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RESEARCH ARTICLE

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Subjective visual vertical/horizontal and video head impulse test in dyslexic children

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Different studies have tried to establish a relationship between dyslexia and the vestibular system function. Subjective Visual Vertical/Horizontal (SVV and SVH) and Video Head Impulse Test (VHIT) are useful for studying the vestibular system and can be easily performed in children. Our aim was to evaluate the vestibular function in dyslexic children by SVV/SVH and VHIT. We enrolled 18 dyslexic children (10M/8F; mean age 10.7 ± 2.3 years; range 7–14 years) and 18 age-matched children with typical development of learning abilities. All children performed VHIT, SVV and SVH. We found normal gain and symmetry of vestibulo-ocular-reflex both in dyslexic and typically developing children. Fifteen out of 18 dyslexic children (83.3%) showed a difference of at least one amongst SVV or SVH. The mean value of SVV was 2.3° and the mean value of SVH was 2.6°. Statistical analysis showed a significant difference between typically developing and dyslexic children for both SVV and SVH. We confirm a relationship between dyslexia and the alteration of SVV and SVH. Our results could be related to the pathogenetic hypothesis of a visual processing impairment related to a dysfunction of the magnocellular pathway or to a general deficit related to a multimodal cortical network.

KEYWORDS
dyslexia, subjective visual vertical/horizontal, vestibular system, video head impulse test, visual processing

1 | INTRODUCTION

Referring to DSM-5 (American Psychiatric Association, 2013), dyslexia is a term used to describe a pattern of learning difficulties characterised by problems with accurate or fluent word recognition, poor decoding and poor spelling abilities in children with normal cognitive development.

Different theories have been suggested to explain the underlying causes of dyslexia, such as phonological deficit, sensory deficit (visual and auditory) and cerebellar impairments (Stoodley & Stein, 2011). Moreover, postural involvement and visual attentional deficit with abnormal oculomotor patterns have been proposed as other possible causes of dyslexia (Bucci et al., 2018). Visual processing impairment has been extensively documented (Demb et al., 1998; Eden et al., 1996). Eye movement control is strongly related to the magnocellular system and a weakness in this system leads to less stable visual fixation, which can result in the movement sensation of words and letters, a common complaint in dyslexia. The development of the magnocellular system is also related to the activation of the cerebellum, which plays an important role in visuomotor control, so it may be implicated in the etiopathogenesis of dyslexia, too. Based on physiological correlations, the vestibular system could be involved, however the modality is currently unclear.

The first hypothesis of a cerebellar-vestibular deficit in children with dyslexia was suggested by Frank and Levinson in 1973 (Frank & Levinson, 1973), and confirmed by Nicolson and Fawcett in 1999 (Nicolson & Fawcett, 1999). The vestibular system is involved in sensory processing and in motor function. The value of the vestibular sensory system to brain functions is related to the perception of self and non-self-motion, spatial orientation, voluntary movement, oculomotor control and autonomic control. Therefore, its role is not limited to balance regulation but also includes postural/motor control and visual stabilisation during reading tasks. The vestibular system can be evaluated extensively by means of different clinical and instrumental tests and a topographic diagnosis can be made to define where the system is impaired. However, a vestibular system evaluation is difficult to perform in children because of side effects and poor compliance. The analysis is based on bedside examination, Video Head Impulse Test (VHIT) (Rodríguez-Villalba & Caballero-Borrego, 2023), functional Head Impulse Test (fHIT) (Caldani et al., 2020; Ölçek et al., 2023), Subjective Visual Vertical/Horizontal (SVV and SVH) (Brodsky et al., 2016), static and dynamic posturography (Shams et al., 2020) and vestibular evoked myogenic potential (VEMPs) (Picciotti et al., 2007).

VHIT measures the gain of the vestibulo-ocular reflex (VOR) during head rotations as the ratio of eye-to-head velocity. This test has been proposed as a sensitive, efficient and well-tolerated vestibular test in children showing gain values increased with age until children reached age 7–10 years and matched the normal values for adults (Rodríguez-Villalba & Caballero-Borrego, 2023). SVV and SVH tests are related to the ability to judge whether the objects are in the vertical or horizontal position. Anatomical structures involved are the otolithic ones and the vestibular central system. This test is simple and non-invasive and it provides a valuable contribution to the assessment of peripheral vestibular function in children (Brodsky et al., 2016).

A recent article compared SVV in reading impaired children under different somatosensory inputs, hypothesising that dyslexic children might show SVV impairment worsened by somatosensory information interference (Goulème et al., 2019). The results are interesting but the evaluation concerns only the vertical plane, neglecting the horizontal one. The cognitive implications related to SVV have been studied in both adults and children. In children it seems that the perception of SVV is developmental, probably related to the maturation of the cortical processes involved in the control of verticality (superior parietal cortex, insula and thalamus) but also to the development of attention (Tringali et al., 2017).

Also in this area, two different studies evaluated functional VOR using fHIT (which is performed by measuring the percentage of correct answers when the patient is asked to identify a chart presented rapidly during the passive impulse of the head) in children with developmental neurological disorders (autism, spectrum disorders, reading disorders and attention-deficit/hyperactivity disorder). Caldani et al. (2020) first found that children with developmental neurological disorders showed lower correct answers than normal children did. Moreover, Ölçek et al. (2023) recently confirmed an impairment of fHIT in dyslexia. Anyway, these interesting findings have been found in a few children with dyslexia, and fHIT is currently a technique used in only a few centres. However, it has possible rehabilitative implications as demonstrated by the same authors in dyslexic children (Caldani et al., 2020, 2021).

Inspired by these interesting studies and considering the involvement of the visuo-perceptive and visuo-motor aspects in reading tasks, the aim of the present study is to investigate the vestibular system in children affected by dyslexia, comparing them with age-matched typically developing children, using VHIT and SVV/SVH.

2 | MATERIALS AND METHODS

We enrolled 18 dyslexic children (Dyslexic Group) from the Phoniatric Unit of the Fondazione Policlinico A. Gemelli IRCCS of Rome (10M and 8F; mean age 10.7 ± 2.3 years; range 7–14 years) and 18 age-matched children with typical development of learning abilities (9M and 9F; mean age 11 ± 1.6 years; range 7–13.6 years) (Typical Developing Group).

2.1 | Subjects

All children were native Italian speakers. Children of the Dyslexic Group were included after receiving a thorough assessment by means of a standardised battery of tests for the evaluation of academic skills (Table 1). In particular, the inclusion criterion for children in the dyslexic group was a diagnosis of dyslexia, made according to Italian guidelines and by means of the following tests: reading passage (Cornoldi & Colpo, 1998), word and nonword reading (Sartori et al., 2007) and cognitive assessment evaluated by Wechsler Intelligence Scale for Children (WISC-IV) (Orsini et al., 2020). As indicated by Italian guidelines, the diagnosis was made when performances in speed and accuracy of reading were below 2 SD or below the fifth percentile in at least 2 reading tests amongst: reading passage, word and nonword reading. Therefore, no additional tests were performed for patient selection, provided they had a dyslexia diagnosis (Mari et al., 2022). Children of the typical development group were enrolled amongst patients coming for otorhinolaryngology visits to our clinic and were selected and included after passing the same test battery as was administered to dyslexic children. Children from both groups underwent an audiological evaluation by pure tone audiometry and impedance audiometry.

Exclusion criteria for both groups were hearing loss, interpreted as a hearing threshold worse than 20 dB HL for frequencies from 0.5 to 4 kHz; neurological diseases, visual deficit, cognitive impairment (IQ score ≥ 85), abnormal psychomotor growth, referred migraine and vertigo. All children performed VHIT, SVV and SVH in the same session.

2.2 | Video head impulse test

VHIT was performed by means of ICS impulse (Otometrics/Natus, Den), a portable lightweight VOG device with an integrated digital high-speed camera (250 frames per second) designed for quantitative HIT testing. The device software (OTOsuite Vestibular Software Version 120 Build 310) automatically calculates individual HIT and aggregate (right- and left-sided) mean VOR gains. We considered normal values of VOR gain >0.8 and asymmetry degree of gain <25%.

TABLE 1 Demographic data and results in the MT and DDE-2 tests for the two studied groups of patients.

	Dyslexia group	Typical developing group	*p* value
Number of patients	18	18	
Sex			
Males	10 (55.6%)	9/18 (50%)	
Females	8 (44.4%)	9/18 (50%)	
Age (years)			>0.05
Mean ± SD	9.3 ± 1.2	9.0 ± 1.1	
sMT			<0.0001
IIAR (<5)	13/18	0	
AR (5–10)	5/18	0	
SP (10–25)	0	9/18	
OP (25–50)	0	9/18	
aMT			<0.0001
IIAR (<5)	3/18	0	
AR (5–10)	9/18	0	
SP (10–25)	6/18	12/18	
OP (25–50)	0	6/18	
cMT			<0.0001
IIAR (<5)	3/18	0	
AR (5–10)	9/18	0	
SP (10–25)	6/18	12/18	
OP (25–50)	0	6/18	
WRs			<0.0001
<5	7/18	0	
5	4/18	0	
10	4/18	0	
25	3/18	9/18	
50	0	9/18	
WRa			<0.0001
<5	8/18	0	
5	3/18	0	
10	7/18	0	
25	0	9/18	
50	0	9/18	
NWRs			<0.0001
<5	10/18	0	
5	2/18	0	
10	6/18	0	
25	0	7/18	
50	0	11/18	
NWRa			<0.0001
<5	9/18	0	

TABLE 1 (Continued)

	Dyslexia group	Typical developing group	*p* value
5	1/18	0	
10	8/18	0	
25	0	7/18	
50	0	11/18	

Abbreviations: aMT, MT test accuracy; AR, attention request (5–10 percentile); cMT, MT test comprehension; IIR, immediate intervention request (<5 percentile); NWRa, non-word reading accuracy percentile (DDE-2 test); NWRs, non-word reading speed percentile (DDE-2 test); O, optimal performance (25–50 percentile); sMT, MT test speed; SP, sufficient performance (10–25 percentile); WRa, word reading accuracy percentile (DDE-2 test); WRs, word reading speed percentile (DDE-2 test).

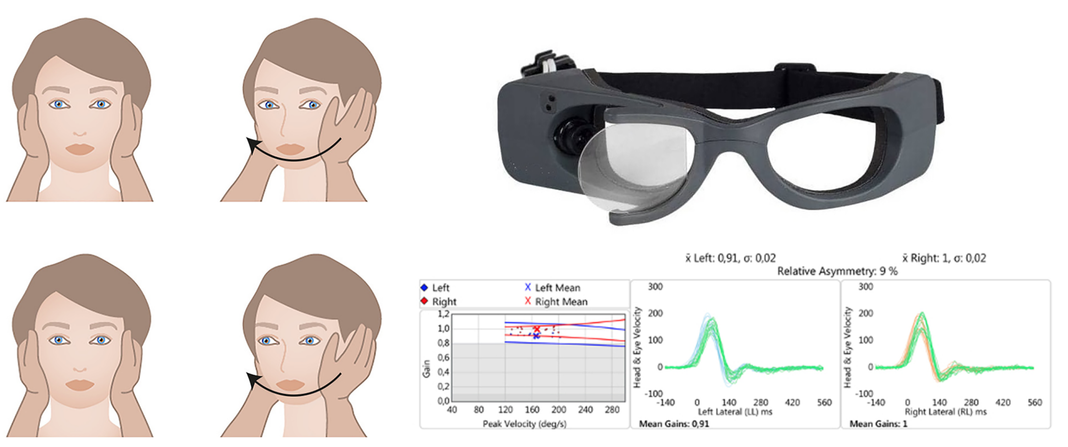

FIGURE 1 Equipment for video head impulse test (top right), an example of graphical output (bottom right) and a scheme of execution of the test (left).

For each child, we calculated the mean of three responses both for VOR gain and asymmetry degree.

Figure 1 shows the equipment for the VHIT test, an example of graphical output and a scheme of execution.

2.3 | Subjective visual vertical/horizontal

SVV and SVH were recorded by Synapsis® SVV Software (Fr). The child was seated in a darkened room (to avoid any visual cues). Head and neck were positioned in the neutral position and the stimulus was projected at a distance of 2 m, in front of the subject. The child was fitted with a contour mask with binocular vision to reduce the chance of visual cues. The stimulus was a projected vertical and/or horizontal illuminated line provided by the software from the equipment. It was presented at a pre-set angle (between 5° and 30°) in a random fashion. Children were required to adjust the line to absolutely vertical and horizontal as perceived by themselves, using a joystick (remote-controlled potentiometer) (Figure 2). The system device calculated the deviation angle between the real vertical and/or horizontal angle value and the subject's perception. For each child, we calculated the mean of the three responses that were performed for the horizontal and vertical conditions. We decided to record three times only to avoid fatigue. The values obtained are expressed in degree as they correspond to the angle of deviation of the vertical or horizontal.

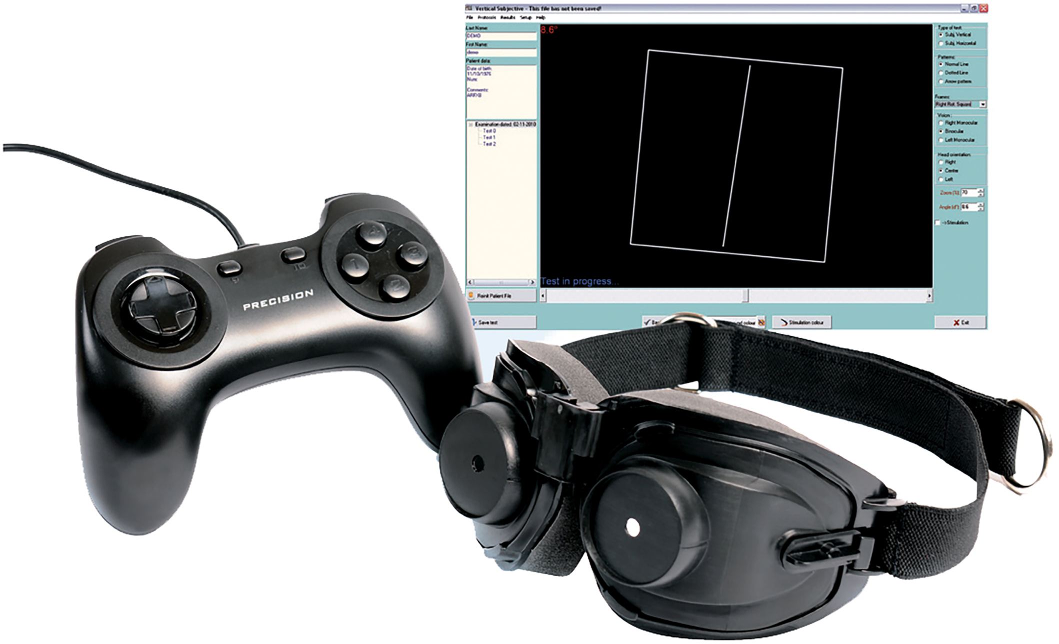

FIGURE 2 Equipment for the SVV/SVH test: the Synapsis® SVV Software with the stimulus projected at a distance of 2 m, in front of the subject; the contour mask with binocular vision; the joystick used to adjust the line to absolutely vertical and horizontal as perceived by the patient. SVH, subjective visual horizontal; SVV, subjective visual vertical.

2.4 | Data analysis

For VHIT we evaluated the gain and the degree of asymmetry of the VOR, expressed as the mean of three different tests for each child, we considered the mean of the values +/− SD obtained in dyslexic children compared to normal controls.

For SVV and SVH we measured the value, expressed in degrees, of the angular deviation with respect to the objective vertical and/or horizontal. Also in this evaluation, the average of three tests was calculated for each child and the mean +/− SD of the values obtained in dyslexic children compared to normal controls was considered. We considered abnormal results when SVV and SVH tilting exceeded 2.0°.

2.5 | Statistical analysis

The statistical analysis was performed using SPSS for Windows (IBM Corp, Chicago, Illinois). The normality of VHIT/SVV/SVH results was verified with the Shapiro–Wilk test (normal for $p > 0.05$). *t* test was used for normally distributed data and the Mann–Whitney *U* test was in the case of non-normally distributed data. The χ^2 test will be used to compare categorical data such as prevalence; the Fisher exact test will be applied in case of comparison of proportions with less than five observations. Bonferroni correction will be applied to adjust for multiple comparisons. All results are reported as mean ± standard deviation (SD). Statistical significance was assumed for *p*-values <0.05.

3 | RESULTS

3.1 | VHIT

The dyslexic group show a mean VOR gain of 0.91 ± 0.09 and an asymmetry degree of 10.1 ± 5.4%. The highest value of gain was 1.04 and the lowest one was 0.81, whilst the highest asymmetry was 17% and the lowest one was 1%. Statistical comparison with data obtained in the Typical Developing Group (mean VOR gain 0.95 ± 0.25; mean asymmetry 6% ± 0.8%) did not show significant differences between the two groups at Mann–Whitney *U* test ($p > 0.05$). Catch-up saccades were found in none of the children of both groups.

3.2 | SVV and SVH

Shapiro–Wilk test demonstrated a normal distribution of results for SVV in both groups, whilst results of SVH were non-normally distributed amongst the two groups. In Table 2, we reported the result obtained at the evaluation of subjective visual vertical and horizontal in both the dyslexic group and the typical developing group. Three out of 18 subjects of the dyslexic group (16.7%) showed normal SVV and SVH, whilst 15 of them (83.3%) showed abnormal values: 12/18 (66.6%) children for the vertical and 9/18 (50%) for the horizontal. In the dyslexic group, the mean value of SVV was 2.3 ± 2.2 (range from −2.4 to 5.7) whilst the mean value of SVH was 2.6 ± 3.0 (range from −1 to 9). All children of the Typical Developing Group had normal values of SVV (mean value: 0.8 ± 1.1; range from −1.8 to 2.0) and SVH (mean value: 0.5 ± 1.0; range from −1.4 to 2.0). In particular, the mean value of SVV was 0.8 ± 1.1 (range from 0.2 to 2) and the mean value of SVH was 0.5 ± 1 (range from 0.3 to 1.9). The difference of SVV between dyslexic and typical developing children was statistically significant at *T* test ($p = 0.032$ with equal variances assumed at Levene's Test). Similarly, also the difference of SVH amongst the two groups was statistically significant at Mann–Whitney *U* test ($p = 0.023$).

4 | DISCUSSION

The first finding of this study concerns the vestibular assessment in children. We found that both VHIT and SVV/SVH are feasible tests in a child. In our experience, children's compliance has been very high, especially for the use of the joystick which is a play tool for children's daily use. As described in the literature (Brodsky et al., 2016; Hülse et al., 2015), we confirm that both these diagnostic tests are useful for vestibular diagnosis in developmental age and have no side effects, are not invasive, not stressing and not expensive.

The second finding is related to the VHIT results. VOR gain was normal in both groups of children without significant differences. These results suggest a normal peripheral vestibular function in dyslexic children that has never been reported in the literature. Recently Caldani et al. (2021) and Ölçek et al. (2023) showed a modification of fHIT in dyslexic children; however, this is a different technique. It is well known that VHIT is useful for studying the quantitative VOR but unable to detect neurological diseases. Instead, fHIT is able to measure visual fixation and reading ability during head movement. Compared to VHIT, fHIT provides a qualitative evaluation rather than quantitative. In fact, patients with vestibular symptoms in recovery can show normal HIT and abnormal fHIT. Ölçek et al. (2023) found that the response percentage of the recognised/read optotype during active head movement was lower in children with dyslexia and they justified this result, especially in the right acceleration of the head, with the low grey matter volume in the right cerebellum showed in the dyslexic children by Pernet et al. (2009). On the other hand, Caldani et al. (2020) evaluated children affected by different neurodevelopmental disorders, such as autism spectrum disorders, reading impairment or attention deficit/hyperactive disorder. They observed significantly lower correct answers in all children with neurodevelopmental disorders compared with normal controls, without significant

TABLE 2 Subjective visual vertical (SVV) and subjective visual horizontal (SVH) values of both dyslexic (Dys) and typical developing (Typ) children. Bold for abnormal values.

Child	Group	Years	SVV	SVH
1	Dys	10	5	8.8
2	Dys	8.9	−0.3	−0.9
3	Dys	11	**4.5**	**7.8**
4	Dys	9.5	0.7	0.7
5	Dys	16	0.9	**2.5**
6	Dys	9.8	−**2.4**	−1
7	Dys	11.5	0	**9**
8	Dys	9.5	**2**	**3**
9	Dys	8.5	**3**	1.4
10	Dys	9.8	**3.8**	0.9
11	Dys	11	**4**	**2.4**
12	Dys	13	0.1	0.1
13	Dys	8	**4.8**	1.4
14	Dys	7	**5.7**	1.8
15	Dys	11	**2.1**	**2.6**
16	Dys	14	1.85	**2.9**
17	Dys	10	**4.1**	**2.55**
18	Dys	14	**2.35**	0.71
19	Typ	9.5	0.4	2
20	Typ	10.9	1.9	1
21	Typ	10.6	0.9	−0.1
22	Typ	10.4	0.9	0.4
23	Typ	7	1.2	1.6
24	Typ	9.2	−0.5	1.5
25	Typ	11.5	−1.8	−1.4
26	Typ	13.6	1.7	2
27	Typ	11.7	1.9	0.3
28	Typ	10.5	1.2	1
29	Typ	10.5	−0.3	0.4
30	Typ	10.1	0.3	−0.8
31	Typ	13.3	2	1.4
32	Typ	9.6	0.1	0.1
33	Typ	10.3	0.2	−0.4
34	Typ	9.1	2	−1.3
35	Typ	9.6	1.8	1.3
36	Typ	12.6	−0.4	0.2

differences between the three groups of affected children. The authors also specified that some affected children had correct responses similar to normal ones, indicating that further studies by VHIT could be necessary (Caldani et al., 2020).

Other studies investigated peripheral and central vestibular systems in dyslexia hypothesising a cerebellar-vestibular involvement. Sales and Colafêmina (2014) described dyslexic children's saccades modifications and clinical changes of dynamic visual acuity.

Balance and gait have been also investigated in dyslexic children and results are really controversial (Mari et al., 2022; Ölçek et al., 2023; Rochelle & Talcott, 2006); nevertheless several studies demonstrated interesting differences between dyslexic and other children reading on postural abilities only in open eyes conditions (Moe-Nilssen et al., 2003; Stoodley et al., 2005). Another study demonstrated in children with dyslexia a greater instability, with greater length, variability and mean power frequency of centre of pressure (CP) displacements in open and closed eyes conditions (Pozzo et al., 2006). More recently, Scheveig and Bucci (2023) confirmed poor motor control, with the occurrence of instability on an unstable support, in dyslexic children. Finally, Poblano et al. (2002) described the results of dynamic posturography in dyslexic children. They showed significant modification in the Motor Control Test without impairment of the Sensory Organization Test and reduction of somatosensorial, visual or vestibular inputs at the sensory analysis. These data obtained with very different techniques, actually seem to highlight postural instability and motor coordination modification in children with dyslexia but do not disagree with our results of normal peripheral vestibular function evaluated by VHIT. We can hypothesise that the abnormal rate and timing precision motor coordination is probably due to a deficit in the multisensory integration of multiple inputs with an important role of the cerebellum as hypothesised by Stoodley and Stein (2011).

The last and most important finding of our research concerns the changes of SVV and SVH in dyslexic children. As known, SVV and SVH together with the VEMPs represent the main tests of otolith function. Cervical (cVEMPs) and ocular (oVEMPs) are short latency surface potentials, due to saccular and utricular activation by sound and vibration. They are dynamic functional tests of the otolith whilst SVV and SVH are considered static tests (Taylor & Welgampola, 2019). We demonstrated a significant increase in the real perception of angle deviation for both vertical and horizontal. Central involvement of the vestibular system can be hypothesised due to the absence of clinical signs of otolitic damage, such as the postural pattern of macular dysfunction called 'ocular tilt reaction' (head tilt, ocular torsion and skew deviation). Goulème et al. (2019) described similar results: they studied only SVV tasks in two different conditions such as with or without somatosensory inputs from the foot, suggesting an immaturity of sensory integration. The SVV and SVH are strictly influenced by cortical and subcortical structures and by the cerebellum and vestibular system. These neuroanatomical considerations could justify our and Goulème's results (Goulème et al., 2019). The role of the cerebellum is probably very important in SVV and SVH changes observed in dyslexia, also for its role in cognitive skills.

Learning to read requires the maturation and integration of different skills: phonological awareness, sensory analysis of the stimulus, visual attention, auditory and visual perception. Theoretically, an alteration of one of the components can result in an impairment of reading skills. In addition to the phonological theory, one of the most accredited theories that have tried to explain the pathogenesis of dyslexia is that of a visual processing deficit related to a dysfunction of the Magnocellular system. This dysfunction may lead to binocular instability, difficulty regulating eye movements, and to visuo-spatial attention and peripheral vision problem (Ahmadi et al., 2015; Demb et al., 1998; Edwards et al., 1996; Galaburda & Kemper, 1979; Gori et al., 2016).

On the other hand, it is also known that cortical otolith afferents, concomitant with information from the visual and proprioceptive systems, participate in spatial orientation and mental representation of the body in the space and perception of verticality/horizontality. These central connection pathways and the visual theory of dyslexia could further justify the SVV and SVH modifications that we found in dyslexic children.

Prior to our study, some authors suggested the use of vestibular rehabilitation techniques in the context of dyslexia. Byl et al. (1989) demonstrated that in people with problems in learning, reading, inattention and vestibular function, a vestibular exercise programme complementing a traditional or special educational programme may enhance the spatial perceptual skills needed for reading. A more recent study by Caldani et al. (2021) proposed vestibular and cognitive training to improve the vestibular network involved in cognition functions leading to improved reading skills in dyslexic children. The results of these studies in addition to our own on SVH and SVV support the hypothesis about the possible role of the vestibular central system in the pathogenesis of dyslexia and may lead to new approaches in the diagnosis and rehabilitation of dyslexia.

5 | LIMITATION AND CONCLUSIONS

In the present study, there are some limitations: the auditory evaluation and the comprehensive vestibular system have been not evaluated. We reported a quantitative VOR evaluation but not a qualitative one obtained by functional HIT. It will be interesting to further study the postural control of dyslexic children to clarify the possible modifications and to identify the sensorial cues affected.

Moreover, we did not evaluate the SVH and SVV results related to deviation to the right or left and we did not analyse the patients' handedness. This could be a potential further study.

In conclusion, our study confirmed that dyslexic children show a deficit of both vertical and horizontal visual subjective, contributing in part to understanding the links between the vestibular system (central and peripheral) and dyslexia and opening new perspectives in the rehabilitative management of these children.

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CONFLICT OF INTEREST STATEMENT

The authors have no funding, financial relationships or conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author [SS], upon reasonable request.

ETHICS STATEMENT

The study was approved by our institutional ethical committee (protocol no. 0025514/21; ID number: 4156). All subjects signed a written informed consent; a dedicated and extensive version of the informed consent was also obtained from both the parents/guardian/legal representative.

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