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Sensory processing patterns in developmental coordination disorder, attention deficit hyperactivity disorder and typical development

Laura Delgado-Lobete, Sonia Pértega-Díaz, Sergio Santos-del-Riego, Rebeca Montes-Montes

University of A Coruña, Faculty of Health Sciences, University of A Coruña, Campus de Oza S/N, A Coruña, Spain

Abstract

Background

Sensory processing difficulties (SPD) are present in children with Developmental Coordination Disorder (DCD) and Attention Deficit and Hyperactivity Disorder (ADHD). However, little is known about sensory processing variability in these disorders.

Objective

The purpose of this study was to explore SPD among children with DCD, ADHD and co-occurring symptoms in comparison to children with typical development (TD) and to determine how potential social confounders may influence these associations.

Methods

The study involved 452 children aged 6–12 years. The Short Sensory Profile-2 was used to assess sensory processing patterns. Multiple linear regressions were utilized to investigate the relationship between DCD, ADHD and co-occurring symptoms and sensory processing patterns, adjusting for social covariates.

Results

Children with DCD and ADHD symptoms showed greater variability of atypical sensory processing patterns compared with TD children. Low registration and sensory sensibility issues were more prevalent in the DCD group. ADHD children showed higher rates of low registration, sensory sensibility and sensory seeking, and all children in the co-occurring symptoms group presented sensory sensibility.

Conclusion

This study reports significant variability in sensory processing among children with DCD, ADHD and co-occurring symptoms using a population-based sample. These differences can contribute to understand how neurological and social factors correlates across diagnoses.

Keywords

Developmental coordination disorder; Attention deficit and hyperactivity disorder; Co-occurring symptoms; Sensory processing; Sensory processing disorder; Sensory patterns

What this paper adds?

This is the first study to explore differences in sensory processing patterns among children with DCD, ADHD and co-occurring symptoms in comparison to typically developing children using a population-based sample and adjusting for social covariates. Our results indicate that children with these disorders show more sensory processing difficulties and greater sensory patterns variability than peers without motor coordination or inattention/hyperactivity issues. Children with co-occurring symptoms experienced more sensory processing variability than any other group. Presence of DCD, ADHD or co-occurring symptoms were significantly and independently associated with atypical sensory processing, but social characteristics such as age, sex and family educational level were also significantly related. These findings highlight the need to consider both sensory processing variability and social background when examining motor coordination or attention/hyperactivity in children with potential neurodevelopmental disorders.

1. Introduction

Developmental Coordination Disorder (DCD) and Attention Deficit and Hyperactivity Disorder (ADHD) are two of the most prevalent neurodevelopmental disorders and their consequences have a long-term impact in everyday life performance (American Psychiatry Association, 2013; Van der Linde et al., 2015). While prevalence rates vary across countries and definitions, it is estimated that DCD is present in at least 6% of schoolchildren, while ADHD prevalence is up to 9.5 % (Blank et al., 2019; Polanczyk, Willcutt, Salum, Kieling, & Rohde, 2014). DCD and ADHD often co-occur and it has been suggested that as many as 50 % of children with ADHD are diagnosed with DCD as well, particularly among clinical samples (Blank et al., 2019). Despite this common co-occurrence, evidence supports that DCD and ADHD are separate disorders with different etiology and distinct neural mechanisms (Gomez & Sirigu, 2015; McLeod, Langevin, Dewey, & Goodyear, 2016). There is evidence that sensory processing difficulties (SPD) are part of the DCD and ADHD phenotypes with significant impact on movement, behavior and everyday performance (Allen & Casey, 2017; Gomez & Sirigu, 2015; Mimouni-Bloch et al., 2018).

Sennsory processing refers to the ability to manage detection, modulation, interpretation and organization of incoming sensory information (Miller, Nielsen, & Schoen, 2012). According to Dunn's Sensory Processing Framework, sensory processing is the emerging result of the interaction between neurological threshold and self-regulation (Dunn, 2016). The neurological threshold refers to the amount of sensory stimuli needed by a person for noticing and responding to it and range from quick to detect (low threshold) to slow to detect (high threshold). In addition, self-regulation refers to the behavioral management of said sensory input. Children with passive strategies do not counteract the stimuli, while children with active self-regulation strategies plan a reaction to counteract it. As result, four sensory processing patterns emerge from the interaction of neurological threshold and self-regulation: low registration or bystander (high threshold and passive self-regulation), seeking or seeker (high threshold and active self-regulation), sensitivity or sensor (low threshold and passive self-regulation) and avoiding or avoider (low threshold and active self-regulation). The child behavior will be heavily influenced by their sensory processing patterns. For example, children with low registration (who detect stimuli slowly and do not try to counteract it) often fail to notice external sensory stimuli and may thus be perceived to be inattention. In addition, difficulties detecting internal proprioceptive input may be perceived as clumsiness (Dunn, 2016).

Sensory processing issues are highly prevalent in children with neurodevelopmental conditions and impact their everyday performance (Jorquera-Cabrera, Romero-Ayuso, Rodriguez-Gil, & Triviño-Juárez, 2017; Mimouni-Bloch et al., 2018). Studies demonstrate that children with ADHD or DCD differ in sensory processing as compared to their typically developing (TP) peers (Allen & Casey, 2017; Pfeiffer, Daly, Nicholls, & Gullo, 2015). Children with ADHD are more likely to seek out sensory input (seeking pattern), be more aware of sensory stimuli (sensor pattern), be more bothered by certain input (avoiding pattern) and also to notice less sensory input than TD children (low registration/bystander pattern) (Little, Dean, Tomchek, & Dunn, 2018). Sensory processing disorders are also present in children with DCD, who have issues regarding sensory sensitivity and difficulties with the stimuli detection of body awareness, and with balance and planning and ideation (Allen & Casey, 2017; Gomez & Sirigu, 2015). Research shows that children with DCD or ADHD have sensory processing deficits, and that there is great sensory processing both between and within-disorder variability, as they do not exhibit just one predominant sensory pattern. Moreover, children with similar sensory processing patterns but different neurodevelopmental conditions may act differently (Little et al., 2018).

It has been proposed that sensory processing issues may be contributing to the etiology and development of neurodevelopmental conditions (Ben-Sasson, Soto, Heberle, Carter, & Briggs-Gowan, 2017; Gomez & Sirigu, 2015), and recently have been included as a diagnosis criteria for Autism Spectrum Disorder (American Psychiatry Association, 2013). Data shows that children with DCD suffer from a deficit of the internal modeling (IMD) of the movement, which heavily relies on spatiotemporal parameters and sensorimotor and visual processing to successfully feedforward movement (Blank et al., 2019; Gomez & Sirigu, 2015). Therefore, sensorimotor processing discrepancies may be partially responsible for motor learning and control difficulties. Regarding SPD and ADHD, children with ADHD show higher sensory sensitivity and have issues in proprioception, vision, auditory and tactile sensory processing. These deficits in sensory processing are related with functional, social, behavioral and learning difficulties. (Sanz-Cervera, Pastor-Cerezuela, González-Sala, Tárraga-Mínguez, & Fernández-Andrés, 2017). However, there is no data about sensory patterns variability between children with DCD, ADHD or co-occurring symptoms in comparison to typical development and between groups, so it remains unclear how sensory processing differs in children with DCD or ADHD. Evidence indicates that children with DCD and ADHD co-occurring disorders exhibit unique neurobiology characteristics in comparison to children with DCD alone or ADHD alone (Gomez & Sirigu, 2015). Potential differences in sensory processing between children with DCD and those with ADHD or with co-occurring DCD and ADHD may contribute to understand how neurological factors with respect to neurological thresholds and self-regulation strategies correlates across diagnoses.

While neurobiology and genetics have been proposed as the main factors explaining neurodevelopmental disorders, social and environmental variables are associated with DCD and ADHD as well (Delgado-Lobete, Santos-del-Riego, Pértega-Díaz, & Montes-Montes, 2019; Gomez & Sirigu, 2015; Miller et al., 2018). Some authors have found associations between sensory processing and sociodemographic factors, such as sex and family socioeconomic status. In children with TD or SPD, low family education is associated with sensory processing issues (Román-Oyola & Reynolds, 2013); Ben-Sasson et al., 2017; (Gouze, Hopkins, LeBailly, & Lavigne, 2009), but there is no data about if and how sensory processing and sociodemographic factors interrelate in children with DCD or ADHD. According to the Dynamic Systems Theory motor behavior is influenced by many factors, including both internal and external constraints (Newell, 1986; Shumway-Cook & Woollacott, 2010). Therefore, exploring the interrelationship of sensory processing and social factors could contribute to understand the underlying mechanisms of motor coordination and inattention/hyperactivity problems not only in children with DCD or ADHD, but in children with typical development.

The main purpose of this study was to explore sensory processing patterns in association with social factors in children with DCD, ADHD and co-occurring symptoms in comparison to TD children using a population-based sample.

2. Methods

2.1. Design

Data was collected from a larger cross-sectional study involving neurodevelopmental and socio-demographic factors in Spanish children (Delgado-Lobete et al., 2019). This study was approved by the Autonomic Research Ethics of Galicia Committee (code 2017/166).

2.2. Participants and procedure

Sample included 452 randomly selected parents of children aged 6–12 (mean age = 8.7 ± 1.8; girls = 53.3 %). Socio-demographic characteristics of the sample are shown in Table 1. All participants were recruited from a northern city in Spain during 2017 and came from six of the forty-four eligible mainstreaming schools in the region. The schools distributed the Short Sensory Profile-2, the Developmental Coordination Disorder Questionnaire and the Attention Deficit Hyperactivity Disorder Rating Scale-IV to the students' parents, who anonymously and voluntarily completed the questionnaires at home and then returned them to the schools. In order for a participant to be included in the study, all the questionnaires had to be completely fulfilled. Children with a parent reported diagnosis of DCD, ADHD or any other neurodevelopmental or learning disorder were excluded. Valid response rate was 45.2 %.

Table 1. Socio-demographic characteristics according to neurodevelopmental disorders symptoms.

	TD	DCD	ADHD	Co-occurring	
	n = 369	n = 46	n = 27	n = 10	F or X^2
Sex (N, %)					7.34
Boys	166 (45.0)	28 (60.9)	10 (37.0)	7 (70.0)	
Girls	203 (55.0)	18 (39.1)	17 (63.0)	3 (30.0)	
Age (M ± SD)	8.6 ± 1.8	9.6 ± 1.7	8.2 ± 1.5	8.8 ± 1.2	5.17**
Family education level (N, %)					9.30*
Non-tertiary education	46 (12.5)	11 (24.4)	7 (25.9)	3 (30.0)	
Tertiary education	322 (87.5)	34 (75.6)	20 (74.1)	7 (70.0)	
School (N, %)					3.60
Public	192 (52.0)	24 (52.2)	19 (70.4)	6 (60.0)	
Concerted/Private	177 (48.0)	22 (47.8)	8 (29.6)	4 (40.0)	

Notes. TD = typically developing; DCD = developmental coordination disorder; ADHD = attention deficit hyperactivity disorder; M = mean; SD = standard deviation; F = ANOVA statistic; X^2= chi square; * = $p < 0.05$; ** = $p < 0.01$.

2.3. Outcome measures

Each parent completed the Spanish versions of the Short Sensory Profile-2 (PS-2B), the Developmental Coordination Disorder Questionnaire (DCDQ-ES) and the Attention Deficit Hyperactivity Disorder Rating Scale-IV (ADHD-RS-IV-ES). An additional question regarding family educational level was included ad-hoc.

The PS-2B is a 34-item parent-report measure of sensory processing characteristics and behavioral response of the child. It provides scores on each sensory quadrant (i.e., registration, seeking, sensitivity and avoiding), where higher scores reflect higher frequency of described behaviors. Quadrant scores are latter categorized as sensory patterns (*bystander*, *seeker*, *sensor* or *avoider*). Scores between one and two standard deviations from the mean are expressed as atypical sensory patterns (*less or more than others*). Scores two standard deviations or more from the mean indicates a definite difference in sensory processing (*much less or much more than others*). The PS-2B has demonstrated excellent psychometric properties within Spanish population (internal consistency $\alpha = 0.72–0.90$; test-retest stability = 0.93–0.97) (Dunn, 2016). As reported by Dean, Dunn & Little (2016) the Sensory Profile 2 shows good construct validity. Confirmatory factor analysis has demonstrated a good fit with the four-factor model based on the four sensory quadrants/patterns (Dean, Dunn, & Little, 2016).

The DCDQ-ES is a 15-item parent-report measure that evaluates three motor coordination dimensions (control during moving, fine motor/handwriting and general coordination), where higher scores are associated with better motor coordination. A diagnosis of probable DCD is given according to child's total score (46 or below for children aged 6–7y11 m; 55 or below for children aged 8–9y11 m or 57 or below for children aged 10–12y). The DCDQ has been cross-culturally adapted into Spanish population (Montes-Montes, Delgado-Lobete, Pereira & Pousada, In press). The DCDQ is one of the most recommended tools to asses for DCD indication and has shown good psychometric properties (Cronbach $\alpha = 0.94$; overall sensitivity = 85 %; overall specificity = 71 %) (Blank et al., 2019; Wilson et al., 2009).

The ADHD-RS-IV-ES is a parent-report behavioral scale that comprises 18 items corresponding to the 18 nuclear DSM-IV ADHD symptoms criteria (Servera & Cardo, 2007). The ADHD-RS-IV-ES provides scores for inattention, hyperactivity-impulsivity and total ADHD symptoms, where higher scores reflect greater frequency and intensity of ADHD symptoms. Child is identified as having probable ADHD if they obtain scores above the 90^{th} percentile calculated for their age and sex. The ADHD-RS-IV-ES has demonstrated excellent internal consistency in Spanish children (Cronbach $\alpha = 0.85–0.95$) (Servera & Cardo, 2007).

Children were identified as having probable DCD or probable ADHD according to total scores on the DCDQ-ES and the ADHD-RS-IV-ES. A co-occurring diagnosis was established if the child showed symptoms of both DCD and ADHD as measured by the DCDQ-ES and the ADHD-RS-IV-ES.

2.4. Data analysis

SPSS v 20 was used for analyses. The prevalence of probable DCD, ADHD and co-occurring disorders in the sample were estimated and 95 % confidence intervals (CI) were calculated for the prevalence estimates. Significance was set at $p < 0.05$. Data were examined for normality using visual inspection and Kolmogorov-Smirnov's test results. We performed one-way analysis of variance (ANOVA) to examine differences in sensory quadrants scores (registration, seeking, sensitivity and avoiding) between diagnosis groups (i.e., TD, DCD, ADHD, co-occurring). Specific differences between groups were assessed with Bonferroni post-hoc tests. Pearson Chi square test (X^2) was used to compare sensory patterns (bystander, seeker, sensor and avoider) between groups. In order to determine the correlation between sensory quadrants and scores on the dimensions of the DCDQ/ADHD symptom scales, we conducted Pearson correlations.

Finally, we determined how sensory processing quadrants and social factors predicted coordination performance and ADHD symptoms. Seven stepwise multiple linear regression models were performed on coordination dimensions as measured by the DCDQ-ES (control during movement, fine motor, general coordination ad total score) and ADHD symptoms as measured by the ADHD-RS-IV-ES (inattention, hyperactivity-impulsivity and ADHD). Independent variables regarding sensory processing quadrants (low registration, seeking, sensitivity and avoiding) and social factors (age, sex and family education level) were entered in the analysis. The final model for each analysis only included those variables that added a statistically significant amount to the overall multiple R squared.

3. Results

Prevalence of neurodevelopmental disorders symptoms was 18.4 % (95 % CI = 4.7–22.0) (probable DCD = 10.2 %, 95 % CI = 7.3–13.1; probable ADHD = 6.0 %, 95 % CI = 3.7–8.3; co-occurring = 2.2 %, 95 % CI = 0.8–3.7).

Parents of children with DCD, ADHD and co-occurring symptoms rated them significantly higher on all sensory quadrants. These children showed higher prevalence of atypical sensory patterns than their TD peers (Table 2). Parents of children with probable DCD scored them significantly lower on all sensory quadrants than children with ADHD or co-occurring symptoms, and parents of children with probable ADHD reported them to show significantly lower sensory difficulties than co-occurring group in sensitivity and avoiding, but not in registration or seeking.

Table 2. Quadrant scores and sensory patterns in TD, DCD, ADHD and co-occurring children.

	TD n = 369	DCD n = 46	ADHD n = 27	Co-occurring n = 10	F or X^2
Quadrant scores					
Low registration (M ± SD)	10.5 ± 3.1	13.2 ± 4.7	15.8 ± 6.9	19.2 ± 5.7	38.35[a]
Seeking (M ± SD)	12.3 ± 4.0	13.9 ± 5.1	19.7 ± 4.5	22.5 ± 5.5	44.58[a]
Sensitivity (M ± SD)	17.0 ± 5.1	19.5 ± 5.9	27.7 ± 7.2	34.3 ± 3.9	65.09[b]
Avoiding (M ± SD)	14.3 ± 5.1	17.0 ± 6.0	22.4 ± 7.5	30.0 ± 7.5	45.66[b]
Sensory patterns					
Bystander (N, %)	37 (10.0)	12 (26.1)	14 (51.9)	9 (90.0)	80.13***
Seeker (N, %)	39 (10.6)	9 (19.6)	18 (66.7)	8 (80.0)	88.87***
Sensor (N, %)	35 (9.5)	10 (21.7)	21 (77.8)	10 (100.0)	136.19***
Avoider (N, %)	48 (13.0)	13 (28.3)	13 (48.1)	9 (90.0)	60.28***

Notes. TD = typically developing; DCD = developmental coordination disorder; ADHD = attention deficit hyperactivity disorder; M = mean; SD = standard deviation; F = ANOVA statistic; X^2=chi square; [a]= significant differences between all groups except for ADHD and co-occurring; [b]=significant differences between all groups; ***=$p < 0.001$.

As expected, atypical sensory processing was increased in children with ADHD and co-occurring symptoms for all quadrants and patterns, especially in the sensitivity quadrant, where more than three-fourths of children with probable ADHD and all children with co-occurring symptoms showed a sensor pattern. At least one atypical sensory pattern was present on 25.7 % in the TD group. Presence of at least one atypical sensory pattern in the DCD, ADHD and co-occurring groups was higher at 45.7 %, 85.2 % and 100.0 %, respectively (X^2 (df = 3) = 65.71; p < 0.001). Definite difference in at least one sensory pattern was present at 7.0 %, 19.6 %, 51.9 % and 80.0 % in TD, probable DCD, probable ADHD and co-occurring groups, respectively (X^2 (df = 3) = 91.32; p < 0.001).

As seen in Table 3, scores on all sensory quadrants significantly correlated with the scores on the three coordination dimensions of the DCDQ-ES, although this correlation was weak to moderate (r = .204–.432 *p* < 0.001). ADHD symptoms showed stronger correlations with sensory patterns (r = .492–.798; *p* < 0.001), especially with sensitivity quadrant.

Table 3. Correlations between sensory quadrants scores, coordination dimensions and ADHD symptoms.

	Control during movement	Fine motor	General coordination	DCDQ total score	Inattention	Hyperactivity-impulsivity	ADHD
Low registration	−.323***	−.293***	−.399***	−.391***	.574***	.492***	.586***
Seeking	−.204***	−.261***	−.347***	−.309***	.638***	.691***	.728***
Sensitivity	−.247***	−.373***	−.432***	−.396***	.798***	.616***	.780***
Avoiding	−.226***	−.320***	−.357***	−.340***	.636***	.511***	.632***

Notes. DCDQ = Developmental Coordination Disorder Questionnaire; ***=*p* < 0.001.

Results for the regression analyses are shown in Table 4. Linear regression revealed that passive self-regulation patterns were associated with poorer motor performance. Low registration predicted control during movement, general coordination and DCDQ-ES total score, while sensitivity predicted fine motor, general coordination and DCDQ-ES total score. In addition, sensory seeking and sensitivity predicted inattention, hyperactivity-impulsivity and ADHD symptoms. Additionally, at least one social factor contributed to explain motor performance and ADHD symptoms in all models. Family education level played a relevant role in DCDQ-ES dimensions and total score, and sex was significant in predicting ADHD symptoms.

Table 4. Multiple linear regression models to identify coordination dimensions and ADHD symptoms using sensory processing and social factors as predictors (stepwise method).

	Control during movement		Fine motor		General coordination		DCDQ total score	
Variable	B	95 % CI	B	95 % CI	B	95 % CI	B	95 % CI
Age	0.23*	0.05, 0.41	–	–	0.19*	0.03, 0.35	0.55**	0.15, 0.96
Sex	–	–	−0.97***	−1.43, −0.51	–	–	−1.43*	−2.86, −0.03
Family education level	−1.51**	−2.43, −0.60	−0.79*	−1.44, −0.14	–	–	−2.91**	−4.93, −0.89
Low registration	−0.28***	−0.36, −0.20	–	–	−0.17***	−0.23, -0.08	−0.47***	−0.70, −0.23
Seeking	–	–	–	–	–	–	–	–
Sensitivity	–	–	−0.14***	−0.18, −0.11	−0.16***	−0.22, −0.10	−0.29**	−0.44, −0.13
Avoiding	–	–	–	–	–	–	–	–

	Inattention		Hyperactivity-impulsivity		ADHD	
Variable	B	95 % CI	B	95 % CI	B	95 % CI
Age	–	–	–	–	–	–
Sex	0.78**	0.19, 1.37	–	–	1.41**	0.39, 2.43
Family education level	–	–	–	–	–	–
Low registration	–	–	–	–	–	–
Seeking	0.12*	0.03, 0.21	0.55***	0.45, 0.65	0.65***	0.49, 0.81
Sensitivity	0.53***	0.46, 0.61	0.19***	0.12, 0.27	0.70***	0.57, 0.83
Avoiding	0.10**	0.04, 0.17	–	–	0.14*	0.03, 0.26

Notes. DCDQ = Developmental Coordination Disorder Questionnaire; ADHD = attention deficit hyperactivity-impulsivity disorder; B = linear regression statistic; CI = confidence intervals; *=$p < 0.05$; **=$p < 0.01$; ***=$p < 0.001$.

4. Discussion

The purpose of this study was to explore sensory processing differences and variability of sensory patterns between children with DCD, ADHD or co-occurring symptoms. This study is the first to compare sensory processing patterns across these diagnosis groups. Our findings are in line with previous research regarding sensory processing variability between disorders in children with neurodevelopmental conditions and in comparison with typically developing children. Furthermore, results showed that sensory processing interrelate with social factors to predict motor coordination performance and ADHD symptoms in general population

A great variability in sensory patterns were found within the probable DCD group, with the least common pattern being seeker (19.6 %) and the most frequent being avoider (28.3 %) and bystander (26.1 %). Parents of the majority of the children with DCD symptoms did not reported atypical or definite different sensory processing, although the prevalence of atypical sensory patterns was significantly higher than in the TD group. This outcome supports the findings of Allen and Casey (2017) regarding definite differences in sensory processing in children with DCD. In their study, 18 % of children with DCD were identified as having definite different sensory processing in the Sensory Processing Measure, indicating presence of SPD. In this study, children with DCD symptoms showed a higher bystander pattern than the TD group (26 % vs 10 %), indicating low registration of sensory stimuli. Low registration issues commonly include difficulties with proprioceptive stimuli, which refers to the subconscious and conscious awareness of spatial and kinesthetic parameters of the musculoskeletal framework and plays a relevant role in body awareness and balance (Chu, 2017). Although there is not previous research about sensory patterns in children with DCD and therefore a direct comparison cannot be made, Allen and Casey also found similar percentages of body awareness and balance problems in this population (24–33 %), which links to low registration issues in DCD (Allen & Casey, 2017). Using univariate analyses, all sensory patterns correlated with motor coordination dimensions. However, when considering social factors in the multivariate linear regression analysis, only low registration and sensory sensitivity predicted motor coordination performance. This finding suggests a relationship between DCD and passive self-regulation strategies, indicating that children with DCD may not try to actively counteract difficulties in stimuli detection.

As internal modelling deficit has been proposed as one of the main factors contributing to the etiology of DCD (Blank et al., 2019; Gomez & Sirigu, 2015; Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013), discrepancies in body awareness registration and processing may be adding to the development of this disorder. Internal modelling relies on spatiotemporal parameters to feedforward movement in order to forward plan or predict motor actions, and therefore sensorimotor kinesthetic and visual processing integrity is crucial to generate signals than allow children to learn, adapt and plan movement (Gomez & Sirigu, 2015). Research has demonstrated that children with DCD struggle in processing visual-spatial information (Wilson et al., 2013) and proprioceptive and tactile stimuli (Elbasan, Kay, Duzgun, & Kayihan, 2012). Visual feedback has been suggested to play a less significant role in adaptation to novel motor dynamics than kinesthetic information (McKenna, Bray, Zhou, & Joiner, 2017), which could mean that difficulties in kinesthetic-related sensory stimuli, such as proprioceptive, vestibular or tactile stimuli may have a greater role in internal modelling discrepancies. Therefore, low registration issues regarding proprioceptive stimuli detection may contribute to the underlying sensorimotor processing factors that influence internal modelling deficit in DCD.

Children with poor motor coordination show an increased risk of psychosocial and emotional problems, including psychological distress, negative self-esteem, anxiety and social participation difficulties (Blank et al., 2019). The link between motor proficiency and social participation has been extensively highlighted in previous research (Allen & Casey, 2017). It may be possible for sensory sensitivity to play a role in behavioral and social issues in DCD. Sensor children are extremely sensitive to external information such as hearing and tactile information, but do not counteract these overwhelming inputs and instead typically react anxiously and irritably (Dunn, 2016), thus potentially leading to behavioral problems.

Regarding sensory processing issues in ADHD, our findings show that most of the children with ADHD symptoms exhibited at least one atypical sensory pattern. While most of these children showed higher sensitivity, a significant number also showed seeker and bystander patterns. Previous research has demonstrated that ADHD is heavily associated with both hypo and hyper-sensitivity and especially with sensitivity, seeking and low registration, and that these issues impact everyday function and social behavior (Little et al., 2018; Mimouni-Bloch et al., 2018).

In our study, ADHD symptoms were strongly correlated with sensory sensitivity, suggesting an intimate relationship in assessment of both constructs. As a matter of fact, it has been questioned whether ADHD and SPD may pose as a unique disorder due to the high overlapping between both conditions. However, recent studies indicate that these disorders are differentiated by distinct somatic, behavioral and physiological characteristics with different clinical conditions, assessment and treatment approaches needed (Ben-Sasson et al., 2017; Miller et al., 2012; Mimouni-Bloch et al., 2018). For example, children with SPD or co-occurring SPD and ADHD present more sensory issues than children with ADHD alone in tactile, taste/smell, visual/auditory and movement sensitivity, and encounter more difficulties to adapt or be flexible in the presence of unexpected occurrences, making them more vulnerable to emotional problems (Miller et al., 2012). Research also indicates that presence of sensory modulation difficulties in children with ADHD increases daily dysfunction compared to children with ADHD only (Mimouni-Bloch et al., 2018). There are also differences in physiological reactivity to sensory stimuli between children with SPD and children with ADHD. Children with sensory modulation disorders have greater electrodermal reactivity compared to children with ADHD, suggesting that sensory-stimulus-elicited electrodermal responses may contribute to the diagnosis of children with SPD from children with ADHD when assessing for co-occurrence of both disorders (Miller et al., 2012). Furthermore, it has been proposed that different clusters based on tactile and auditory sensory processing differences can effectively identify and differentiate children with ADHD or SPD, adding to the evidence of ADHD and SPD being two frequently overlapping but distinct conditions (Ben-Sasson et al., 2017).

Findings from this study contribute to demonstrate that DCD and ADHD are different diagnosis although commonly overlapping. Children with probable DCD showed different sensory processing patterns than children with probable ADHD or co-occurring conditions, who presented more sensory processing difficulties in all quadrants. Although DCD and ADHD share prevalence rates and co-occurrence alongside similar psychosocial issues, research demonstrates that they may be separate conditions due to differences in motor, attention and executive functioning and disparities in brain underpinnings (Goulardins et al., 2015; McLeod et al., 2016). Sensory patterns variability found in this study highlight that sensory processing differences may manifest differently in children with DCD or ADHD.

In this sample, children with co-occurring symptoms showed the highest scores on all patterns. This was to be expected as research has demonstrated that children with co-occurring conditions usually face more challenges in multisensory integration, behavior and participation (Allen & Casey, 2017; Blank et al., 2019; Masi & Gignac, 2017; Sanz-Cervera et al., 2017). An important clinically relevant finding of this particular outcome is that sensory patterns variability in DCD and DCD and ADHD co-occurring symptoms had not been previously evaluated. Occupational therapists working with children with motor coordination and inattention/hyperactivity difficulties can use these findings to further assess the sensory processing features of these children in order to plan intervention programs that consider both individual sensory pattern preferences and characteristics, and child's specific social background.

5. Limitations and future research prospects

This study has several limitations that need to be disclosed. We used parent report measures, and although all questionnaires are well-validated and ecologically valid to assess DCD and ADHD symptoms and sensory processing, they could lead to potential biases, and therefore future studies may consider methods of direct and objective assessment. This work was also limited as other conditions that may be related to differences in sensory processing patterns in DCD or ADHD were not considered (i.e., social anxiety). The sample size of the group with DCD and ADHD co-occurring symptoms was little and sex imbalanced, and therefore this may introduce bias. Finally, this research used cross-sectional data from a specific region population-based sample. Although this is interesting regarding how sensory features are present in general population, future research is needed to explore how underlying neurological mechanisms of sensory processing disclose over time in clinical samples.

6. Conclusion

Children with DCD, ADHD or co-occurring symptoms show greater variability in sensory processing patterns and more sensory processing issues than TD children. Frequency of atypical sensory patterns increased in children with DCD or ADHD symptoms, and all children with co-occurring symptoms exhibited at least one atypical sensory pattern, being sensitivity the most prevalent pattern. When considering social factors, low registration, sensitivity, age and family educational level predicted motor coordination performance, while sex, seeking and sensitivity were associated with ADHD symptoms (i.e., inattention and hyperactivity-impulsivity). This study highlights that motor coordination difficulties and ADHD in general population are heavily influenced by sensory processing variability and social factors, and therefore assessment of these disorders needs to address sensory processing and environmental features.

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Declaration of Competing Interest

The authors indicate that they have no conflicts of interest to disclose.

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