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Dyspraxia in specific motor areas in children with Developmental Coordination Disorders and Attention Deficit/Hyperactivity Disorder

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ABSTRACT

Dyspraxias are neurodevelopmental disorders that affect one or more areas of motor development and can be expressed in different ways in Attention Deficit/Hyperactivity Disorder and Developmental Coordination Disorder. The aim was to identify dyspraxia in specific motor areas in children with Developmental Coordination Disorder and Attention Deficit/Hyperactivity Disorder. Children (6–10 years old) were recruited from ten Brazilian public schools. The sample consisted of 49 children with Attention Deficit/Hyperactivity Disorder and 11 with Developmental Coordination Disorder. Additionally, 180 children with typical development were included as controls. The Motor Development Scale was used to identify dyspraxia in specific motor areas. Our findings revealed lower general motor quotient results in children with Developmental Coordination Disorder and with Attention Deficit/Hyperactivity Disorder when compared with typical development children. More specifically, the Attention Deficit/Hyperactivity Disorder group showed lower scores in perceptive domains compared to the Developmental Coordination Disorder and typical development groups. In the coordinative and proprioceptive areas, the Developmental Coordination Disorder group showed lower scores than the Attention Deficit/Hyperactivity Disorder and typical development groups. These data suggest that dyspraxia acts in different motor areas for children with Attention Deficit/Hyperactivity Disorder and Developmental Coordination Disorder. We conclude that specific motor dysfunctions facilitate understanding of neurodevelopmental disorders, can contribute to differential diagnosis, and favour the development of motor intervention programs.

KEYWORDS: neurodevelopmental disorders; motor skills; motor skills disorders; attention deficit hyperactivity disorder.

INTRODUCTION

Dyspraxia is characterised as a dysfunction in motor control represented by the difficulty in selecting and planning a motor action appropriately (Chang & Yu, 2016) and can be defined as a disturbance in the planning of intentional, conscious, and learned movements (Ajuriaguerra, 1977). Dyspraxia also refers to the ability to perform a sequence of intentional and conscious movements when interacting with and manipulating materials and tools (Miller et al., 2014), meaning that this disorder affects one or more motor areas: coordinative (fine and gross motor skills), perceptive (spatial and temporal), and proprioceptive (balance and body scheme).

It is important to note the differences between Dyspraxia and Developmental Coordination Disorder (DCD). Baxter (2012) affirms that the concept of Dyspraxia applies not only to the coordinating function of the limbs and trunk (as observed in DCD), but also to eye movements, facial movements, postural control, laterality, spatial and temporal organization, and orofacial functions. When symptoms and signs of dyspraxia are present in a child, DCD is undoubtedly the most frequent cause; in other words, dyspraxia is a symptom, while DCD is one of the possible causes directed at a motor area (Baxter, 2012).

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DCD affects 5–6% of children worldwide (American Psychiatric Association [APA], 2013). The diagnosis criteria involves the assessment of four criteria, as dricribed in the Diagnostic and Statistical Manual of Mental Disorders (APA, 2013): A) Learning and execution of coordinated motor skills below expected level for age, given opportunities for skill learning; B) Motor skill difficulties significantly interfere with activities of daily living and impact academic/school productivity, prevocational and vocational activities, leisure and play; C) Onset is in the early developmental period; and D) Motor skill difficulties are not better explained by other disabilitie or neurological conditions that affect movement (APA, 2013). A variety and combination of methods should be used to identify DCD, such as medical history, interview, questionnaires, clinical examination, and motor tests (Caçola & Lage, 2019). DCD tends to be a secondary diagnosis, however, delays and difficulties are typically observed early in life (Criterion C) and children may present delays in typical developmental milestones (crawling, walking, talking) and in the acquisition of motor skills expressed in difficultis in dressing, playing with a toy, drawing, writting, etc. (Blank et al., 2012). Difficulties can also be expressed in a group of behavioural, emotional, and social problems (Pimenta et al., 2023).

A co-occurrence of motor problems and Attention Deficit/Hyperactivity Disorder (ADHD) is approximately 50% (Farran et al., 2020). Although the symptoms of ADHD may predispose children to motor problems, it is unclear whether motor difficulties are inherent to ADHD or are mediated by the presence of DCD (Goulardins et al., 2017). In addition, neuroimaging assessments indicate that, although their manifestations generally overlap, ADHD and DCD are probably two distinct disorders, with specificities related to aetiology, neurophysiological mechanisms, and impaired brain regions (McLeod et al., 2016). Attention Deficit/Hyperactivity Disorder is one of the most diagnosed neurodevelopmental disorders in children. It is characterised by inappropriate levels of activity, impulsivity, and inattention, which frequently and persistently interfere with functioning and development, leading to psychosocial impairments (APA, 2013). The prevalence of ADHD is estimated as 2–7% of the general population, with an average of around 5% (Sayal et al., 2018).

Children with ADHD demonstrated lower scores on motor development tests when compared to typical developing peers (Rosa Neto et al., 2015). More specifically, motor dyspraxias in individuals with ADHD are observed in different domains of motor development, such as problems in gross motor skills (Harvey et al., 2007; Scharoun et al., 2013) precision and fine motor integration, fine motor skills, manual dexterity and bimanual coordination (Brossard-Racine et al., 2012; Çak et al., 2018), coordination (Piek et al., 2004), balance (Amini et al., 2018; Çak et al., 2018), gait and postural control (Bucci et al., 2017; Papadopoulos et al., 2014).

Two hypotheses to explain the motor impairments in ADHD are observed: first, of the hypotheses links motor impairments to the triad of symptoms inherent to ADHD (hyperactivity, impulsivity, and inattention), suggesting that these symptoms are affecting the development of motor skills (Ghanizadeh, 2009; Kaiser et al., 2015) second hypothesis attributes delays in motor development to the presence of comorbidities, especially DCD (Athanasiadou et al., 2020; Kaiser et al., 2015).

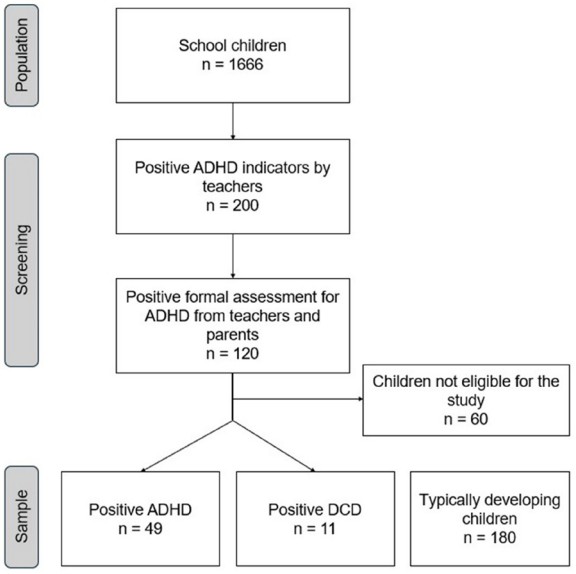
It is observed that both ADHD and DCD can present dyspraxia as a comorbidity. However, the impairments in motor areas seem to be different. In this sense, there seems to be no consensus on the motor difficulties perceived both in children with ADHD and in children with DCD. Therefore, the aim of this study was to identify dyspraxias in specific motor areas among children with Developmental Coordination Disorders and Attention Deficit/Hyperactivity Disorder.

METHODS

We conducted a cross-sectional study, approved by the Ethics and Research Committee of Santa Catarina, Brazil. We sent invitations to ten public schools in the southern region of Santa Catarina, Brazil. We obtained parental consent forms for all participants included in this study.

Sample

We recruited 1666 children from 10 public schools in Brazil to participate in the study. Of this population, 200 children, aged between six and ten years, showed positive indicators for ADHD and DCD. Of the 200 children, 49 (2.94%) were clinically diagnosed with ADHD (5 girls and 44 boys; age 9.07 ± 1.50 years) and 11 (0.66%) diagnosed with DCD (3 girls and 8 boys; age 6.58 ± 1.55 years). We excluded individuals meeting criteria for intellectual disability, autism, physical, neurological disorder, or regular use of medication that may impact motor control. This information was obtained through a psychosocial questionnaire evaluated by the parents, which included questions about pregnancy, childbirth, motor development, previous diagnoses, socioeconomic conditions, and the child's behaviour. The control group was composed of typically developing children (TD group; n = 180) matched by sex and age group, being 3:1 (24 girls, 156 boys, mean age 8.61 ± 1.50 years) (Figure 1). Children in the control group were randomly selected by inviting their



ADHD: attention deficit/hyperactivity disorder; DCD: developmental coordination disorder.

Figure 1. Participant selection and group distribution.

families. The invitations were promoted in schools and on the research laboratory's social media channels.

Instruments

SNAP-IV Scale - Parents and Teachers

The Swanson, Nolan, and Pelham Scale-IV (SNAP-IV) is a behaviour rating scale, including nine items for inattention and nine for hyperactivity/impulsivity, based on DSM-IV-TR criteria (Swanson et al., 2001). The shortened Brazilian version of the SNAP-IV (18 items) was used in the present study. The scale allows parents and teachers to rate each symptom on a four-point scale, from 0 (none) to 3 (very much). A clinical cutoff of six ADHD symptoms was used in this study, as the DSM-IV-TR criteria (Bussing et al., 2008).

Motor Development Scale

The Motor Development Scale (MDS) (Rosa Neto, 2021) is a motor assessment protocol, indicated for children aged between 2 and 11 years, which includes three motor areas: coordinative (fine and gross motor skills), proprioceptive (balance and body scheme), and perceptive (spatial and temporal organization) (See Supplemental material). The instrument provides quantitative and qualitative values for each motor domain. Motor ages represent the results of specific tests and general development. Motor quotients are classified into levels: "Very High" (equal to or greater than 130 points); "High" (120–129); "Average High" (110–119); "Average" (90–109); "Average Low" (80–89); "Low" (70–79) and "Very Low" (less than 70). MDS was administered individually to children in the ADHD and DCD groups in a single session lasting approximately 40 minutes. This scale is widely used in Brazil, especially for its low cost and ease of application (Pimenta et al., 2020).

Procedures

We conducted a screening process to identify ADHD and DCD, wherein we provided teachers with an information guide detailing the symptoms of both neurodevelopmental disorders. Subsequently, we requested teachers and parents of these children to complete the Swanson, Nolan, and Pelham Scale-IV (SNAP-IV) (Swanson et al., 2001). Those children who showed six or more ADHD symptoms, according to both parents and teachers, were then referred for formal clinical evaluation. A multidisciplinary team from the Maternal and Child Outpatient Clinic attended to and evaluated 120 children. Among the children evaluated, 49 were diagnosed with ADHD, and 11 were diagnosed with DCD. A multidisciplinary team composed of professionals from Neuropediatrics, Psychology, Social Assistance, Nursing, and Physical Education conducted evaluations and complementary exams for both groups. Clinical diagnoses were performed according to Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition, criteria (APA, 2000). The fourth edition of the DSM was used because the data were collected in a period prior to the DSM-5. The control group attended the schools where they studied on a previously scheduled day and time. The assessments were carried out on a day and time that did not interfere with the children's academic routine. A room provided by the school was used, separate from the other children. Two experienced professionals administered the tests.

Statistical analysis

We conducted statistical analyses using SPSS Statistics version 20.0 for Windows. We used descriptive statistics to characterise participants' motor characteristics. To examine possible differences between Groups (ADHD x DCD x TD) on the motor domains (final motor skills, gross motor skills, balance, body scheme, spatial organization, and temporal organization), motor areas (coordinative, proprioceptive, and perceptive) and general motor quotient, we utilized the Kruskal-Wallis H-test given the nature of our sample and the characteristics of the data. We also employed the Dwass-Steel-Critchlow-Fligner (DSCF) post hoc test to determine specific group differences. We measured the effect

size using epsilon squared (ε^2), considering the ranges negligible [0.00, 0.01], weak [0.01, 0.04], moderate [0.04, 0.16], relatively strong [0.16, 0.36], strong [0.36, 0.64] and very strong [0.64, 1.00] (Rea & Parker, 2014).

RESULTS

In Table 1, we present the quotients for the motor domains evaluated in the ADHD, DCD, and TD groups. We found significant differences between the Groups in all motor domains: fine motor skill ($H = 46.2$; $p < .001$; $\varepsilon^2 = 0.193$), gross motor skill ($H = 26.8$; $p < .001$; $\varepsilon^2 = 0.112$), balance ($H = 64.4$; $p < .001$; $\varepsilon^2 = 0.269$), body scheme ($H = 12.8$; $p = 0.002$; $\varepsilon^2 = 0.053$); spatial organization ($H = 38.3$; $p < .001$; $\varepsilon^2 = 0.160$) and temporal organization ($H = 22.2$; $p < .001$; $\varepsilon^2 = 0.093$) with effect size between moderate and relatively strong. The DCD group showed lower scores in fine and gross motor skills and balance compared to the TD group, as shown in Table 1. When we compared the ADHD group with the TD group, the ADHD group showed lower values across all domains. The ADHD group showed lower scores in spatial organisation and temporal organisation compared to the DCD group.

In Table 2, we illustrate the motor quotient of the coordinative, proprioceptive, and perceptive areas, as well as the general motor development (general motor quotient). We observed a significant effect of the Group across all the motor areas: coordinative ($H = 49.9$; $p < .001$; ε^2=0.209), proprioceptive ($H = 57.3$; $p < .001$; ε^2 =0.240), perceptive ($H = 36.6$; $p < .001$; $\varepsilon^2 = 0.153$) and in the general motor quotient ($H = 63.1$; $p < .001$; $\varepsilon^2 = 0.264$) with effect size between moderate and relatively strong. The DCD group showed lower values in the coordinative area and proprioceptive area compared to the TD group. At the same time, the ADHD group presented lower values in all three areas and the general motor quotient. In comparing the ADHD and DCD groups, we found that the ADHD group displayed lower scores in the perceptive area.

Figure 2 shows the distribution of the classification of the general motor quotient in children in the ADHD, DCD, and TD groups, according to the Motor Development Scale. General motor quotient: in the ADHD group, the most frequent classifications were "low" and "average low"; in the DCD group, they were "average low"; and in the TD group, they were "average".

Table 1. Mean values of motor quotients referring to the motor domains of the group of children with attention deficit/hyperactivity disorder, developmental coordination disorder and typical development children.

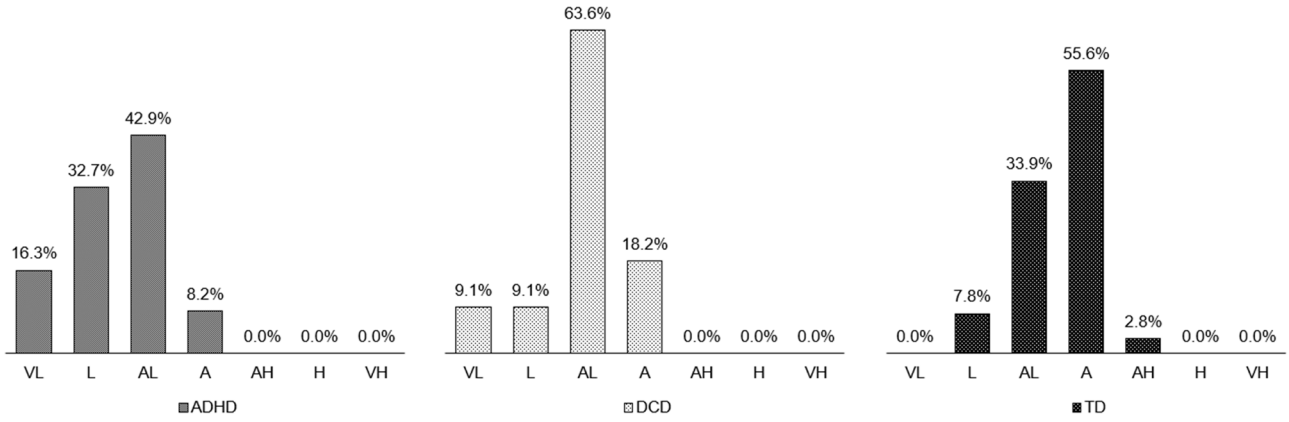
Variables		TD	DCD	ADHD	*p*-value*	effect size (ε^2)
Coordinative area	FFMS	96.7 ± 14.1 ^{a,b,c}	83.7 ± 16.9 ^{a,b}	80.7 ± 12.7 ^{a,c}	< .001	0.193
	GGMS	97.5 ± 12.9 ^{a,b,c}	79.3 ± 13.5 ^{a,b}	88.8 ± 10.9 ^{a,c}	< .001	0.112
Proprioceptive area	BBL	94.3 ± 16.9 ^{a,b,c}	62.8 ± 11.5 ^{a,b}	73.7 ± 15.2 ^{a,c}	< .001	0.269
	BBS	93.6 ± 12.8 ^{a,c}	88.9 ± 13.9 ^{b}	85.4 ± 12.8 ^{a,c}	.002	0.053
Perceptive area	SSO	89.8 ± 19.2 ^{a,b,c}	104.9 ± 17.7 ^{a,b,c}	73.5 ± 15.4 ^{a,b,c}	< .001	0.160
	TTO	83.0 ± 19.4 ^{a,c}	89.7 ± 17.2 ^{b,c}	69.4 ± 12.7 ^{a,b,c}	< .001	0.093

*Kruskal-Wallis *H*-test, post-hoc DSCF test; equal letters = significant difference; $p < .05$. ADHD: attention deficit/hyperactivity disorder; DCD: developmental coordination disorder; TD: typical development; FMS: fine motor skills; GMS: gross motor skills; BL: balance; BS: body scheme; SO: spatial organisation; TO: temporal organisation; ε^2: epsilon squared.

Table 2. Mean values of motor quotients referring to the coordinative, perceptive, and proprioceptive areas and the general motor quotient of the group of children with attention deficit/hyperactivity disorder, developmental coordination disorder and typical development children.

Variables	TD	DCD	ADHD	*p*-value*	effect size (ε^2)
Coordinative area	97.1 ± 10.9 ^{a,b,c}	81.5 ± 11.7 ^{a,b}	84.7 ± 10.2 ^{a,c}	< .001	0.209
Proprioceptive area	93.9 ± 11.4 ^{a,b,c}	75.8 ± 11.3 ^{a,b}	79.5 ± 11.3 ^{a,c}	< .001	0.240
Perceptive area	96.4 ± 16.4 ^{a,c}	97.3 ± 15.7 ^{b,c}	71.4 ± 12.1 ^{a,b,c}	< .001	0.153
General motor quotient	92.5 ± 9.3 ^{a,b,c}	84.9 ± 10.8 ^{b}	78.6 ± 8.5 ^{a,c}	< .001	0.264

*Kruskal-Wallis *H*-test, post-hoc DSCF test; equal letters = significant difference; $p < .05$. ADHD: attention deficit/hyperactivity disorder; DCD: developmental coordination disorder; TD: typical development; ε^2: epsilon squared.



ADHD: attention deficit/hyperactivity disorder; DCD: developmental coordination disorder; TD: typical development; VL: very low; L: low; AL: average low; A: average; AH: average high; H: high; VH: very high.

Figure 2. General motor quotient distribution within groups of attention deficit/hyperactivity disorder, developmental coordination disorder and typical development children.

DISCUSSION

Our investigation aimed to identify dyspraxias in ADHD and DCD, revealing distinct dysfunctions in motor areas for each condition. Both groups showed differences when compared to the group of children with typical development, showing motor development values considered "relatively strong" lower. The result agrees with the literature in stating that both children with ADHD and DCD have motor difficulties. Both DCD and ADHD are neurodevelopmental disorders that hamper adaptive functioning and compromise development (Athanasiadou et al., 2020; Goulardins et al., 2015), so it is expected that the motor development of children with such disorders will be different from that of children with typical development. The aetiology of neurodevelopmental disorders is multifactorial and remains inconclusive, involving genetic factors, exposure to teratogens, infections, malnutrition, perinatal brain injuries, and adverse environmental experiences. These factors may contribute to atypical brain development, which is frequently observed in children with ADHD and children with DCD (Dewey & Bernier, 2016). Regardless of whether the origin is genetic or related to disruptions in the developing nervous system, this atypical development tends to manifest through motor, cognitive, and/or behavioural impairments. Although each disorder has specific clinical criteria, a common denominator is alterations in the central nervous system.

However, it is important to affirm that motor difficulties are expressed in different ways when comparing children with DCD and ADHD. While children with ADHD presented greater difficulties in the perceptive areas (spatial organisation), those with DCD have significant difficulties in the coordinative (gross motor skills) and proprioceptive (balance) areas. In addition, the ADHD group showed lower scores in spatial organisation and temporal organisation compared to the DCD group.

Although studies (Brossard-Racine et al., 2012) indicate that 50% of children with ADHD have motor difficulties (also described as DCD), it seems that the motor deficit observed in most children with ADHD is not part of the phenotype of the disorder (Farran et al., 2020). Also, the motor impairment presented does not simply reflect developmental delay, but rather an uneven profile of impairment across different motor skills. Thus, it is possible to affirm that the results observed in the study point to impairments in different areas of motor development that are related to the identity of the disorders. In this sense, we can state that dyspraxias can be observed in very specific areas regarding each neurodevelopmental disorder. It is important to state that children with ADHD have lower general motor quotient values. This can be explained by the fact that motor difficulties in children with DCD are limited to the areas of coordination and proprioception, and, in the case of children with ADHD, motor problems extend to the perceptive area.

Accordingly, the results showed that children with ADHD exhibit greater delays in the perceptual domain (spatial and temporal organisation), as reflected in motor tasks such as shape recognition, size perception, direction perception, right-left perception, sequence of actions, structural rhythms, memory, and expressive language. Such activities place greater demands on the executive function, especially

attention, concentration, organisation, and task execution. Thus, the dyspraxia observed in ADHD may be, at least in part, a product of the inattention that characterizes the disorder, as suggested by a study that observed motor differences in fine motor skills for the non-dominant hand, justifying that the performance of the non-dominant hand requires attention more sustained in relation to the performance of the dominant hand (Hyde et al., 2021). In addition to the characteristic impairments related to attention, overall, 65–70% of young people with ADHD exhibit impairments in working memory (Fosco et al., 2020). Working memory refers to a multi-component system responsible for numerous complex functions that involve coordination and action on the information held in short-term memory (Baddeley, 2012), as well as the ability to shape or manipulate information stored internally (Kasper et al., 2012). In addition, one study (Sabhlok et al., 2021) points out that executive control failures manifest selectively as symptoms of inattention disguised as problems with organisation, forgetfulness, and distraction, often confused with symptoms of DCD (children with DCD are commonly described as clumsy and awkward, showing less accuracy and speed when performing motor skills) (Tamplain & Miller, 2021). Lower values in the perceptive areas may represent problems of organisation and forgetfulness that negatively influence the motor tasks of spatial and temporal organisation used in the battery of tests of the present study.

In addition, the findings of this study reveal consistent impairments in temporal functions in children with ADHD, agreeing with previous research showing problems such as time estimation, temporal prediction, and motor timing (Albajara et al., 2019; Hart et al., 2012). These findings suggest that time perception and temporal control are significantly impaired in children with ADHD. Functional neuroimaging studies corroborate this understanding, by evidencing deficits in the recruitment of regions involved in timing, such as the inferior and dorsolateral prefrontal cortex, the cerebellum, the parietal lobes and the basal ganglia, the latter, in particular, have been described as an "internal clock" due to their participation in the integration of cortical oscillatory activity and in the timing of stimuli, especially on subsecond scales (Hart et al., 2012; Kaiser et al., 2015).

The cerebellum, basal ganglia, and other extrapyramidal structures are also affected in children with DCD, although the resulting motor impairments tend to manifest differently. The cerebellum plays a key role in motor functions such as balance maintenance, coordination of eye and head movements, fluidity of movement, regulation of muscle tone, and temporal regulation of motor sequences that may influence motor action (Vaivre-Douret, 2014). In children with DCD, cerebellar dysfunction can also lead to symptoms such as motor slowing, reduced precision, and increased motor task variability (D'Arrigo et al., 2021; Wang et al., 2014). Functions of the extrapyramidal system are likewise known to contribute to tone regulation, postural adaptation, and motor control.

In DCD, motor planning is also altered in regions such as the basal ganglia and thalamus, where extracorporeal sensory-perceptual information required for task execution (tactile, kinesthetic, visual, and auditory inputs) is integrated. When this information is incorrectly processed and sent to cortical regions (prefrontal, parietal, temporo-occipital), motor planning is disrupted and cannot be automatically corrected due to dysfunction within the cerebello-thalamo-basal ganglia circuitry. However, the role of motor planning is to provide spatial and temporal parameters for movement, supported by proprioceptive and vestibular feedback systems (proprioception provides information about limb positioning and body displacement, while the vestibular system contributes to postural balance during changes in position). This circuit projects input to the premotor cortex (responsible for movement encoding) and to the motor cortex, enabling movement execution. The basal ganglia, therefore, play a key role in movement preparation and initiation, as well as in the suppression of unwanted movements (Vaivre-Douret, 2014).

In an attempt to contribute to the discussion presented by Goulardins et al. (2017) that states that although ADHD may predispose children to motor difficulties, it is not clear whether the motor difficulties observed in this population are inherent to ADHD or are mediated by the comorbidity of DCD, our study points out in direction that ADHD and DCD affect different areas of neurodevelopment and, therefore, motor difficulties must be observed by specific areas related to the identity of the disorder. The evidence reinforces the understanding that the motor deficits observed in individuals with ADHD and DCD have important implications in the central nervous system, but with different manifestations in neurological structures and functions. The difficulties related to the coordinative areas are directly related to the DCD, and the perceptive areas to the ADHD. This result also has important implications for the protocol used to identify dyspraxia in neurodevelopmental disorders, suggesting a reliable assessment. The motor assessment method should cover all areas (coordinative, proprioceptive, and perceptive), thus avoiding false positives.

This study had limitations that should be considered when interpreting the results. The use of a non-probabilistic sampling technique and a reduced sample size, especially in the DCD group, reduces the generalisability of the findings.

Furthermore, the results should be interpreted as preliminary, given the small sample size. However, the statistical analyses used are adequate for the sample size, and the results indicate paths, albeit preliminary, for future studies and for planning interventions that better serve groups of children with DCD and ADHD. Additionally, possible factors that could influence the results, such as gender and chronological age, were not taken into consideration. However, the present research provides useful descriptive data to identify the motor specificities presented in ADHD and DCD when compared to TD children.

CONCLUSIONS

Dyspraxia affects different motor areas in children with ADHD or DCD. Children with ADHD presented greater difficulties with spatial and temporal organisation, therefore, in perceptive areas. Children with DCD showed the greatest difficulties in fine motor skills, gross motor skills, and balance; therefore, in the coordinative and proprioceptive areas. These specific motor dysfunctions, named Dyspraxias, facilitate the understanding of neurodevelopmental disorders and can contribute to the differential and clinical diagnosis and favour the development of motor intervention programs. The presented conclusions should be interpreted with caution, given the small sample size, especially in relation to the DCD group. The results should be interpreted as preliminary.

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