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# Sensory Organization of Balance Control in children with Developmental Coordination Disorder

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## Highlights

> Children with DCD demonstrate deficits in functional balance and sensory organization of balance control.
> The suboptimal balance ability can partly explain the lower participation diversity in this group of children.
> Balance training program for children with DCD should be multidimensional and designed to enhance functional balance and sensory organization ability, thereby improving activity participation.

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# Abstract

This study aimed to (1) To compare functional balance performance and sensory organization of postural control between children with and without Developmental Coordination Disorder (DCD), and (2) determine the association between postural control and participation diversity among children with DCD. We recruited 81 children with DCD and 67 typically developing children. Balance was evaluated with the Sensory Organization Test (SOT) and the Movement Assessment Battery for Children-2 (Movement ABC-2). Participation patterns were evaluated using the Children Assessment of Participation and Enjoyment assessment. Analysis of variance was used to compare outcome variables between the two groups. Multiple regression analysis was performed to examine the relationship between participation diversity and balance performance in children with DCD. The DCD group had significantly lower Movement ABC-2 balance scores, SOT-derived equilibrium scores, and sensory ratios than the control group ($p<0.05$). However, only the Movement ABC-2 balance score was significantly associated with participation diversity in children with DCD. After accounting for the effects of age and gender, Movement ABC-2 balance score remained significantly associated with participation diversity, explaining 10.9% of the variance ($F_{change1,77}=9.494$, $p=0.003$). Children with DCD demonstrate deficits in sensory organization of balance control. This suboptimal balance ability contributes to limited participation in activities.

**Keywords:**
Clumsy children
Activity
Postural control
Rehabilitation

## 1. Introduction

Developmental coordination disorder (DCD) is a relatively common motor disorder, affecting 6% of children (APA, 2000). Balance dysfunction is one of the most common sensorimotor impairments observed among children with DCD. Indeed, it has been reported that 73-87% of children with DCD have balance problems (Macnab, Miller, & Polatajko, 2001). The ability to maintain balance requires optimal reception, processing, and integration of sensory information from different systems (i.e., somatosensory, visual, and vestibular).

Several studies have investigated sensory contributions to postural control deficits in children with DCD, and results have been inconsistent (Cherng, Hsu, Chen, & Chen, 2007; Grove & Lazarus, 2007; Inder & Sullivan, 2005). Using the EquiTest Sensory Organization Test (SOT), Grove & Lazarus (2007) evaluated 16 children with DCD and 14 typically developing children and found that the ability to use vestibular feedback for postural control was impaired in children with DCD; somatosensory and visual inputs were therefore weighted more heavily for postural control. In contrast, Cherng et al. (2007) used the modified Clinical Test of Sensory Interaction and Balance (CTSIB) and found that sensory ratio scores, which indicate the ability to use information from the somatosensory, visual, and vestibular systems to maintain balance, was not significantly different between children with DCD (n=20) and their typically developing peers (n=20). These conflicting results may be due to small sample sizes and different testing instruments used across studies. To more accurately characterize the relationship between sensory organization and balance control in children with DCD, it is thus important to use standardized tools and evaluate larger samples.

The suboptimal balance performance demonstrated in children with DCD (Inder & Sullivan, 2005) needs to be addressed in both clinical practice and research, as any bodily impairments, including postural control, may limit activity participation, according to the International Classification of Functioning, Disability and Health model (Grove & Lazarus, 2007; WHO, 2001). Although many daily activities require good postural control (e.g., attending school and playing sports), few studies have explored the relationships among functional balance, sensory organization, and activity participation in children with DCD. Inder & Sullivan (2005) provided the first glimpse into the relationship between motor performance and participation in a sample of four children with DCD, and speculated that poor functional balance may influence activity participation patterns in these children. However, due to the small sample size, no conclusion about the relationship between balance performance and activity participation could be drawn.

The objectives of this study were to (1) compare the functional balance performance, sensory organization of standing balance control between children with DCD and their typically developing peers; and (2) determine the relationships among different aspects of postural control with activity participation diversity among children with DCD.

## 2. Methods

### 2.1. *Study design*

This was a cross-sectional, exploratory study.

### 2.2. *Participants*

Sample size calculations were based on a statistical power of 0.80 and an alpha level of 0.05 (two-tailed). Grove & Lazarus (2007) previously reported SOT composite equilibrium scores of 63.9% (14.1%) and 72.4% (11.7%) for the DCD group (n=16) and control group (n=14) respectively, which translates into a medium to large effect size (0.66). Based on this study, the minimum sample size needed to detect a significant between-group difference in outcomes (objective 1) is 38 for each group (children with DCD and control) (Portney &

Watkins, 2009). Regarding the regression analysis (objective 2), Jarus, Lourie-Gelberg, Engel-Yeger, & Bart (2011) reported that the Movement Assessment Battery for Children-2 (Movement ABC-2) percentile score had fair to good correlation with various activity participation scores (r=0.29–0.64) among children with DCD. Therefore, with three predictors and an effect size of 0.20 (medium to large), a minimum sample size of 59 children with DCD would be required for multiple regression analysis (Portney & Watkins, 2009).

Participants with DCD were recruited from a local Child Assessment Centre and hospital by convenience sampling. Inclusion criteria were: (1) formal diagnosis of DCD according to the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR) (APA, 2000); (2) age 6 to 12 years; (3) study in a regular education framework; and (4) no intellectual impairment. Exclusion criteria were: (1) formal diagnosis of emotional, neurological, or other movement disorders; or (2) significant musculoskeletal or cardiopulmonary conditions that may influence motor performance. For the control group, children with normal development were recruited from the community on a volunteer basis using the same inclusion and exclusion criteria stated above, except that they did not have any history of DCD.

### *2.3. Procedures*

The study was approved by the human subjects ethics review subcommittee of the Hong Kong Polytechnic University and by the Hospital Authority. After explaining the study to each participant and their guardian, written informed consent was obtained. Data were collected by two experienced pediatric physiotherapists. All procedures were conducted in accordance with the Declaration of Helsinki.

#### *2.3.1. Demographic information*

Basic demographic information was obtained by interviewing the children and their guardians.

#### *2.3.2. Sensory organization of balance control*

The SOT, which has demonstrated good reliability and validity, is used to evaluate the sensory organization of balance control in our participants (Di Fabio & Foudriat, 1996; NeuroCom, 2008). During the test, participants stood with bare feet on the platform of the computerized dynamic posturography machine (Smart EquiTest® system, NeuroCom International Inc., Oregon, USA), wearing a security harness to prevent falls. They were instructed to stand quietly with arms resting on both sides of the trunk. Participants were exposed to six different combinations of visual and support surface conditions, in the order specified by the manufacturer’s protocol (Table 1) (NeuroCom, 2008). Each participant was tested three times under each condition.

The device detected the center-of-pressure (COP) trajectory of the participant, which was used to calculate the equilibrium score (ES). ES was defined as a dimensionless score (percentage) representing the participant’s peak amplitude of anteroposterior (AP) sway relative to the theoretical limits of AP stability. An ES of 100 represented no sway, whereas 0 indicated a sway exceeding the limit of stability, resulting in a fall (Nashner, 1997; NeuroCom, 2008).

After obtaining the ES under all six conditions, the mean ES under each testing condition was calculated and used to calculate the somatosensory, visual, and vestibular ratios (Table 2). A high sensory ratio of close to 1 indicated a superior ability to use that particular sensory input to maintain balance (Nashner, 1997). The composite ES was generated, taking into account the mean ES attained under the six testing conditions (NeuroCom, 2008).

### *2.3.3. Functional balance*

The Movement ABC-2 was used to measure functional balance. It is a standardized tool for measuring motor performance in 3- to 16-year-old children that consists of eight tasks for each of the three age ranges. The eight tasks are divided into three domains: manual dexterity, aiming and catching, and balance. Test items in the balance domain include static and dynamic balance tasks (single-leg standing, tandem walking, hopping, etc.). The raw score of each item was converted into the item standard score and domain standard score. The balance domain standard score was the only score used for analysis (Henderson, Sugden, & Barnett, 2007). The test-retest reliability, inter-rater reliability, and criterion-related validity of Movement ABC-2 have been established (Henderson et al., 2007).

### *2.3.4. Out-of-school time activity participation*

The Children's Assessment of Participation and Enjoyment (CAPE) was used to assess participation in out-of-school time activities. CAPE is a reliable and valid self-report measure of participation in outside school activities for children and youth (6–21 years old) (Imms, 2008; King et al., 2004). Telephone or face-to-face interviews were conducted with participants and their guardians to complete the CAPE assessment. The total activity diversity and intensity scores were used for analysis.

## *2.4. Statistical analysis*

Descriptive statistics were used to describe all the relevant variables. The normality of the data was ascertained with the Kolmogorov-Smirnov test. Continuous and categorical demographic variables were compared by independent *t*-test and chi-square test.

To compare the Movement ABC-2 balance domain standard scores, SOT-derived ES and sensory ratios, and CAPE-derived participation scores between groups, multivariate analysis of covariance (MANCOVA) was performed with body mass index (BMI) as the covariate. The Bonferroni adjustment was carried out to reduce the risk of type I error due to multiple comparisons. Effect sizes (indicated by partial eta-square) were computed for between-group comparisons. By convention, small, medium, and large effect sizes were defined as partial eta-square values of 0.01, 0.06, and 0.14, respectively (Portney & Watkins, 2009).

Pearson's correlation coefficients (for continuous variables) or Spearman's rho (for ordinal variables) were used to examine the bivariate association of balance scores (Movement ABC-2 balance domain standard score and SOT composite ES and sensory ratios) with the CAPE total activity scores (diversity and intensity scores) and other relevant variables (e.g., age) among children with DCD. Next, multiple regression analyses were performed to determine which balance parameters were the strongest determinants of the CAPE total diversity and intensity score. Selection of the predictors for regression analysis was based on physiological relevance and results of the bivariate correlation analysis. Age and gender were first entered into the regression model, because these factors may influence activity participation (Bult, Verschuren, Jongmans, Lindeman, & Ketelaar, 2011). The relevant balance parameter (e.g., Movement ABC-2 balance domain standard score) was then entered into the regression model. To avoid multicollinearity, the degree of association among the predictor variables was also assessed. Data were analyzed with SPSS 17.0 (SPSS Inc., Chicago, IL, USA), and a significance level of 0.05 was adopted for all statistical tests (two-tailed).

## 3. Results

### 3.1. *Demographic characteristics*

Basic demographic characteristics of the DCD group (n=81) and the control group (n=67) are outlined in Table 3. No significant difference in age, boy-to-girl ratio, height, or weight was observed between groups in all measured variables except BMI ($p<0.05$).

### 3.2. *Sensory organization and balance performance*

Children with DCD had significantly lower Movement ABC-2 balance domain standard scores than the control group. In addition, the SOT-derived ES for all six test conditions, composite ES, and all three sensory ratio scores were significantly lower among children in the DCD group ($p<0.05$) (Table 4).

### 3.3. *Relationships among balance performance, sensory organization and participation pattern in children with DCD*

Children with DCD showed significantly lower CAPE total activity diversity and intensity scores than the control group (Table 4). A fair correlation ($r=0.318$, $p\leq0.01$) was found between Movement ABC-2 balance domain standard score and CAPE total diversity score in children with DCD. No correlation was found between SOT-derived measures and CAPE-derived scores ($p>0.05$) (Table 4).

### 3.4. *Determinants of diversity of activity participation in children with DCD*

The results of multiple regression analysis showed that, after accounting for age and gender, the Movement ABC-2 balance score remained independently associated with activity participation diversity ($F_{change1,77}=9.494$, $p=0.003$), explaining 10.9% of the variance in the total CAPE diversity score. As a number of children in our DCD group had comorbidities (Table 3), sensitivity analyses were carried out by analyzing only DCD children without comorbidities, with similar results (not shown).

## 4. Discussion

### 4.1. *Sensory organization and balance control in children with and without DCD*

This study revealed that children with DCD had poorer static and dynamic balance performance than typically developing children, as evidenced by their lower Movement ABC-2 balance domain standard score and lower SOT ES. Among the three sensory systems, the visual system appears to be the most critical, as the visual ratio showed the greatest between-group difference (effect size, 0.053), compared with the somatosensory ratio (effect size, 0.036) and vestibular ratio (effect size, 0.027) (Table 4). These findings are consistent with previous studies that reported that static postural sway was more severe (Cherng et al., 2007; Grove & Lazarus, 2007; Inder & Sullivan, 2005) and dynamic balance (e.g., postural muscle activation during dynamic reaching) was altered in children with DCD (Johnston, Burns, Brauer, & Richardson, 2002).

Postural control requires the ability to integrate and appropriately select visual, somatosensory, and vestibular inputs to generate coordinated motor actions (Nashner, 1997). Visual-spatial processing, visual perception, and visual-kinesthetic integration are prerequisites for successful maintenance of postural stability and coordinated movements, but they are usually impaired in children with DCD (Cermak & Larkin, 2002; Wilson & McKenzie, 1998). Difficulty in processing visual information has been found in children with DCD; this results in poor eye–hand coordination (Cermak & Larkin, 2002) and poor visually guided matching of limb orientation (Mon-Williams, Wann, & Pascal, 1999). In the context of balance, we found that children with DCD were less able to use visual information to maintain static posture, as reflected by their significantly lower visual ratio score. Indeed, this impaired ability to use visual information to maintain balance was reported by Inder & Sullivan (2005) and Wann, Mon-Williams, & Rushton (1998), who found that some children with DCD exhibited postural control problems and tended to use visual information in a manner similar to that of nursery school children (Wann et al., 1998).

Recent neuroimaging studies have provided insight into why children with DCD have difficulty maintaining balance when forced to rely on visual input. Kashiwagi, Iwaki, Narumi, Tamai, & Suzuki (2009) showed reduced activity in the left posterior parietal cortex of the brain in boys with DCD. The parietal cortex integrates multimodal sensory information relevant to motor control; its dysfunction can cause visual-motor deficits that result in poor balance (Kashiwagi et al., 2009). In addition, Knuckey, Apsimon, & Gubbay (1983) reported abnormalities including nonspecific ventricular dilatation and cortical sulcal prominence in clumsy children, suggesting poor visual-motor integration. This may be another cause underlying the visual-balance problem associated with DCD.

Kinesthetic proprioceptive input provides continuous feedback about static posture and superimposed movements of the body and is therefore also important for postural control (Laszlo, 1990). As children with DCD have deficits in kinesthetic perception and cross-modal integration (e.g., visual-kinesthetic) (Piek & Coleman-Carman, 1995; Piek & Dyck, 2004), it is reasonable that this group of children were less able to use somatosensory feedback for postural stability. Consistent with our finding, Inder & Sullivan (2005) reported that three of the four children with DCD in their study had a lower somatosensory ratio than the norm. In contrast, Grove & Lazarus (2007) reported similar somatosensory ratios in the SOT for the DCD group (n=16) and control group (n=14) groups. This finding could be attributed to low statistical power because of their relatively small sample size. Moreover, the boy to girl ratio differed between the DCD and comparison groups, which may have confounded the results (Grove & Lazarus, 2007).

Among the three sensory systems, vestibular system is the most important and reliable sensor for postural control because it measures acceleration of the head relative to gravity (Nashner, 1997). A normal functioning vestibular system is critical for balance control, particularly in challenging postural conditions. We found that children with DCD were less able to use vestibular information to maintain balance, as reflected by their significantly lower vestibular ratio (14% lower; small to medium effect size of 0.027). This is consistent with previous studies reporting that vestibular function may be impaired in children with DCD (Grove & Lazarus, 2007; Inder & Sullivan, 2005). Inder & Sullivan (2005) reported that the mean vestibular score of children with DCD aged 6 to 12 years was lower than that of typically developing children aged 3 to 4 years (Inder & Sullivan, 2005; Hirabayashi & Iwasaki, 1995). We found a smaller discrepancy in vestibular scores between children with DCD and the norm (Hirabayashi & Iwasaki, 1995), and it was the least affected sensory system, as reflected by the smallest between-group difference and smallest effect size (Table 4). One possible explanation for this finding is that the vestibular system takes longer to reach full maturation compared with the other two sensory systems in typically developing children. The ability to use vestibular information to maintain balance is not fully optimal until 14 to 15 years of age (Ferber-Viart, Ionescu, Morlet, Froehlich, & Dubreuil, 2007). Because the children in our study were younger than 13 years, those in the control group may not have had optimal vestibular function. Thus, the between-group difference in vestibular function may have been less apparent.

Only one previous study (Cherng et al., 2007) reported no deficits in all three sensory ratios in children with DCD. Although they found lower sensory ratios in children with DCD than controls, these differences were not significant. The research group suggested that poor balance (increased COP sway area) in children with DCD might be due to a general deficit in sensory organization rather than problems in individual sensory systems. The difference in results may be attributable to several factors. Their sample size was smaller (each group, n=20) and the participants were younger (4–6 years old) compared with our study (DCD group, n=81; control group, n=67; 6–12 years old). The assessment method also differed. The standardized computerized dynamic posturography device used in our study creates conditions of conflicting sensory inputs through the sway-referenced support and surround, whereas the modified CTSIB used in their study provides only compliant support without the sway-referenced function (Grove & Lazarus, 2007; Inder & Sullivan, 2005; Nashner, 1997). In addition, their participants swayed in different directions to produce the COP sway area. In our study, we calculated the equilibrium score, which is a dimensionless number (percentage) that represented the participant's peak amplitude of AP sway relative to the theoretical limits of AP stability (12.5°) (Nashner, 1997).

### *4.2. Participation patterns and determinants of participation diversity in children with DCD*

Our results agree with findings from previous studies (Jarus et al., 2011), which showed that children with DCD participated in fewer activities (less diverse) and less intensely than their typically developing peers. However, this study provides the first evidence that decreased diversity of activity participation is independently associated with poor functional balance, as measured by Movement ABC-2, accounting for 10.9% of the observed variance. This contribution is considerable, considering that participation itself is multidimensional and is influenced by many factors (e.g., cognitive ability and communication skills) (Bult et al., 2011). In contrast, we found no correlation between SOT-derived balance scores and CAPE diversity score. One potential explanation for this finding is that SOT measures only static standing balance, whereas most out-of-school time activities measured by CAPE (e.g., playing non-team sports, going for a walk or hike, learning to dance) involve both static and dynamic balance in various postures, which could be better captured by the Movement ABC-2 functional balance tests.

Our results confirmed the speculation that poor balance performances may affect activity participation diversity in children with DCD (Inder & Sullivan, 2005). A previous study reported that very poor performance on balance tasks was related to nonparticipation in active and social activities such as football (Smyth & Anderson, 2001). This could be due to anxiety regarding the motor challenges posed by social engagement (Bar-Haim & Bart, 2006).

### *4.3. Clinical implication*

Our results have important clinical and research implications. As children with DCD demonstrate significant deficits in balance ability and sensory organization of balance control, interventions to enhance balance should be an important component of the clinical management of this condition. A balance training program should be multidimensional and designed to (1) improve both static and functional balance, (2) improve sensory organization ability, and (3) avoid a vicious cycle of activity avoidance, poor functional balance performance, and decreased participation in all activities (Barnhart, Davenport, Epps, & Nordquist, 2003). The results of this study also provide the basis of future research to investigate the clinical efficacy of balance training programs on improving balance ability, sensory organization, and activity participation for children with DCD.

### *4.4. Limitations and consideration for future studies*

Some limitations of this study need to be considered. First, this was a cross-sectional study and causality could not be established. Second, our regression model accounted for only 10.9% of the variance in activity participation diversity. Further studies are needed to determine the relative contributions of balance ability and other factors (personal, familial, and environmental) to activity participation diversity (Jarus et al., 2011).

## 5. Conclusions

Children with DCD demonstrate deficits in balance control and sensory organization. This suboptimal balance ability is independently associated with limited participation in activities.

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## Declaration of interest

No funding was provided for this study. The authors have no conflicts of interest that are directly relevant to the content of this paper.

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## Tables

**Table 1. The six testing conditions of the SOT and the sensory ratio analysis**

| SOT | Description |
|---|---|
| **Testing condition** | |
| 1 | Eyes open, fixed support |
| 2 | Eyes closed, fixed support |
| 3 | Sway-referenced[a] vision, fixed support |
| 4 | Eyes open, sway-referenced[a] support |
| 5 | Eyes closed, sway-referenced[a] support |
| 6 | Sway-referenced[a] vision and support |
| **Sensory ratios** | |
| Somatosensory | The ability of the child to utilize somatosensory information to maintain balance (ES condition 2/1). |
| Visual | The ability of the child to utilize visual information to maintain balance (ES condition 4/1). |
| Vestibular | The ability of the child to utilize vestibular information to maintain balance (ES condition 5/1). |

[a] Sway-referenced refers to tilting of the support surface and/or the visual surround about an axis colinear with the ankle joints to directly follow the anteroposterior sway of the subject's center of gravity (NeuroCom, 2008).

**Table 2. Description of scores within each participation dimension**

|  | CAPE dimensions |  |
|---|---|---|
|  | **Diversity** | **Intensity** |
| **Raw data** | Yes/no response to whether an activity was done within past 4 months | Frequency scores:<br>1 = Once/4 months<br>2 = Twice/4 months<br>3 = Once/month<br>4 = 2-3 times/month<br>5= Once/week<br>6 = 2-3 times/week<br>7 = Once/day |
| **Score** | Number of activities in which the child participates. | Sum of frequency score divided by total number of items in scale of interest. |
| **Score range** | Overall: 0-55<br>Formal: 0-15<br>Informal: 0-40<br>Recreational: 0-12<br>Physical: 0-13<br>Social: 0-10<br>Skill-based: 0-10<br>Self-improvement: 0-10 | 0-7 |

**Table 3. Demographic characteristics of the participants**

| | DCD group (n=81) Mean (SD) | Control group (n=67) Mean (SD) | p-value |
|---|---|---|---|
| **Age, year** | 8.07 (1.49) | 8.25 (1.60) | 0.481 |
| **Gender (Male/female), n** | 63/18 | 48/19 | 0.391 |
| **Height, cm** | 130.53 (11.87) | 129.87 (10.41) | 0.720 |
| **Weight, kg** | 33.09 (11.55) | 30.33 (8.69) | 0.109 |
| **BMI, kg/m$^2$** | 18.85 (3.72) | 17.65 (2.97) | 0.035[a] |
| **Comorbidity** | | | |
| **Attention deficit hyperactivity disorder** | 9 | 0 | |
| **Attention deficit disorder** | 9 | 0 | |
| **Dyslexia** | 9 | 0 | |
| **Asperger syndrome** | 5 | 0 | |
| **Autism spectrum disorder** | 1 | 0 | |

[a] $p \leq 0.05$

**Table 4. Comparison of balance ability and participation patterns**

| | DCD group (n=81) Mean (SD) | Control group (n=67) Mean (SD) | p-value | Effect size ($\eta^2_p$) |
|---|---|---|---|---|
| **Movement ABC-2** | | | | |
| Balance standard score | 7.23 (3.09) | 10.70 (2.53) | $<0.001^c$ | 0.295 |
| **Sensory Organization Test** | | | | |
| Equilibrium score | | | | |
| Composite | 55.88 (13.75) | 65.04 (10.08) | $<0.001^c$ | 0.127 |
| Condition 1 | 85.55 (6.96) | 89.83 (4.22) | $<0.001^c$ | 0.119 |
| Condition 2 | 80.37 (10.43) | 87.21 (5.44) | $<0.001^c$ | 0.151 |
| Condition 3 | 78.19 (14.74) | 86.65 (8.18) | $<0.001^c$ | 0.121 |
| Condition 4 | 56.69 (22.14) | 68.08 (15.47) | $0.001^c$ | 0.081 |
| Condition 5 | 37.28 (18.28) | 45.11 (17.27) | $0.010^b$ | 0.045 |
| Condition 6 | 32.71 (21.49) | 44.21 (18.03) | $0.001^c$ | 0.070 |
| Sensory ratio score | | | | |
| Somatosensory ratio | 0.94 (0.10) | 0.97 (0.04) | $0.022^a$ | 0.036 |
| Visual ratio | 0.66 (0.24) | 0.76 (0.16) | $0.005^b$ | 0.053 |
| Vestibular ratio | 0.43 (0.21) | 0.50 (0.19) | $0.049^a$ | 0.027 |
| **CAPE Total activities** | | | | |
| Diversity score | 23.40 (6.74) | 27.94 (4.99) | $<0.001^c$ | 0.082 |
| Intensity score | 108.37 (28.67) | 133.76 (26.61) | $<0.001^c$ | 0.131 |

$^a p \leq 0.05$
$^b p \leq 0.01$
$^c p \leq 0.001$