Low Levels of Attentional Interference have Similar Effects on Static Balance Control of Typically Developing Children and Those with Symptoms of Developmental Coordination Disorder (DCD)

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Abstract

Conceptually, attentional interference should affect balance of typically developing children and even more so those with Developmental Coordination Disorder (DCD). However, due to equivocal findings and limited methodologies this issue remains unclear. Thus, the purpose of this study was to examine the effects of cognitive task on static balance control in typically developing children and those with symptoms of DCD by using traditional and non-traditional measures of postural sway. Ten typically developing children and ten with symptoms of DCD, between 8 and 10 y of age, were recruited. A dual-task methodology was implemented involving quiet standing as a motor task and a numeric classification as an attentional task. Mean and intra-individual variability for three traditional (Ao, Ap sway, Lat) and non-traditional measures of sway (f_{dis}, f_{mode}, P_p) were derived from 10 trials performed with and without attentional interference. The results showed no interaction effects, and aside from area of sway, the differences between the groups or attentional conditions were marginal. In terms of non-traditional measures, the impact of interference was evident from two out of three measures (f_{dis}, f_{mode}), but the emerging values were still within what would be considered as adult-like performance. Collectively, the expected differences between the groups did not emerge, and like-wise the impact of attentional interference was measure-specific as majority of analyses failed to reveal any reliable effects. The emerging small effect sizes further confirmed that the differences between the group means were marginal. However, due to the characteristics of sample these inferences should be treated with caution as they may not generalize to all children with this diagnosis (e.g., ADHD and DCD).

Keywords: DCD; Balance control; Dual-task

What This Paper Adds

The primary result emerging form this research is that the data failed to show expected differences between the groups, particularly in a dual-task condition. Also, the sample as a whole was not substantially affected by a cognitive task when attempting to maintain stance. The robustness of these finding is further supported by the fact that the trend was evident across different types of sway measures. As indicated in previous motor control literature, the degree of interference between motor and cognitive task is likely constrained by many different factors. Thus, it is plausible that children of different ages or those exhibiting more pronounced difficulties in the perceptuo-motor functioning may be affected, particularly when the demands of the motor and/or cognitive tasks were to be enhanced.

Introduction

Balance control represents a fundamental skill that affords carrying out many every-day activities [1]. Generally, a distinction is made between static and dynamic tasks, where the implicit goal of the former is to minimize sway, whereas the latter

involves self-initiated perturbations often associated with completion of a supra-postural task (e.g., leaning to intercept a ball). Developmentally, the ability to perform either type of tasks becomes adult-like between 7 and 10 y of age [2]. This type of performance coincides with mastery of different motor control mechanisms (e.g., open, closed or integrated type of control) [3], and associated sensory [4] motor sub-systems [5]. Traditionally, it has been assumed that balance control, particularly static, is automatic and it can be maintained in the absence of attention. However, some research studies involving a dual-tasking paradigm, with postural task as the primary task, and a cognitive activity as a secondary task, showed otherwise [6-8]. This is particularly true for young children who exhibit more postural sway when attempting to maintain stance in the presence of cognitive interference [9]. The literature also revealed that the degree of the interference is task dependent, as enhancing the demands of the postural [10, 11] and/or cognitive activity [12, 13] may have even more pronounced impact on one's stability and the coinciding measures. Interestingly, it has also been reported that the performance of the secondary (cognitive) task does not always result in more postural sway. This counterintuitive effect has been attributed to the emergency of a "stiffening" strategy which reduces the amount of sway in order to meet the demands of dual-tasking condition [6].

Analysis of balance represents a prominent area in the study of motor control issues in children who are often referred to as "awkward, but otherwise normal". These individuals are often formally diagnosed with Developmental Coordination Disorder (DCD). This disorder affects approximately 6% of the school-age population [14], and despite its heterogeneity, many of the diagnosed children experience problems in balance control domain [15, 16]. Up till now the primary focus has been on examining how children with DCD use different sensory systems [16], the anticipatory mechanisms [17], and musculo-skeletal synergies [18, 19] to maintain unperturbed or perturbed stance. The emerging results were mixed. Some studies showed pronounced differences between the groups in static balance (e.g., quiet standing task) [20, 21], others revealed differences only on few but not all measures [22], or those were manifested only when the task demands were enhanced [23]. At this point, the underlying motor control limiters associated with these problems are still not well understood, and they may result from many different perceptual-motor, and as hypothesized here, attentional issues.

The less than optimal ability to deal with attentional interference, hence the situation where the cognitive and motor tasks have to be performed simultaneously may be an indication of automatization deficit [24]. The problems in automatic processing may force children, particularly those with movement problems, to relay on serial type of processing which is cognitively demanding [25]. In balance control domain this would translate in delayed muscular adaptations to any self- or externally initiated perturbations, likely leading to falls, staggering or implementation of inappropriate postures. Thus, conceptually the ability to sense/perceive the postural state of the system and programming the respective motor responses may be jeopardized by slower information processing. Despite this potential link between the underlying cognitive mechanisms and balance control, the role of attentional constraints has not been extensively investigated. Laufer et al. [26] investigated the impact of a relatively simple cognitive task, involving object identification, while standing on a firm and a compliant surface, in 5 y old children with and without DCD. The results showed that regardless of the condition children with DCD swayed more as compared to typically developing children. However, the expected effect of cognitive interference was minimal. Tsai et al. [27] showed a similar scenario using five different cognitive tasks administered to children with and without DCD, between 9 and 10 y of age. Once again, children with DCD swayed more than typically developing children, but no reliable differences were reported for the performance of children with DCD in the dual-task and balance-only conditions. In the latest study, Chen and colleagues examined how different memory task may affect the ability to maintain balance, as inferred from the amount of head and torso movement. Once again, the impact of attentional load was not substantial for either group.

One common trend across these investigations was that balance control was examined solely by implementing the traditional measures of center of pressure (COP). These variables are extracted from time-domain, and allow making inferences about several aspects of postural sway such as area (Ao), path length (L), amount of excursions in anterior-posterior (Ap) and lateral directions (Lat) [28]. In comparison, a non-traditional method known as spectral analysis allows for a more in-depth investigation of control mechanisms underlying the process of balance control [29]. These frequency-domain measures allow capturing the distribution of the power density of the signal at different frequencies around the mean frequency. In other words, the reveal the degree of variability within the frequency signal, with smaller values indicate more consistency of postural control behavior. Frequency mode is another useful variable which represents a frequency value corresponding to the dominant peak amplitude of the signal power density [30]. For quiet standing, larger power density values (>1 Hz) imply greater rates of change of the COP, thus a less optimal performance [31, 32]. Peak power density captures the largest peak in amplitude of the signal, and in the case of quiet standing it is expected that power measures located at lower frequencies will be evident in an effective behaviour [32]. Developmentally, children under the age of 6 display a more ballistic type of control during quiet standing. This outcome is generally inferred from postural profiles characterized by high frequency, high power (amplitude) sway resulting in chaotic and large movements of the COP [33]. Thus, power density measures at lower frequencies (<1 Hz) are generally indicative of a more optimal performance, coinciding with smooth and subtle COP excursions [34]. The frequency domain analysis has not been implemented in many studies examining the performance of children with and without DCD in balance tasks. In fact, there is only research which investigated power spectral characteristics of postural adaptations in boys with and without DCD [31]. The results indicated that children with DCD displayed higher peak power density frequency values when compared to the age matched typically developing children. It was postulated that this may be due to less than optimal processing of proprioceptive inputs.

Collectively, it is plausible that coalition of different constraints can affect balance control of children with DCD, with attentional interference potentially representing one of those factors. However, in comparison to the volumes of research devoted to delineating the perceptuo-motor limiters, still relatively little is known regarding the impact of cognitive load on balance. Therefore, the purpose of this study was to examine the effects of cognitive task on static balance control in typically developing children and those with symptoms of DCD by using traditional and non-traditional measures of postural sway.

Method

Participants

Ten children who met the criteria for DCD (8 males and 2 females) (M=9 y, SD=3 months) and ten typically developing individuals (5 males and 5 females) (M=8 y, SD=8 months) were recruited from the local elementary schools. Although, the children recruited for this study were not formally diagnosed with DCD, as only a paediatrician can do so, clinically they exhibited the symptoms for DCD as indicated by Geuze et al. [35]. The motor coordination problems were inferred from the first version of Movement Assessment Battery for Children (MABC) [36]. The MABC scores provide information about the overall motor skill level (Total Impairment Score; TIS) and balance abilities (Total Balance Score; TBS). To be included in the DCD group a child had to score at or below the 10th percentile for the TIS and below 15th percentile for the TBS scores. To infer whether motor coordination issues impacted activities of daily living (ADL) or academic achievement a Developmental Coordination Disorder Questionnaire (DCDQ) was filled out for each child [37]. The DCDQ is a parent based report that asks them to compare their child's motor performance to that of his/her peers using a 5 point Likert scale, ranging from 'not at all like your child' to 'extremely like your child'. A score below 57 indicates that there was no interference in academic achievement and ADL due to movement difficulties. Children with DCD also did not have any known medical condition, and had no intellectual deficits as evident from the medical histories obtained from the schools from which the children were recruited, with the parents' permission. In contrast, children who scored above the 30th percentile on TIS and above 15th percentile on BS components of the test were included in the comparison group. They were not diagnosed with a known medical or intellectual condition as evident from their medical histories.

Apparatus and procedures

Once the height, weight, foot width and length were recorded, participants carried out four different conditions. The participant stood motionless on an Advanced Mechanical Technologies Incorporated (AMTI) force platform with feet approximately shoulder width apart, arms resting comfortably at the sides, while avoiding extraneous movements such as bobbing of the head or twitching of the arms or fingers. The first set of trials was performed without attentional interference, while in the second set of attempts a numeric classification task was implemented. The participant was asked to delineate a correct response given the information recited from an audio recording. For example, once the numbers 1 and 6 were recited, the participant was to identify the number as 16, and then indicate if it was lower or higher than 50. The participants completed 20 trials in total, 10 per each condition, and all trials lasted 10 s. All participants were tested individually, and each session lasted approximately 45 min. All testing was completed on an AMTI force plate with an amplifier gain set at 4000 and a low pass filter of 10.5 Hz. The force platform data were collected at a sampling rate of 100 Hz.

Dependent measures and analyses

The AMTI BioDaq analysis package was used to compute the center of pressure (COP) measures. The mean and intra-individual variability (SD) were derived for area of sway (A_o), path length (L), and anterior-posterior sway (AP). The A_o makes inferences regarding the area of COP excursions during the performance of each balance condition (cm^2). Path length (cm) measures the total distance travelled by the COP, whereas anterior-posterior sway (cm) was used to make inferences about displacement of the COP in the sagittal plane of motion. The Fast Fourier Transform (FFT) is a mathematical technique used to perform a spectrum analysis of the COP data. Power density measures of COP in a frequency range of 0 to 5 Hz were used to compute dependent variables in frequency domain. These variables included frequency dispersion (f_{sd}; Hz), mode (f_{mode}; Hz), and peak power density (Pp; cm^2/Hz). As previously stated in the literature, frequency dispersion captures the distribution of energy at different frequencies, and how it is dispersed around the mean frequency [30]. Frequency mode is the frequency value characterized by the dominating peak in amplitude of the signal [30], whereas peak power is representative of the largest peak in amplitude of the signal [32].

The statistical analysis involved a series a 2 Group (DCD vs. $_{no}$DCD) × 2 Condition (attentional interference *vs.* no interference) mixed factorial ANOVA, with repeated measures on the second factor. The alpha value was set at p<0.05, and Eta squared (η^2) was used to infer the magnitude of the respective effect size [38]. A small effect is represented by a value below 0.03, a medium effect is a value between 0.06 and 0.09, and a large effect is any value above 0.15 [38]. Independent samples t-tests were also used for the comparison of morphological characteristics between the groups.

Results

MABC scores and morphological characteristics

The analysis of the MABC scores showed significant differences between the groups in total impairment and balance scores. In terms of the intra-group variability (SD) the typically developing children constituted a homogenous sample, in regards to their overall motor performance and balance skills. However, this was not the case for children with DCD, particularly in regards to the balance scores as three participants exhibited scores (0.5, 0.5, 1.5) that were comparable to those evident in the performance of their typically developing peers. In terms of DCDQ measures, children with DCD scored below 57 (M=34.2, SD=16.7), indicating that movement problems had an impact on their academic achievement and/or activities of daily living. Children without DCD did not exhibit such issues scoring above 57 (M=65.8, SD=7.21). Also, no significant differences were found between the groups for height, weight, foot width and length **(Table 1)**.

Table 1 Descriptive statistics and independent samples t-test results for morphological characteristics and MABC scores for both groups.

Variable	Typically Developing Children		Children with DCD		Statistics	
	M SD		M SD		t value	Sig.
Height (cm)	136.4 6.29		140.6 9.03		1.20	0.24
Weight (kg)	33.7 5.49		39.5 8.44		1.82	0.08
Foot width (cm)	7.91 1.49		8.65 0.44		1.50	0.15
Foot length (cm)	21.45 1.07		22.06 1.47		1.05	0.30
TIS score	2.90 2.31		16.95 3.46		10.68	0.001
TBS score	0.35 0.53		4.66 2.46		5.40	0.001
DCDQ score	34.2 16.7		65.80 7.21		4.03	0.001

Note: TIS (Total Impairment Score); TBS (Total Balance Score) and DCDQ (Developmental Coordination Questionnaire)

Traditional measures of static balance control

The analysis revealed no statistically significant interaction effects. A significant main effect for Group was found for area of sway (A_o). Children with DCD demonstrated larger amount of sway from the vertical (M=0.6, SD=0.03) as compared to the typically developing children (M=0.25, SD=0.01). Also, a significant Condition main effect (F (1, 18) =11.95, p<0.05, η^2=0.40), once again in respect to the area of sway, showed larger excursions from the vertical when attentional interference (M=0.6, SD=0.02) and no-interference conditions were compared (M=0.25, SD=0.01) **(Table 2)**.

There was no statistically significant interaction or main effects for the mean AP sway as well as path length. In fact, the review of group data **(Table 2)** showed that the differences between the groups/conditions were minimal, if any. In regards to the intra-individual variability, once again no reliable differences were found across area of sway, path length and AP sway **(Table 3)**.

Non-traditional measures of static balance control

The analysis of non-traditional measures extracted from the frequency domain, revealed a trend similar to that emerging from the traditional descriptors of sway conducted in time domain. A main effect for Condition was found for (mean) frequency mode (f_{mode}) (F (1, 18) =23.87, p<0.05, η^2=0.57), revealing a significant increase when no-interference (M=1.10, SD=0.3) and interference conditions (M=1.50, SD=0.2) were compared. A significant main effect for Condition was also found for variability of frequency dispersion (f_{sd}) (F (1, 18) =5.86, p<0.05, η^2=0.25), once again indicating that attentional interference condition resulted in higher values (M=0.21, SD=0.11) when compared to the baseline condition (M=0.15, SD=0.06). The remaining analyses of variance did not reveal any other significant interaction or main effects for mean and intra-individual variability for the respective measures **(Table 3)**.

Discussion

MABC scores and morphological characteristics

The ability to control balance, static or dynamic, depends on a coalition of morphological, sensory, biomechanical as well as cognitive constraints [1]. In this study both groups did not differ in regards to their morphological characteristics relevant to the ability to maintain stance. As expected, the differences in perceptuo-motor status, as inferred from the formal assessment test, were present across measures of overall performance (TIS) as well as balance skills (BS). However, despite the differences emerging at the group level, there were three children in the DCD group who exhibited balance proficiency comparable to that evident in the performance of the typically developing peers. This outcome indicates that although they had symptoms of DCD, their balance problems were not as pronounced when compared to the rest of their peers, who scored at or below the 5th percentile. Although the presence of these children may have affected the homogeneity of the group, and the coinciding inferential analysis, they were not excluded from the sample because DCD population is in fact very heterogeneous.

Traditional measures

It has been suggested in the literature that children with DCD prioritize the cognitive task while simultaneously attempting to maintain stance, thus leading to jeopardized balance control [26]. This has been referred to as a symptom of automatization deficit [27]. It is assumed that a fully automatized skill does not require conscious monitoring and its performance should result in no or little decrement even if there are other demands placed upon conscious processing capacity [39]. The present results predominantly failed to support this claim. The implementation of attentional interference was expected to affect the balance control of children, particularly those with DCD. However, the anticipated Group by Condition interaction effect was not found for any of the analyses **(Table 3)**. In fact, the only significant effect involving a group factor was found for area of sway, showing that overall across both conditions children with DCD exhibited further excursions away from the vertical position when compared to their peers. However, the lack of differences in mean performance and intra-individual variability in AP sway and path length indicated that they exhibited a comparable amount of sway in the sagittal plane of motion and in the overall distance travelled by the COP. Thus, not only that attentional interference did not impact the DCD group more as compared to their peers, but also the overall differences between the groups were minimal. This finding supports previous studies showing that in relatively simple, unperturbed, quiet standing task the differences between these two groups are marginal, if any [22, 23, 40, 41]. The fact that the performance across the conditions was comparable, aside from area of sway, may further indicate that static balance has minimal attentional demand. Alternatively, it is also plausible that developmentally children by

Table 2 Mean scores (M) and intra-individual variability (SD) of typically developing children (TD) and those with DCD, across traditional and non-traditional measure of sway.

Variable	Group	No Interference M SD	Interference M SD
AP sway	DCD	0.26 0.09	0.28 0.11
	TD	0.22 0.11	0.24 0.14
	Total	0.24 0.10	0.26 0.13
A_o	DCD	0.4 0.03	0.8 0.05
	TD	0.1 0.01	0.4 0.03
	Total	0.25 0.02	0.6 0.04
L	DCD	4.01 1.77	4.22 1.05
	TD	4.07 0.89	4.35 0.89
	Total	4.04 1.37	4.28 1.37
P_p	DCD	14.26 7.55	16.79 7.72
	TD	9.56 3.11	11.26 8.48
	Total	11.91 5.02	13.03 7.79
f_{mode}	DCD	1.11 0.3	1.16 0.4
	TD	0.9 0.1	1.4 0.5
	Total	0.10 0.02	0.15 0.04
f_{sd}	DCD	0.80 0.14	0.71 0.22
	TD	0.60 0.17	0.65 0.20
	Total	0.70 0.15	0.68 0.21

Note: AP sway=Anterior Posterior Sway; Ao=Area of Sway; L=Path Length; Pp=Peak Power; f_{mode}=Frequency Mode; f_{sd}=Frequency Dispersion

Table 3 Statistical results for the mean performances and intra-individual variability (SD) for the group x condition mixed ANOVA analyses.

Variable	Group F p η²	Condition F p η²	Group x Condition F p η²
AP	0.76 0.395 0.04	1.68 0.212 0.09	1.09 0.0 0.01
SD	0.091 0.766 0.01	0.85 0.369 0.05	0.20 0.659 0.01
Ao	5.33 0.033* 0.23	11.95 0.003* 0.40	0.33 0.574 0.02
SD	3.58 0.075 0.17	0.591 0.452 0.03	1.50 0.237 0.08
L	0.04 0.836 0.00	1.53 0.232 0.08	0.03 0.867 0.00
SD	3.05 0.098 0.15	0.27 0.613 0.02	0.06 0.808 0.00
P_p	0.73 0.405 0.04	0.59 0.453 0.03	2.02 0.173 0.10
SD	1.04 0.320 0.06	0.72 0.407 0.04	1.26 0.277 0.07
f_{mode}	1.02 0.326 0.05	23.87 0.001* 0.57	0.71 0.411 0.04
SD	2.32 0.145 0.11	2.67 0.120 0.13	2.30 0.075 0.12
f_{sd}	0.40 0.535 0.02	0.04 0.846 0.00	0.16 0.691 0.01
SD	0.434 0.518 0.02	5.86 0.026* 0.25	0.13 0.726 0.01

Note: AP sway=Anterior Posterior Sway; Ao=Area of Sway; L=Path Length; Pp=Peak Power; f_{mode}=Frequency Mode; f_{sd}=Frequency Dispersion
* $p<0.05$

this age are able to cope with the cognitive demands of the task, irrespective of their perceptuo-motor status. This rationale is in line with previous research showing that the capacity to allocate attention in parallel to both motor and cognitive tasks starts to emerge around 8 or 9 years of age, while reaching its maturity in 11 year old children [6, 42, 43].

At first glance the findings from this research seem to be counterintuitive and in drastic contrast with the previous studies examining the impact of attention on balance control of children with DCD. However, a closer review of the previously reported data seems to indicate otherwise. Tsai et al. [27] postulated that children with DCD exhibit automatization deficit as they tested two groups of interest across seven different conditions, including four dual-task conditions. Nevertheless, the results showed no significant interactions or group main effects for any of the experimental conditions, thus indicating "that these dual tasks were of similar level of difficulty for both groups" (p. 555). As it stands, the only study which reported strong effect of cognitive interference on balance control of children with DCD was carried out by Laufer et al. [26]. They compared performance of 5 y old children with and without DCD across different balance tasks, with and without attentional interference. The results showed that children with DCD exhibited higher COP velocity and more AP and Lat sway when dual-task and baseline conditions were compared. However, it should be noted that the typically developing children were also affected by the cognitive task across all but one condition. As a result, it is plausible that five-year old children may not be able to deal with the attentional demands of this motor task. Thus, the degree to which cognitive processes impact motor processes associated with balance control may be affected not only by the complexity of the motor and cognitive tasks, but also by the developmental stage of the children, regardless of their perceptuo-motor status.

Non-traditional measures

The potential impact of cognitive interference on balance control of both groups was also tested by implementing spectral analysis. Although past research is limited, Przysucha et al. [31] reported that children with DCD exhibited a high frequency mode, high power postural sway in comparison to their typically developing peers. The present study failed to confirm those findings. As evident from group data, the dominant frequency (f_{mode}) of the signal for both groups, and across both conditions, was comparable and close to 1 Hz. These values are in line with previously reported data for typically developing children [44, 32], thus indicating that participants in the present study did not exhibit extensive corrective adjustments [30]. Also, although there was an increase in frequency mode with the addition of the attentional load, the values still remained in the low end of the frequency spectrum (around 1 Hz), thus indicating that the balance control processes were not jeopardized substantially. A similar scenario emerged from the analysis of power density measures (Pp), indicating that both groups exhibited smooth and controlled adjustments of the COP [32]. Lastly, the low variability in the dispersion measure for both groups confirmed consistent and relatively stable performance in relation to center of pressure measures for the frequency domain analysis. That is, the concentration of power density measures was located close to the frequency mean, which was in the very low end of the (frequency) spectrum. This outcome further confirmed the effectiveness of performance. In regards to previous studies involving typically developing individuals, it was shown that peak power density measures found at a lower frequency coincide with optimal balance performance [32]. This pattern of behaviour was evident around 7 y of age, when typically developing children start to display more mature levels of performance. These inferences are also in line with the adult literature revealing low frequency/ low power sway during quiet standing [30]. Thus, collectively the frequency domain analyses failed to show substantial differences between the groups, which is also in line with the findings emerging from the traditional measures of sway.

Conclusion

Dual-task interference occurs when task's requirements exceed the attentional capacity of the central nervous system (CNS). The present results predominantly failed to reveal such effect. In terms of the primary aim, the data confirmed previous trends in the literature showing that the addition of small degree of attentional loading does not present a significant threat to dual task performance in typically developing children as well as those exhibiting symptoms of DCD [6-8]. Thus, it appears that static balance control in itself is a task which can be accomplished more automatically through parallel type of (information) processing. However, it is also plausible that an increase in the complexity or novelty of the balance, and/or attentional task would result in more pronounced effects [12].

In terms of the potential limitations to this study, the size and characteristics of the sample warrant some caution. In case of the former issue, it may be speculated that small "n" potentially contributed to Type 2 error in this study. However, it should also be pointed out that for the majority of the analyses revealing non-significant results the coinciding effect sizes (eta squared) were also very small **(Table 3)**. The effect size emphasises the magnitude of the difference between the means, rather than confounding this with (small) sample size. Thus, here it can be inferred that in fact the actual magnitude of the differences between the means were negligible. From the standpoint of the characteristics of the sample, it is plausible that children with more severe movement problems may have responded differently to the attentional loading [45]. Also, since the sample was not explicitly tested for a presence of the potential comorbidity between DCD and ADHD, it is difficult to speculate how, or if the attentional interference affects to the same degree those with dual versus solitary DCD diagnosis. Considering that the dual diagnosis between the two conditions is prevalent in this population, and the "pure" DCD cases account for only about 5% [35], the presence inferences likely do not generalize to all children exhibiting the symptoms of DCD.

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