmus) typically impacts adversely on reading rate (~30 % or more).¹⁵ In addition, and somewhat paradoxically, in some with congenital, idiopathic nystagmus, the nystagmus actually *decreases* considerably during reading,¹⁵ which presents a potential confound. In another study,²⁰ the DEM and Visagraph tests were performed in a cohort of visually-normal children presumably without any reading disability, for which these tests were not designed to be administered. However, there were statistical relations found between some parameters but not all between the two tests. Thus, one would need to record objectively basic versional eye movements (e.g., fixation, saccades) and reading eye movements incorporating the aforementioned tests, and others such as standardized educational reading tests (e.g., the Nelson-Denny test,¹⁵) for a more complete analysis and understanding of the complex global picture.

It would be interesting and important to determine the link, if any, between the present reading-related oculomotor dysfunctions and their potentially inter-related conditions of C/mTBI, migraine, and VSS, as listed in the Methods section. However, given the relatively small sample size ($n = 32$) in the present retrospective study, further divisions into yet smaller sample subsets may not prove convincing. This is additionally complicated by the differences and range of oculomotor dysfunctions (i.e., 11 to 56 %) found for the three test systems with their different criteria and metrics

used. Despite the aforementioned limitations, some inferences can be made. First, the high frequency of oculomotor problems found here (i.e., up to 56 %) is similar to that found in an earlier study in those with VSS (i.e., up to 60 %).⁴ Second, since only 29 % had a history of VSS before their C/mTBI occurred, then the first presence of their VSS can be attributed to the C/mTBI in the majority of cases (71 %). Third, while 72 % had a history of migraine, only 18 % had such a history prior to their C/mTBI event, and thus most occurred subsequently (72 %). Fourth, while most (72 %) had a history of migraine, there is no scientific evidence that migraine alone can result in the reading-related deficits found in many of those with VSS. Lastly, many (43 %) had a diagnosis of migraine but not C/mTBI. While the possible inter-relations would be of interest to ascertain to improve both diagnostic and treatment aspects, and our general understanding of the condition, it will require a large population of those with VSS, and the above co-morbid conditions, preferably prospective in nature, to assess statistically into the necessary subsets with confidence.

The neurophysiology related to VS/VSS remains elusive. Several possibilities have been suggested, with hyperexcitability of the angular gyrus being a primary focus.²¹ However, recently an alternate site has been proposed.⁵ It is well-established that the extrastriate region of the middle temporal (MT) area is intimately involved in both the generation and perception of visual motion.^{22,23} Normally, stimulation of very small, discrete regions of its cells produces directionally-specific visual motion. However, if injured, there would be an increase in its spontaneous neural activity, with resultant hyperexcitability of its cells. If sustained current spread occurred, which in turn would now stimulate large regions of cells, multi-directional neural signals would be produced. Hence, the perception of visual motion occurring in *all* directions would result (i.e., no longer being directionally-specific). Thus, the occurrence of dynamic, multi-directional visual snow would occur. Furthermore, since MT is known to have a chromatic input,²⁴ this could account for the typical and more common occurrence of chromatic versus achromatic visual snow. This interesting idea should be further tested in the research laboratory.

Interestingly, these patients frequently manifest more general motor abnormalities, such as tremor and balance problems.¹⁻³ Thus, one might speculate that the aforementioned general oculomotor dysfunctions (e.g., impaired fixation, saccadic dysmetria) might reflect a more general, widespread neuromotor deficit. Further research is required to confirm this notion.

There were three potential study limitations. First, it was retrospective and not prospective in nature. Second, the sample size was relatively small. Third, most but not all subjects were assessed on all three tests.

In conclusion, individuals with VSS have a high prevalence of basic oculomotor dysfunctions based on clinical testing. Thus, for the *first* time, they were also manifested during reading, as we had hypothesized. Further research is needed in this area to detail and quantify using objective techniques, the oculomotor dysfunction found in patients with VSS, with a goal of uncovering the neurological mechanisms (e.g., hypersensitivity) and neural substrates (e.g., MT), along with their diagnostic, prognostic, and therapeutic ramifications.

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Conflicts of interest

The authors have no conflicts of interest to declare.

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