Postural instability in children with specific learning disorder: A neurodevelopmental perspective

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SUMMARY

Objective: This study examined whether postural instability in children with Specific Learning Disorder (SLD) is associated with cognitive-attentional processes or broader motor involvement.

Method: Seventy children aged 7–11 years participated in the study, including 41 children with SLD and 29 typically developing controls. Postural stability was assessed using the NeuroCom Balance Master and the Modified Clinical Test of Sensory Interaction on Balance (mCTSIB) across four conditions: hard surface eyes open (HSEO), hard surface eyes closed (HSEC), foam surface eyes open (FSEO), and foam surface eyes closed (FSEC). Attention was measured using the Swanson, Nolan, and Pelham Scale–IV (SNAP-IV), and cognitive performance was estimated using the Vocabulary and Block Design subtests of the Wechsler Intelligence Scale for Children–Revised (WISC-R). Parent-reported motor coordination difficulties were assessed using the Developmental Coordination Disorder Questionnaire–2007 (DCDQ'07). Group differences were examined using independent samples tests, followed by ANCOVA models adjusting for attentional symptoms, verbal ability, and parent-reported motor coordination difficulties. Hierarchical multiple regression analyses were conducted to identify predictors of postural performance.

Results: Children with SLD demonstrated significantly greater postural sway across all balance conditions (all $p < .001$). Group differences remained significant after adjusting for attentional symptoms and verbal ability. Additional ANCOVA models including DCDQ'07 scores also indicated persistent group differences in postural control parameters. Hierarchical regression analyses showed that SLD diagnosis was significantly associated with postural instability across conditions, whereas BMI was associated only in the HSEO condition.

Discussion: Postural control difficulties were more frequently observed in children with SLD compared with typically developing peers, even after adjusting for attentional symptoms, verbal abilities, and parent-reported motor coordination difficulties. However, given the cross-sectional design and potential confounding factors, including ADHD comorbidity and socioeconomic differences, these findings should be interpreted cautiously. Overall, the results suggest that postural instability may be related to broader neurodevelopmental mechanisms involving sensorimotor integration.

Key Words: specific learning disorder, postural instability, attention-deficit/hyperactivity disorder

INTRODUCTION

Specific Learning Disorder (SLD) is defined in the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5) as a neurodevelopmental condition characterized by persistent difficulties in learning and using academic skills such as reading, writing, or mathematics, despite adequate intelligence, instruction, and cultural opportunity (1). In clinical practice, children often present with mixed learning difficulties across reading, spelling, and arithmetic, reflecting the heterogeneous nature of SLD (2). Comorbidity is highly prevalent, with approximately 60% of individuals with dyslexia meeting the criteria for at least one neuropsychiatric disorder. Among these, ADHD is the most common comorbidity, whereas findings regarding associations with anxiety and mood disorders remain inconsistent across studies (3). These observations suggest that learning disorders extend beyond isolated linguistic deficits and may

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involve broader impairments in attention, executive functioning, and sensorimotor coordination (4).

Postural stability—the ability to maintain the body's center of mass within the base of support—depends on the efficient integration of visual, vestibular, and proprioceptive inputs within cerebellar and cortical motor networks (5). Disruptions in these systems can lead to balance instability and inefficient motor responses. Children with neurodevelopmental disorders, including SLD frequently display subtle motor coordination and balance difficulties (6,7). Several theories propose that cerebellar and sensorimotor connectivity abnormalities contribute to these impairments. Specifically, cerebellar dysfunction may hinder the automatic coordination of sensory and motor information, reducing the ability to compensate for postural disturbances and affecting the automatization of reading-related skills (6, 8, 9,10). Such deficits can manifest as difficulties in balance, ocular fixation, or fine motor tasks (11). The cerebellum therefore plays a central role linking motor and cognitive domains, and postural instability may represent a behavioral marker of broader cerebellar inefficiency in SLD (12).

In addition to neurobiological mechanisms, attention and body composition can influence postural control. Children with SLD frequently present with attentional deficits, and those with combined motor and attention problems show greater instability (13). Likewise, higher body-mass index (BMI) has been associated with increased body sway and delayed postural adjustments, suggesting that biomechanical factors may exacerbate balance difficulties (14). These interactions highlight the importance of considering attentional and physical variables when evaluating postural performance in SLD.

Although postural instability has been reported in specific learning disorders, findings remain inconsistent. Some studies have demonstrated significant increases in body sway or center-of-pressure displacement, whereas others have found no differences compared to typically developing peers. Previous research has investigated postural control in dyslexic children using diverse approaches, including large-scale cohorts, task-based paradigms, and intervention studies (15,16,18). However, few studies have examined the influence of covariates such as attention and intelligence on postural performance. The present study therefore aimed to compare static and dynamic postural control under two visual conditions (eyes open and eyes closed) in children with and without SLD, while controlling for attentional and intellectual factors to determine whether postural instability represents a secondary consequence of cognitive deficits or an independent marker of motor involvement.

METHOD

Participants

The study included 70 children aged 7–11 years, comprising 41 with SLD and 29 typically developing controls. To form the SLD group (SLDG), all files of children (n = 790) registered with a diagnosis of SLD in the hospital registry system were reviewed with the permission of hospital management. Among these, 529 children aged 7–11 years were screened, and 138 children who had been followed up in the child psychiatry clinic between 2018 and 2019 were included in the preliminary pool. Sixty-four children whose contact information was up to date and who met DSM-5 criteria for SLD were successfully reached by telephone. After the children and their parents were informed about the study, 43 children agreed to participate and were scheduled for assessments at the child psychiatry and physical therapy and rehabilitation clinics. Two children who did not attend their appointments were excluded, resulting in a final sample of 41 participants.

For the control group (CG), 40 typically developing children were initially recruited from local primary schools in the same geographical area and comparable socioeconomic backgrounds. However, 11 children did not attend the scheduled evaluation sessions due to logistical reasons (e.g., scheduling conflicts or family availability) and were therefore excluded, resulting in a final sample of 29 participants. Group matching was used to ensure compa-

rable mean age and sex distribution between the SLD and control groups. Control participants were free of learning problems, as confirmed by parent and teacher reports and a brief clinical interview.

Exclusion criteria for both groups included neurological or chronic medical conditions, physical disability, intellectual disability, autism spectrum disorder, psychotic disorder, adoption, or institutionalization. All participants were native Turkish speakers and attended regular educational settings representative of the urban school-age population served by the clinic. The SLDG comprised 15 girls (36.6%) and 26 boys (63.4%), while the control group included 10 girls (34.5%) and 19 boys (65.5%).

The study was approved by the Clinical Research Ethics Committee of the Marmara University School of Medicine (Decision No: 09.2018.205) and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from the parents, and verbal assent was obtained from all participating children prior to enrollment.

Procedure

The parents of the children were contacted by telephone and scheduled for appointments at the child psychiatry clinic and the physical therapy and rehabilitation clinic. A child and adolescent psychiatrist conducted mental status examinations of 41 children in the SLD group and 29 children in the CG, as well as their parents, using the K-SADS-PL. The diagnosis of SLD was confirmed according to DSM-5 criteria through a structured clinical interview conducted by the same psychiatrist, together with a review of prior educational and clinical records when available.

During the psychiatric evaluation, which lasted approximately 45 minutes, parents completed a sociodemographic data form, the SNAP-IV, and the Developmental Coordination Disorder Questionnaire (DCDQ'07), a parent-report screening instrument designed to identify children at risk for developmental coordination difficulties. As the DCDQ'07 is a screening measure rather than a diagnostic tool, the results were interpreted in conjunction with the clinical evaluation. To estimate the children's intellectual level, the Vocabulary and Block Design subtests of the Wechsler Intelligence Scale for Children–Revised (WISC-R) were administered.

Following the psychiatric assessment, each child underwent postural control and balance testing at the physical therapy and rehabilitation clinic. These assessments were conducted by a physical therapy specialist and lasted approximately 30 minutes. Body mass index (BMI) was also measured at the same clinic while the children were wearing light indoor clothing and no shoes.

All evaluations were conducted individually in a quiet clinical setting and followed the same standardized order for all participants to ensure procedural consistency. Each session was completed within approximately 75 minutes in total. Both the children and their parents were informed about the procedures and instructed on how to proceed.

Materials

Sociodemographic Questionnaire

Parents completed a questionnaire providing information on the child's age and sex, parental education level, number of family members, and family income.

Wechsler Intelligence Scale for Children–Revised (WISC-R): In the present study, the WISC-R was administered to both groups to estimate full-scale IQ scores (19). The Turkish adaptation of the WISC-R was developed by Savaşır and Şahin (20). The WISC-R comprises two main sections—verbal and performance—each including six subtests assessing distinct aspects of intelligence. In this study, only the Vocabulary and Block Design subtests were administered. The Block Design subtest consists of 11 items that assess visual discrimination, organization, visuomotor coordination, and processing speed. The Vocabulary subtest measures the ability to define and describe words and concepts, reflecting verbal reasoning and long-term

memory. Estimated IQ scores were calculated based on the formula derived from the Vocabulary and Block Design subtests (21).

Swanson, Nolan, and Pelham Scale–IV (SNAP-IV): The Swanson, Nolan, and Pelham Scale–IV (SNAP-IV), developed as part of the Multimodal Treatment Study for Attention-Deficit/Hyperactivity Disorder (MTA), was completed by parents (22). The first 18 items assess ADHD symptoms based on DSM-IV criteria—nine for inattention and nine for hyperactivity/impulsivity—rated on a 4-point Likert scale from 0 (not at all) to 3 (very much). Total scores, inattention subscale scores, and hyperactivity/impulsivity subscale scores were calculated and labeled as SNAP-Total, SNAP-I, and SNAP-H/I, respectively.

Developmental Coordination Questionnaire (DCDQ'07): Motor coordination was assessed using the parent-report Developmental Coordination Questionnaire (DCDQ'07) (23). The DCDQ'07 is a 15-item, 5-point Likert-type screening tool for children aged 5–15 years, evaluating motor performance across three domains: Control During Movement, Fine Motor/Handwriting, and General Coordination. Lower scores indicate greater motor difficulties. The revised version has demonstrated good internal consistency (Cronbach's $\alpha > .85$) and satisfactory sensitivity and specificity. The Turkish version has been shown to have acceptable validity and reliability in pediatric samples (24). As a screening instrument, DCDQ'07 results were interpreted alongside comprehensive clinical evaluation and additional assessment measures.

Kiddie Schedule for Affective Disorders and Schizophrenia for School-Age Children – Present and Lifetime Version (K-SADS-PL): Parents and children were interviewed using the Turkish version of the Kiddie Schedule for Affective Disorders and Schizophrenia – Present and Lifetime Version (K-SADS-PL-T) to identify current and lifetime psychiatric diagnoses. The K-SADS-PL is a semi-structured diagnostic interview developed by Kaufman et al. (1997) and adapted to Turkish by Gökler et al. (25,26). It assesses present and past psychopathology in children and adolescents through interviews with both the child and parent, followed by a clinician's best-estimate diagnosis. Diagnoses not covered by the K-SADS-PL-T were determined through a clinical interview based on DSM-5 diagnostic criteria.

NeuroCom Balance Master

Postural balance was assessed using the NeuroCom Balance Master® system with the Modified Clinical Test of Sensory Interaction on Balance (mCTSIB). This method has been shown to be reliable for evaluating postural control in healthy children aged 9–11 years (27, 28).

Each child's postural sway was evaluated under four experimental conditions:

1. Hard surface, eyes open (HSEO)
2. Hard surface, eyes closed (HSEC)
3. Foam surface, eyes open (FSEO)
4. Foam surface, eyes closed (FSEC)

The hard surface condition involved standing directly on the force plate, while in the foam surface condition, a 30 × 30 cm foam pad was placed on the plate to reduce somatosensory input. Participants stood upright during each condition while the system recorded postural oscillation velocity (°/s). Each condition was repeated three times, and the mean oscillation rate was used for analysis (29). Postural sway velocity (°/s) was automatically calculated by the system, with higher values indicating greater body sway and poorer postural stability. This parameter reflects the participant's ability to integrate visual, vestibular, and somatosensory inputs to maintain balance under varying sensory conditions.

Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics for Windows, version 22.0 (IBM Corp., Armonk, NY, USA). The adequacy of the sample size was verified through an a priori power analysis using G*Power. Assuming a medium effect size ($d = 0.5$), $\alpha = 0.05$, and desired power of 0.72, a total sample of 70 participants was determined to

Table 1. Sociodemographic characteristics of the SLD and control groups

Variable	SLDG (n = 41) Mean ± SD	CG (n = 29) Mean ± SD	Test / p
Age (years)	9.41 ± 0.92	9.70 ± 1.09	Z = −0.870, p = .420
Maternal age (years)	35.80 ± 5.41	35.45 ± 3.44	t = 0.312, p = .756
Paternal age (years)	41.39 ± 7.36	39.10 ± 3.45	Z = −0.717, p = .473
Monthly per capita income (TL/month)	642.68 ± 479.11	1306.90 ± 1262.56	Z = −3.684, p < .001
Variable	N (%)	N (%)	
Maternal education level			
Primary school graduate	30 (73.2%)	16 (55.2%)	
High school graduate	8 (19.5%)	4 (13.8%)	
University graduate	3 (7.3%)	9 (31.0%)	x† = 6.735, p = .034
Paternal education level			
Primary school graduate	31 (75.6%)	11 (37.9%)	
High school graduate	9 (22.0%)	10 (34.5%)	
University graduate	1 (2.4%)	8 (27.6%)	x† = 13.356, p = .001

Note. Data are presented as mean ± standard deviation (SD) or n (%). Independent samples *t* tests were used for normally distributed continuous variables, whereas Mann–Whitney U tests were used for non-normally distributed variables. Z denotes the Mann–Whitney U test statistic; x† denotes the chi-square test statistic. Bold values indicate statistically significant differences ($p < .05$).

be sufficient.

The normality of continuous variables was examined using the Kolmogorov–Smirnov test. Depending on the distribution, between-group comparisons were performed using Student's t-test or the Mann–Whitney U test. The chi-square (χ^2) test was used for categorical variables.

Bivariate Pearson correlation analyses were conducted to examine the relationships among postural control parameters (HSEO, HSEC, FSEO, FSEC), WISC-R subtests (Vocabulary and Block Design), and SNAP-IV subscales (SNAP-I, SNAP-H/I, SNAP-Total). Partial correlation analyses were subsequently performed to evaluate the associations between postural control parameters and WISC-R scores while controlling for SNAP-I scores. To further examine group differences while controlling for potential confounders, two separate analyses of covariance (ANCOVA) were conducted with group (dyslexia vs. control) as the independent variable and postural control scores as the dependent variables. In Model 1, SNAP-I and the WISC-R Vocabulary subtest score were included as covariates. In Model 2, the DCDQ'07 total score was entered as a covariate to evaluate whether group differences in postural control remained after accounting for developmental coordination difficulties.

Finally, multiple linear regression analyses were conducted separately for each postural control parameter (HSEO, HSEC, FSEO, FSEC) to identify predictors of balance performance. Body mass index (BMI), SLD group status (SLD vs. control), and SNAP-I scores were entered as predictors in the models. Preliminary analyses confirmed that the assumptions of normality, linearity, multicollinearity, and homoscedasticity were not violated. All statistical tests were two-tailed, and $p < 0.05$ was considered statistically significant.

RESULTS

Demographics and Clinical Characteristics

Mean age in the SLDG was 9.41 ± 0.92 years versus 9.70 ± 1.09 years in the CG; the difference was not significant (Z = –0.870, p = .420). The proportion of girls was similar between groups (36.6% vs. 34.5%; $\chi^2 = 0.033$, p = .856). Mean maternal and paternal ages did not differ significantly (maternal: t = 0.312, p = .756; paternal: Z = –0.717, p=.473). Monthly per capita income was significantly lower in the SLDG (642.68 ± 479.11 TL) than in the CG (1306.90 ± 1262.56 TL; Z=–3.684, p<.001). Fathers in the CG had higher education levels (χ^2 =13.356, p=.001), whereas maternal education also differed significantly between groups (χ^2= 6.735, p=.034). Detailed sociodemographic and physical characteristics are presented in Tables 1 and 2. Table 2 presents the anthropometric characteristics of participants. Mean BMI was significantly higher in girls in the SLDG than in those in the control group (t=2.140, p=.044), while boys in the CG were significantly taller and had higher height percentiles (t=–2.583, p=.013; Z=–1.999, p =.046).

In the SLDG (n = 41), 34 participants (82.9%) had attention-deficit hyperactivity disorder (ADHD), 19 (46.3%) had an anxiety disorder, 17 (41.5%) had

Table 2. Sex-specific anthropometric characteristics of the SLD and control groups

Variable	SLDG (Mean ± SD)	CG (Mean ± SD)	Test / p
Boys			
Height (cm)	134.11 ± 9.17	140.78 ± 7.63	t = -2.583, p = .013
Height percentile	43.10 ± 29.55	63.67 ± 36.87	t = -2.077, p = .044
Weight (kg)	34.69 ± 9.46	37.98 ± 7.88	t = -1.233, p = .224
Weight percentile	57.29 ± 33.44	68.86 ± 30.31	t = -1.192, p = .240
BMI (kg/m†)	19.10 ± 3.52	19.03 ± 2.80	t = 0.078, p = .938
Girls			
Height (cm)	135.33 ± 8.13	140.22 ± 11.50	t = -1.220, p = .235
Height percentile	49.82 ± 30.51	51.69 ± 34.37	Z = -0.030, p = .976
Weight (kg)	37.60 ± 11.07	33.97 ± 5.63	Z = -0.628, p = .530
Weight percentile	70.34 ± 26.59	48.58 ± 29.19	t = 1.872, p = .075
BMI (kg/m†)	20.21 ± 3.99	17.21 ± 1.57	t = 2.140, p = .044

Note. Data are presented as mean – standard deviation (SD). Independent samples *t* tests were used for normally distributed variables, whereas Mann□Whitney U tests (reported as Z statistics) were used for non-normally distributed variables. BMI = body mass index.

developmental coordination disorder (DCD), 7 (17.1%) had oppositional defiant disorder (ODD), 3 (7.3%) had a tic disorder, and 1 (2.4%) had depressive disorder, whereas in the CG (n = 29), 5 participants (17.1%) had ADHD, 9 (31.0%) had an anxiety disorder, and 1 (3.4%) had depressive disorder. ADHD ($\chi^2 = 22.52$, $p < .001$), ODD ($\chi^2 = 5.48$, $p = .02$), and DCD ($\chi^2 = 15.88$, $p < .001$) were significantly more frequent in the SLD group, whereas anxiety, tic, and depressive disorders did not differ significantly between groups (all $p > .05$). Overall, 36 participants in the SLD group (87.8%) and 4 participants in the control group (13.8%) had at least one comorbid psychiatric diagnosis ($\chi^2 = 37.99$, $p < .001$).

The control group obtained significantly higher scores on the WISC-R Vocabulary and Block Design subtests and on the estimated IQ. The SLD group had significantly higher scores on the SNAP-I, SNAP-H/I, and SNAP-Total subscales (all $p < .01$). The SLD group also demonstrated significantly lower DCDQ'07 total scores compared with the control group ($p < .001$), suggesting greater developmental coordination difficulties in the SLD group. Postural control performance differed significantly between groups across all conditions of the mCTSIB. The SLD group demonstrated higher sway velocities (poorer stability) in both hard-surface (HSEO, HSEC) and foam-surface (FSEO, FSEC) conditions (all $p < .001$). Corresponding effect sizes (Cohen's $d = 0.70–1.63$) indicated large between-group differences. Higher sway velocity scores on the mCTSIB indicate greater postural instability and reduced sensory integration efficiency. Descriptive and comparative results are summarized in Table 3.

Table 3. Comparison of cognitive, attentional, motor coordination, and postural control measures between the SLD and control groups

Variable	SLDG (Mean ± SD)	CG (Mean ± SD)	Statistical analysis	Cohen□s d
WISC-R Vocabulary subtest (raw score)	6.75 ± 2.37	11.44 ± 2.52	t = -7.897, p < .001	1.93
WISC-R Block Design subtest (raw score)	10.50 ± 2.66	14.02 ± 3.17	Z = -4.200, p < .001	1.19
WISC-R Verbal score	77.92 ± 16.15	109.86 ± 16.90	t = -7.993, p < .001	1.89
WISC-R Performance score	102.56 ± 17.99	126.27 ± 20.21	Z = -4.263, p < .001	1.23
Estimated IQ	89.66 ± 12.43	120.86 ± 17.73	Z = -5.972, p < .001	2.03
SNAP-I	13.43 ± 4.78	5.62 ± 5.67	Z = -5.135, p = .001	1.46
SNAP-H/I	9.78 ± 6.09	5.89 ± 4.56	Z = -2.748, p = .006	0.70
SNAP-Total	23.21 ± 9.25	11.51 ± 8.22	t = 5.453, p < .001	1.32
DCD-Q7	49.60 ± 12.56	64.75 ± 8.70	t = -5.606, p < .001	1.36
HSEO	0.75 ± 0.30	0.51 ± 0.12	Z = -4.086, p < .001	1.06
HSEC	0.96 ± 0.52	0.62 ± 0.15	Z = -3.457, p = .001	0.81
FSEO	1.58 ± 0.52	0.88 ± 0.24	Z = -5.572, p < .001	1.63
FSEC	2.07 ± 0.62	1.34 ± 0.25	Z = -4.772, p < .001	1.41

Note. WISC-R=Wechsler Intelligence Scale for Children-Revised; SNAP-IV = Swanson, Nolan, and Pelham Rating Scale□IV; SNAP-I =Inattention subscale; SNAP-H/I = Hyperactivity/Impulsivity subscale; SNAP-Total = Total score; DCDQ□07≠Developmental Coordination Disorder Questionnaire-2007; HSEO = Hard surface-eyes open; HSEC=Hard surface-eyes closed; FSEO=Foam surface-eyes open; FSEC = Foam surface-eyes closed. Independent samples t tests were used for normally distributed continuous variables, whereas Mann-Whitney U tests (reported as Z values) were used for non-normally distributed variables. (0.20 = small, 0.50 = medium, 0.80 = large).

Table 4. Pearson correlation coefficients (r) between postural control parameters and cognitive, attentional, and motor measures

Measure	WISC-R Vocabulary subtest score	WISC-R Block Design subtest score	SNAP-I	SNAP-H/I	SNAP-Total	DCD-Q
HSEO	r = -.318, p = .008	r = -.153, p = .211	r = .300, p = .012	r = .267, p = .026	r = .330, p = .005	*r = -0.304 p = 0.010*
HSEC	r = -.337, p = .005	r = -.223, p = .066	r = .298, p = .012	r = .110, p = .364	r = .243, p = .043	*r = -0.252 p = 0.036*
FSEO	r = -.457, p < .001	r = -.308, p = .010	r = .452, p < .001	r = .295, p = .013	r = .438, p < .001	*r = -0.364 p = 0.002*
FSEC	r = -.460, p < .001	r = -.253, p = .036	r = .257, p = .032	r = .179, p = .139	r = .255, p = .033	*r = -0.309 p = 0.009*

Note. ADHD = Attention-Deficit/Hyperactivity Disorder; HSEO = Hard Surface-Eyes Open; HSEC = Hard Surface-Eyes Closed; FSEO = Foam Surface-Eyes Open; FSEC = Foam Surface-Eyes Closed; SNAP-I = Swanson, Nolan, and Pelham Scale Inattention Subscale; SNAP-H/I = Swanson, Nolan, and Pelham Scale-Hyperactivity/Impulsivity Subscale; SNAP-Total = Swanson, Nolan, and Pelham Scale-Total Score. DCDQ 07 Developmental Coordination Disorder Questionnaire-2007. Values represent Pearson correlation coefficients (r). p < .05 indicates statistical significance.

Correlations Between Postural Control, Cognitive Performance, Attention, and Motor Coordination

Pearson correlation analyses (Table 4) were performed for the combined sample (N = 70). Poorer postural stability (higher sway velocity) was significantly associated with lower WISC-R Vocabulary subtest scores (r = –.46 to –.32, p < .01) and, to a lesser extent, with lower Block Design scores (r = –.31 to –.25, p < .05). In addition, higher sway velocity was positively correlated with SNAP-I and SNAP-Total scores (r = .24 to .45, p < .05), indicating that greater attentional difficulties were associated with poorer postural control. Postural sway parameters were also negatively correlated with DCDQ'07 scores (r = –.36 to –.25, p < .05), suggesting that children with greater developmental coordination difficulties exhibited poorer balance performance. When inattention (SNAP-I) was controlled for, the associations between postural control and Block Design scores became non-significant (all p > .10), whereas the negative association with Vocabulary scores remained significant under the FSEO and FSEC conditions (r = –.301, p = .013; r = –.396, p = .001). Correlation analyses were conducted for the combined sample to capture the full variability across participants and maximize statistical power.

ANCOVA Results: Postural Control After Adjustment for Attentional, Cognitive, and Motor Factors

To further examine whether group differences in postural control remained after adjusting for potential confounders, two separate analyses of covariance (ANCOVA) were conducted.

In the first model, SNAP-I and WISC-R Vocabulary subtest scores were included as covariates. After adjusting for these variables, the SLD group exhibited significantly greater postural sway than the control group in the HSEO ($F(1, 68) = 7.81$, $p = .007$, $\eta p^2 = .11$), FSEO ($F(1, 68) = 15.22$, $p < .001$, $\eta p^2 = .19$), and FSEC ($F(1, 68) = 16.17$, $p < .001$, $\eta p^2 = .20$) conditions. The difference in HSEC did not reach statistical significance ($F(1, 68) = 2.08$, $p = .155$, $\eta p^2 = .03$). In the second model, DCDQ'07 total scores were included as a covariate to account for parent-reported motor coordination difficulties, and the SLD group remained significantly different from the control group across all postural control parameters, including HSEO ($F(1, 67) = 8.99$, $p = .004$, $\eta p^2 = .12$), HSEC ($F(1, 67) = 7.22$, $p = .009$, $\eta p^2 = .10$), FSEO ($F(1, 67) = 28.91$, $p < .001$, $\eta p^2 = .30$), and FSEC ($F(1, 67) = 22.82$, $p < .001$, $\eta p^2 = .25$).

All ANCOVA assumptions were satisfied, including homogeneity of regression slopes (non-significant group × covariate interactions) and equality of variances as verified by Levene's test. These findings indicate that group differences in postural control remained significant after adjusting for attentional symptoms, verbal abilities, and parent-reported motor coordination difficulties. Importantly, the persistence of these differences after statistical adjustment suggests that postural control deficits in children with SLD may be associated with broader neurodevelopmental mechanisms related to sensorimotor integration; however, these findings should be interpreted cautiously given the presence of overlapping neurodevelopmental and psychiatric comorbidities.

Hierarchical Multiple Regression Analyses

Hierarchical regression results are presented in

Table 5. Hierarchical multiple regression analyses predicting postural control

Independent Variable	HSEO (Beta)	p	HSEC (Beta)	p	FSEO (Beta)	p	FSEC (Beta)	p
Constant	-	< .001	-	< .001	-	< .001	-	< .001
BMI	-0.277	.012	-0.135	.243	0.066	.496	0.073	.482
Diagnosis of SLD	0.471	< .001	0.324	.026	0.580	< .001	-0.662	< .001
SNAP-I	0.048	.719	0.141	.328	0.112	.356	-0.175	.176
Model summary	R^2 = .282	F(3,65)=8.489, p<.001	R^2 = .177	F(3,65)=4.659, p=.005	R^2= .417	F(3,65)=15.498, p<.001	R^2= .344	F(3,65)=11.344, p<.001
Adjusted R^2	.249		.136		.390		.315	

Note. Abbreviations: HSEO = Hard surface-eyes open; HSEC = Hard surface-eyes closed; FSEO = Foam surface-eyes open; FSEC = Foam surface-eyes closed; Beta = standardized regression coefficient; BMI = Body Mass Index; SNAP-I = Swanson, Nolan, and Pelham Scale-Inattention Subscale. Predictors were entered hierarchically into the regression models (Step 1: BMI; Step 2: SLD diagnosis [SLD = 1, control = 0]; Step 3: SNAP-I).

Table 5. Separate models were computed for each postural condition (HSEO, HSEC, FSEO, FSEC). Body mass index (BMI) was entered at Step 1, SLD diagnosis at Step 2 (dummy-coded: SLD = 1, control group = 0), and inattention (SNAP-I) at Step 3. All regression models were statistically significant: HSEO (R^2 = .28, F(3, 65) = 8.49, p < .001), HSEC (R^2 = .18, F(3, 65) = 4.66, p = .005), FSEO (R^2 = .42, F(3, 65) = 15.50, p < .001), and FSEC (R^2 = .34, F(3, 65) = 11.34, p < .001). Multicollinearity diagnostics indicated acceptable levels of collinearity among predictors (VIF < 2.0; tolerance > .50). In the HSEO model, both BMI (β = –.28, p = .012) and SLD diagnosis (β = –.47, p < .001) were significant predictors of postural performance. In the FSEO and FSEC models, only SLD diagnosis remained a significant predictor (β = –.58 and β = –.66, respectively; both p < .001). SNAP-I did not significantly predict postural control performance in any of the models (all p > .10).

Overall, the models explained between 18% and 42% of the variance in postural control measures. The consistent predictive effect of SLD diagnosis across postural conditions highlights its clinical relevance as a determinant of balance performance.

Post-hoc power analyses conducted using G*Power 3.1 for between-group comparisons, correlational analyses, and regression models indicated achieved statistical power (1–β) ranging from .88 to .99 for large effects, confirming adequate sensitivity to detect meaningful group differences. Taken together, these findings suggest that SLD diagnosis represents the most consistent predictor of postural control performance across different sensory conditions.

DISCUSSION

The present study compared postural stability between children with SLD and typically developing controls and further examined factors associated with postural control. In addition to cognitive and attentional measures, developmental coordination difficulties were also considered in the analyses. In our sample, postural control parameters were associated with several neurocognitive factors, including verbal abilities (Vocabulary subtest of the WISC-R), visuospatial abilities (Block Design subtest), attention scores, and motor coordination (DCDQ'07 scores). When attentional symptoms were controlled for, the association between visuospatial abilities and postural control was no longer significant, whereas the relationship between verbal abilities and postural control persisted under foam surface conditions. Importantly, group differences in postural stability remained observable after adjusting for attentional symptoms, verbal abilities, and developmental coordination scores; however, these findings should be interpreted within the context of a clinically complex and comorbid sample.

From a broader neurodevelopmental perspective, motor coordination and sensorimotor integration difficulties are increasingly recognized as shared features across multiple neurodevelopmental conditions. Contemporary models such as the ESSENCE framework emphasize that cognitive, behavioral, and motor difficulties frequently co-occur across disorders rather than representing entirely distinct diagnostic entities (Gillberg, 2010).

A large population-based cohort study of approximately 13,000 children aged 10–11 years who were screened for SLD reported that potentially affected

children showed weaker motor skills, even after accounting for literacy levels. More recent evidence also supports the presence of motor difficulties in children with dyslexia. A recent meta-analysis reported that children and adolescents with dyslexia show significantly poorer performance across multiple motor tasks compared with typically developing peers, highlighting the close relationship between motor and academic functions (31). Similarly, McPhillips and Sheehy (2004) observed that children with poor reading skills exhibited impairments in static and dynamic balance tasks, although these were not significantly associated with a diagnosis of SLD (32). Given these findings, researchers have increasingly examined postural stability in children with SLD to better understand the interplay between cognitive and motor functions.

Studies using center-of-pressure (CoP) measures have shown that postural sway along the anteroposterior and lateral axes is significantly greater in children with SLD (8,33). Consistent with these findings, previous studies have suggested that postural instability in dyslexia may reflect broader sensorimotor integration difficulties rather than deficits restricted solely to academic skills (34). Furthermore, all children, regardless of diagnosis, demonstrated improved postural stability when the distance to the visual fixation point was reduced (35). Legrand et al. (2012) reported that both SLD and control groups exhibited weaker postural control during a reading task, but this effect was significantly more pronounced in children with SLD (36). Similarly, tasks requiring attention and cognitive engagement, such as reading or visual fixation, have been shown to negatively affect postural control in SLD (17). The use of dual-task paradigms in SLD is based on the notion that such conditions minimize conscious compensatory strategies, thereby revealing subtle deficits in motor automaticity that are not evident under single-task conditions.

Consistent with these observations, children with SLD in the present study demonstrated greater postural impairments than those in the control group. Even after controlling for attentional processes, the relationship between verbal abilities and postural control remained significant under foam-surface conditions. Verbal abilities have previously been linked to motor difficulties (32), suggesting that attentional demands involved in reading and motion perception may influence CoP oscillations in both SLD and control groups. Consistent with previous findings, the current study showed that children with SLD performed worse than controls on most postural control parameters, even when attention and verbal ability scores were included as covariates (37). Importantly, these group differences remained significant after additionally adjusting for parent-reported motor coordination difficulties as assessed by DCDQ'07 scores, suggesting that the observed postural instability in the SLD group may not be entirely explained by attentional, cognitive, or motor coordination differences alone, although the contribution of overlapping neurodevelopmental and psychiatric comorbidities cannot be ruled out. Taken together, these findings suggest that balance impairments observed in children with SLD may reflect broader neurodevelopmental mechanisms rather than merely secondary consequences of attentional, cognitive, or motor coordination difficulties. It should also be noted that the DCDQ'07 is a parent-report screening instrument and does not provide a formal clinical diagnosis of developmental coordination disorder. Therefore, the present findings reflect adjustment for parent-reported motor coordination difficulties rather than confirmed DCD.

Importantly, the SLD group in the present study represents a clinically referred population with high rates of comorbid conditions, including ADHD and developmental coordination difficulties. Although statistical adjustments were applied, it is not possible to fully disentangle the specific contribution of SLD from overlapping neurodevelopmental and psychiatric features. In addition, socioeconomic differences between groups, including parental education and income levels, may have broader developmental implications, such as differences in access to structured activities and environmental stimulation, and residual confounding related to these factors cannot be excluded. Furthermore, although attentional symptoms were statistically controlled using SNAP-I scores, this approach reflects dimensional symptom severity rather than categorical diagnosis and therefore does not fully capture the broader clinical impact of

comorbid ADHD, which was more prevalent in the SLD group. Accordingly, the findings should be interpreted cautiously and are more reflective of a clinically complex SLD sample rather than a disorder-specific effect.

A notable finding of this study was that BMI and SLD diagnosis were associated with postural stability in the HSEO condition, explaining approximately one-third of the variance in the model. While BMI was significant only in this specific condition, SLD diagnosis remained a significant statistical predictor of postural performance across postural conditions, particularly on the foam surface, where it explained up to 50% of the variance. Previous studies have reported that body weight and height influence postural control in children and that BMI may be a stronger predictor of balance when visual information is available (14). In line with these findings, BMI affected postural control under hard-surface, eyes-open conditions but lost significance in more challenging conditions (e.g., foam surface or eyes closed). These findings suggest that postural imbalance in SLD may involve complex multisensory processes requiring increased integration of sensory inputs to maintain stability. According to the cerebellar deficit hypothesis proposed by Nicolson, Fawcett, and Dean (2001), motor coordination and balance difficulties in dyslexia may be related to broader alterations in cerebellar-mediated sensorimotor integration rather than deficits limited to reading processes (38). These mechanisms warrant further investigation in larger and longitudinal studies.

From a clinical perspective, these findings suggest that motor and sensorimotor characteristics may represent part of the broader neurodevelopmental profile of children with SLD rather than merely secondary consequences of academic or attentional difficulties. Assessing motor and balance functions may therefore provide additional insight into the neurodevelopmental characteristics of children with SLD and contribute to more comprehensive clinical evaluations. In addition, the findings highlight the potential importance of screening for motor coordination difficulties, such as developmental coordination disorder, in children presenting with learning problems. Early identification of motor and balance difficulties may inform multidisciplinary assessment and support the development of targeted motor or sensorimotor interventions.

The present study has several limitations. First, the sample size was relatively small, which may limit the generalizability of the findings. Future studies with larger and more diverse samples are needed to confirm these results. Second, attentional symptoms were assessed using parental reports (SNAP-IV) rather than objective behavioral attention measures. Including performance-based attention assessments in future research may help to further clarify the relationship between attention and postural control. Third, visual and auditory factors that may influence postural control were not systematically evaluated. Sensory impairments can affect balance performance and may contribute to postural instability. In addition, postural control was not examined during reading or other dual-task conditions, which might provide additional insight into the interaction between cognitive load and postural regulation in children with SLD. Another limitation is that socioeconomic differences were observed between the groups, including parental education and monthly income levels. These factors may influence children's access to organized physical activities or sports participation, which could potentially affect balance performance. Information regarding participation in structured physical activity was not available in the present dataset and therefore could not be included in the analyses. Despite these limitations, the study also has several strengths. Postural control was assessed using an objective balance assessment system (NeuroCom Balance Master), and standardized measures of intelligence, attention, and motor coordination (DCDQ'07) were included, allowing several potential confounding factors to be considered in the analyses.

Given the substantial diagnostic overlap among neurodevelopmental disorders, postural impairment may not have diagnostic specificity for SLD and may instead reflect broader neurodevelopmental dysfunction. The present findings suggest that the relationship between SLD and balance is influenced by cognitive and attentional processes, including verbal abilities and attention. However, even after statistically controlling for these factors, balance difficulties remained more frequently

observed in children with SLD compared with typically developing peers within a clinically referred and comorbid sample. These findings support the view that postural instability may represent a transdiagnostic marker of sensorimotor integration difficulties rather than a disorder-specific feature, highlighting the potential value of broader cognitive and motor assessments in clinical evaluation (34).

Ethics Declarations

Conflict of Interest: The authors declare that they have no conflicts of interest, financial or otherwise, related to the material presented in this study.

Ethical Approval: The study was approved by the Clinical Research Ethics Committee of the Marmara University School of Medicine (Decision No: 09.2018.205) and was conducted in accordance with the Declaration of Helsinki.

Informed Consent: Written informed consent was obtained from the parents, and verbal assent was obtained from all participating children prior to enrollment.

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