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Postural control during standing reach in children with Down syndrome

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ABSTRACT

The purpose of the present study was to investigate the dynamic postural control of children with Down syndrome (DS). Specifically, we compared postural control and goal-directed reaching performance between children with DS and typically developing children during standing reach. Standing reach performance was analyzed in three main phases using the kinematic and kinetic data collected from a force plate and a motion capture system. Fourteen children with DS, age and gender matched with fourteen typically developing children, were recruited for this study. The results showed that the demand of the standing reach task affected both dynamic postural control and reaching performance in children with DS, especially in the condition of beyond arm's length reaching. More postural adjustment strategies were recruited when reaching distance was beyond arm's length. Children with DS tended to use inefficient and conservative strategies for postural stability and reaching. That is, children with DS perform standing reach with increased reaction and execution time and decreased amplitudes of center of pressure displacements. Standing reach resembled functional balance that is required in daily activities. It is suggested to be considered as a part of strength and balance training program with graded task difficulty.

1. Introduction

Trisomy 21 also known as Down syndrome (DS), characterized by the presence of a third chromosome 21 in the genome, occurs about 1 in every 800 births (Roizen & Patterson, 2003). Individuals with DS demonstrate deficits in motor skills throughout development (Gupta, Rao, & Kumaran, 2011; Tudella, Pereira, Basso, & Savelsbergh, 2011). Hypotonia, ligamentous laxity, longer reaction time, balance deficits and poor postural control were identified as the reasons behind these children demonstrating different movement patterns qualitatively, as well as quantitatively (Shumway-Cook & Woollacott, 1985; Tudella et al., 2011).

Researchers have studied postural control in individuals with DS because it was considered as the foundation of motor skill development (Galli et al., 2008; Rigoldi, Galli, Mainardi, Crivellini, & Albertini, 2011; Villarroya et al., 2012).

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Center of pressure (CoP), reflecting the pattern of body sway while performing postural control tasks (e.g. standing), has been widely used to quantify the performance of postural control (Grangeon, Gauthier, Duclos, Lemay, & Gagnon, 2014; Kyvelidou, Harbourne, Stuberg, Sun, & Stergiou, 2009). Studies showed that individuals with DS often demonstrated deficits in maintaining static standing balance than their healthy controls, evidenced by greater CoP displacement and higher frequency of postural sway (Cabeza-Ruiz et al., 2011; Gomes & Barela, 2007; Villarroya et al., 2012).

Static standing balance, however, does not necessarily represent posture control that is required in real life. In order to be able to function in daily life, one needs to integrate postural system and coordinate with task-oriented behaviors in a way that allows specific tasks to be performed while balance is maintained (Gardner, Mark, Ward, & Edkins, 2001; Haddad, Rietdyk, Claxton, & Huber, 2013; Mitra, 2004). During our literature review, we located only one study that investigated dynamic postural control under conditions of task-oriented movement in children with DS. Wang, Long, and Liu (2012) examined dynamic postural control by asking children with DS to perform ball throwing in the standing position. They reported that children with DS exhibited greater medial–lateral but smaller anterior–posterior postural sway, than their control peers during the task-oriented movement (Wang et al., 2012).

Wang et al. (2012) in their study demonstrated how children with DS control their posture while performing a task, but they did not incorporate levels of task difficulty into their studied variables. Task difficulty influences postural control and has been postulated by many theoretical frameworks that applied to postural–suprapostural dual-task performance (Mitra & Fraizer, 2004; Woollacott & Shumway-Cook, 2002). Studies have shown that postural control is modified when a suprapostural task is executed simultaneously (Streepey & Angulo-Kinzler, 2002). For most activities, posture must be controlled in a manner that affords both upright stance and the completion of a task. In some circumstances, the individual may choose to accept reduced performance of the task-oriented activity so that they can remain upright (Haddad et al., 2013). Exploration of task-oriented postural control in children with DS will help us understand how these children function and interact with their environment, and the strategies they use for maintaining postural control. This information may be beneficial for designing rehabilitative programs to enhance dynamic postural control in this group, thereby improving their participation in daily life.

The purpose of the present study was to investigate the dynamic postural control of children with Down syndrome (DS). Specifically, we compared postural control and goal-directed reaching performance between children with DS and typically developing children during standing reach by examining the CoP movement in three phases: anticipatory postural control (APA), reaching, and returning phase. In this study, reaching tasks to three distances enabled the examination of dynamic postural control in the context of graded task difficulty.

2. Methods

2.1. Participants

Convenient sample of 28 children were recruited from the Down syndrome foundation of Taiwan and the local community, where the research was conducted. Fourteen children with DS (7 boys, 7 girls, 8.26 ± 0.82 years, 120.87 ± 8.63 cm, 23.1 ± 3.32 kg) and fourteen age and gender matched TD children (7 boys, 7 girls, 8.04 ± 0.74 years, 128.04 ± 7.47 cm, 28.75 ± 10.08 kg) participated in this study. The inclusion criteria for children with DS were (a) aged 7–9 years; (b) a diagnosis of DS determined by physicians; (c) able to follow simple instructions; (d) able to walk independently. Children with comorbidity of autistic spectrum disorders, cerebral palsy, congenital heart defects, deafness, blindness or other neuro-musculoskeletal diseases were excluded in the present study. TD children were free of any developmental delay or physiological impairment. There were no significant differences in age and body weight between the two groups, but the children with DS were shorter ($p = 0.029$). The arm lengths of the children with DS were also shorter than those of the TD children (DS: 48.26 ± 4.39 cm vs. TD: 54.00 ± 4.36 cm, $p = 0.002$). Permission to conduct the study was provided by the Institutional Human Research Ethics Committee of the National Taiwan University. Informed consents from parents, and assents from participating children were obtained prior to data collection.

2.2. Equipment setup

A force plate (Advanced Mechanical Technology Inc., USA) with 1080 Hz recorded the ground reaction force and center of pressure (CoP). Three foot markers, placed on both heels and second metatarsal head of one foot, were used to define the coordinate system of the CoP. CoP is defined as the point where the total sum of a pressure field acts on a body, causing a force to act through that point. A six-camera Vicon MX system (Oxford Metrics Group, UK) with 120 Hz sampling rate recorded 3D kinematics of the reaching arm with retroreflective markers attached to styloid processes of ulna and radius of the dominant arm, and to both acromion processes. The markers on the styloid processes of ulna and radius were used to represent arm movements, and the markers on both acromion processes were used to represent shoulder width. The position of a push-button which was used as the reaching target was adjusted to each child's height and arm length. The button was placed along the child's mid-sagittal plane at a height corresponding to 50% of body height.

2.3. Procedures

Prior to the start of data collection, body height and weight, arm and foot length, as well as shoulder width, were measured and recorded. Three test conditions were designed for the study. Each child was asked to reach for the push-button at three distances which were set at an 80%, 100%, and 120% arm-length distance (D80, D100, D120). Each child was given three practice trials before actual administration of the test to familiarize himself/herself with the test protocol. To avoid learning effects and anticipation, the orders of the trial and test conditions were randomized. The randomization was programmed as part of the computer software program.

In the initial position, the child was instructed to stand barefoot on the force plate. Arms were at his/her sides and feet were comfortably positioned at shoulder width. CoP data collected at initial standing were set as the baseline postural sway. The child was then instructed to recognize an auditory "Go" signal (sound of beep), which was a cue for him/her to reach and press the button using the index finger of his/her dominant hand, and then return to initial position as quickly and precisely as possible without moving his/her feet from the initial standing point. Go signal and signal from the button pressing were synchronized with force plate and motion capture system. The child repeated the sequence of tasks of standing reach, until five successful trials for each condition were performed and recorded.

2.4. Data analysis

Standing reach performance was analyzed in three main phases using the kinematic and kinetic data collected from a force plate and a motion capture system. Outputs of the force plate were two orthogonal components of CoP peak displacement in medial/lateral direction (M–L CoP, in cm) and in anterior/posterior direction (A–P CoP, in cm). Phase 1 was the phase of APA. The APA phase started at the onset of A–P CoP displacement, and ended at the onset of reaching movement. A threshold of 5% peak velocity was used to determine the onset of A–P CoP and A–P arm trajectory movements. Phase 2 was the reaching phase. The reaching phase started at the time of APA offset and ended when the child pressed the button. Phase 3 was the returning phase which started at the time of reaching offset and ended when the time that A–P CoP velocity below 5% of its peak value. To allow inter-subject comparison, A–P and M–L CoP displacements were normalized to each participant's foot length and shoulder width, respectively.

Three additional kinematic parameters collected from markers placed on the arm were used to quantify the reaching performance. They were reaction time (RT, in s), peak velocities (PV, in % arm length/s) and the percentage of movement time when peak velocity occurred (PPV, in %). The PV and PPV were only computed for the A–P direction. The reaction time was defined as the time between an auditory signal given for the child to start the reaching task and the onset of actual arm movement. The movement time (MT, in s) was defined as the time at which the maximum distance of the arm was first reached, minus the time at which the arm first moved forward. In our study movement time is also the duration of reaching phase. RT represents the efficiency of motor preplanning while PV and PPV represent the force control strategy during reaching (Wu, Chen, Tang, Lin, & Huang, 2007; Wu, Chuang, Lin, Chen, & Tsay, 2011). In addition, we used the difference between arm PPV and CoP PPV of the A–P direction movement to evaluate the temporal coordination of arm movements and CoP (Haddad et al., 2012).

2.5. Statistical analysis

The effects of group and reaching distance on all the calculated variables were evaluated using 2 (groups: DS, TD) × 3 (reaching distance: D80, D100, D120) mixed two-way analysis of variance (ANOVA) for repeated measures. The significance level was set at $p = 0.05$. When an interaction was found, simple main effects of reaching distance were then examined using one-way repeated measures ANOVA. Simple main group effects were examined by independent *t*-test. Post hoc analysis with Bonferroni correction was performed to reduce possible type I error. All statistical analyses were performed using SPSS, version 22.0 (IBM-SPSS, Armonk, NY).

3. Results

3.1. Postural control

In postural control, we examined the duration of time that children needed to complete each phase during reaching performance, as well as the A–P CoP and M–L CoP displacements in all three phases.

Children with DS took significantly longer to complete the APA and reaching phases in all three standing reach conditions (3 reaching distance: D80, D100, D120), when compared to children with TD (Table 1). However, there was no distance effect in both groups for all the phases (Table 1). That is, the distance of where the reaching target was set at did not influence the time children needed to complete either APA or reaching phases.

We found that during the APA phase, the A–P CoP displacement increased with increased reaching distance for both the DS and TD groups ($F_d = 10.41$, $p_d = 0.002$; Fig. 1a). There were no differences between the groups in the A–P CoP displacement for all reaching distances ($F_g = 0.001$, $p_g = 0.97$; Fig. 1a). Neither group nor distance effects ($F_d = 1.009$, $p_d = 0.375$; $F_g = 1.408$, $p_g = 0.251$; Fig. 1d) were found for the M–L CoP displacement in the APA phase.

Table 1
Group comparison of the duration of APA, reaching and returning phases at three test conditions (reaching distance was set at an 80%, 100% and 120% arm-length distance; D80, D100, D120).

Phase duration (s)	D80		D100		D120		Main effects	
	Mean	S.D.	Mean	S.D.	Mean	S.D.		
P1: APA								
DS	0.102	0.057	0.102	0.056	0.138	0.055	$F_{\mathrm{g}} = 13.63$	$p_{\mathrm{g}} = 0.002^{*}$
TD	0.066	0.036	0.049	0.019	0.054	0.027	$F_{\mathrm{d}} = 1.74$	$p_{\mathrm{d}} = 0.19$
P2: reaching								
DS	1.061	0.412	1.043	0.281	1.084	0.284	$F_{\mathrm{g}} = 33.89$	$p_{\mathrm{g}} < 0.0001^{*}$
TD	0.458	0.112	0.484	0.098	0.583	0.114	$F_{\mathrm{d}} = 1.46$	$p_{\mathrm{d}} = 0.25$
P3: returning								
DS	0.689	0.129	0.628	0.092	0.614	0.074	$F_{\mathrm{g}} = 0.71$	$p_{\mathrm{g}} = 0.411$
TD	0.589	0.072	0.609	0.109	0.658	0.102	$F_{\mathrm{d}} = 0.31$	$p_{\mathrm{d}} = 0.74$

DS, children with Down syndrome; TD, typically developing children; S.D., standard deviation; p_{g}, p-value of group effect; p_{d}, p-value of distance effect.
* Significant group effect $p_{\mathrm{g}} < 0.05$.
† Significant task effect $p_{\mathrm{d}} < 0.05$.

There were interactions between group and distance effects for the A–P CoP displacement in both reaching (P2) and returning phases (P3) ($F = 13.24$, $p < 0.001$) (Fig. 1b and c). The A–P CoP displacement increased with increased reaching distances for both DS and TD groups (P2: DS: $F_{\mathrm{d}} = 22.93$, $p_{\mathrm{d}} < 0.001$; TD: $F_{\mathrm{d}} = 97.68$, $p_{\mathrm{d}} < 0.001$; P3: DS: $F_{\mathrm{d}} = 12.52$, $p_{\mathrm{d}} < 0.001$; TD: $F_{\mathrm{d}} = 72.84$, $p_{\mathrm{d}} < 0.001$; Fig. 1b and c). The group effect on the A–P CoP displacement was only found in the D120 condition in reaching and returning phases (P2: $F_{\mathrm{g}} = 26.15$, $p_{\mathrm{g}} < 0.001$; P3: $F_{\mathrm{g}} = 17.99$, $p_{\mathrm{g}} < 0.001$; Fig. 1b and c). Specifically, children with DS had significantly smaller A–P CoP displacement than children with TD in the D120 condition in both reaching and returning phases. For the M–L CoP displacement, distance effects were found for both groups in both reaching and returning phases (P2: $F_{\mathrm{d}} = 9.42$, $p_{\mathrm{d}} = 0.001$; P3: $F_{\mathrm{d}} = 6.02$, $p_{\mathrm{d}} = 0.006$; Fig. 1e and f). There was no group effect for the M–L CoP displacement (P2: $F_{\mathrm{g}} = 0.01$, $p_{\mathrm{g}} = 0.92$; P3: $F_{\mathrm{g}} = 1.80$, $p_{\mathrm{g}} = 0.2$; Fig. 1e and f). That is, children in both groups significantly increased the amplitude of M–L CoP in reaching phase for the most difficult task.

3.2. Reaching performance

Reaching performance was examined using reaction time, arm PV and arm PPV, as well as arm–CoP coordination (Table 2). The results showed that children with DS exhibited significantly longer reaction time than children with TD ($F_{\mathrm{g}} = 9.61$, $p_{\mathrm{g}} = 0.006$). Children with DS had significantly smaller arm PV and arm PPV, than those in TD group in all test conditions (arm PV: $F_{\mathrm{g}} = 19.81$, $p_{\mathrm{g}} < 0.0001$; arm PPV: $F_{\mathrm{g}} = 13.45$, $p_{\mathrm{g}} = 0.002$). We found that the arm PV increased with increased reaching distance in both groups ($F_{\mathrm{d}} = 20.23$, $p_{\mathrm{d}} < 0.0001$), but there was no distance effect on the arm PPV ($F_{\mathrm{d}} = 0.25$, $p_{\mathrm{d}} = 0.78$). For the arm–CoP coordination, the results of negative values represented that the arm PPV was performed earlier than CoP PPV. The PPV difference between arm and CoP was smaller in children with DS than that of children with TD ($F_{\mathrm{g}} = 4.39$, $p_{\mathrm{g}} = 0.05$).

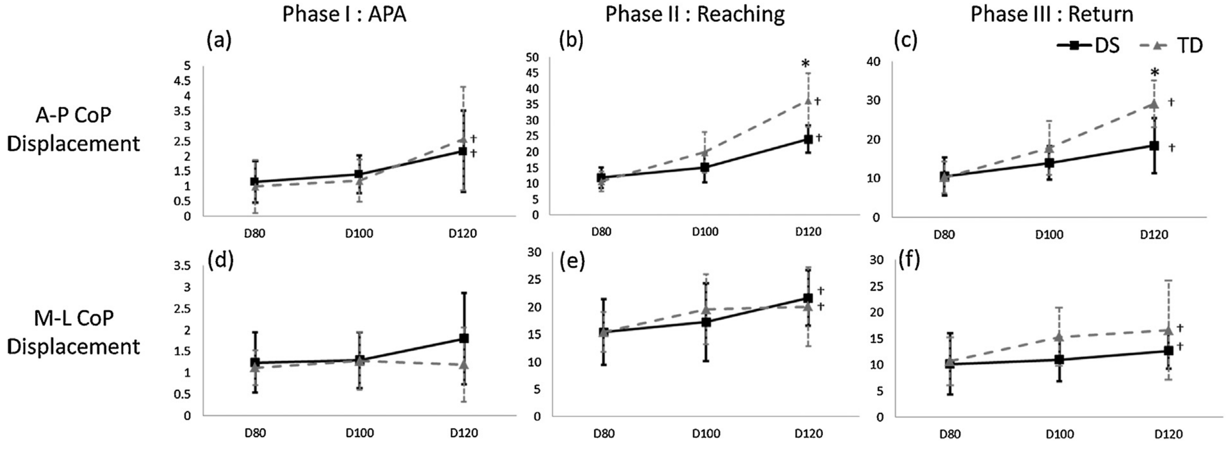

Fig. 1. Center of pressure displacements in both A–P and M–L directions during 3 phases of standing reach in all three test conditions. A–P and M–L CoP during APA phase (P1) (a, d), reaching phase (P2) (b, e) and returning phase (P3) (c, f). D80, D100 and D120 representing 3 different test conditions with reaching distance was set at an 80%, 100% and 120% of arm length respectively. (*Significant group effect; †significant distance effect.)

Table 2
Group comparison of the reaching performance during reaching phase (P2) in three different conditions (reaching distance was set at an 80%, 100%and 120% arm-length distance; D80, D100, D120).

		D80		D100		D120		Effects	
		Mean	S.D.	Mean	S.D.	Mean	S.D.		
Reaction time (s)	DS	0.28	0.06	0.30	0.06	0.33	0.06	$F_g = 9.61$	$p_g = 0.006^*$
	TD	0.25	0.04	0.25	0.04	0.24	0.03	$F_t = 1.30$	$p_d = 0.29$
Arm_PV (% AL/s)	DS	145.95	26.83	165.52	36.43	209.70	33.53	$F_g = 19.81$	$p_g < 0.0001^*$
	TD	230.28	65.99	259.47	67.58	288.04	51.79	$F_t = 20.23$	$p_d < 0.0001^\dagger$
Arm_PPV (% of P2)	DS	31.73	9.16	29.11	5.87	30.37	5.72	$F_g = 13.45$	$p_g = 0.002^*$
	TD	38.02	5.81	38.52	6.07	39.08	5.72	$F_t = 0.25$	$p_d = 0.78$
Arm–CoP coordination (%)	DS	−22.92	12.35	−21.12	12.27	−22.36	8.36	$F_g = 4.39$	$p_g = 0.05$
	TD	−34.78	11.93	−32.84	17.64	−24.75	10.05	$F_t = 1.38$	$p_d = 0.26$

DS, children with Down syndrome; TD, typically developing children; S.D., standard deviation; AL, arm length; p_g, p-value of group effect; p_d, p-value of distance effect.

* Significant group effect $p_g < 0.05$.

† Significant distance effect $p_d < 0.05$.

4. Discussion

In this study, we investigated the performance of a task-oriented postural control from a kinematic and kinetic perspective in children with Down syndrome, using the performance of typically developing children as a comparison. The results showed that the demand of the standing reach task affected both dynamic postural control and reaching performance in children with DS, especially in the most difficult task condition: beyond arm's length reaching.

4.1. Postural control

Our findings showed that different dynamic postural control strategies were adopted by children with DS during all three phases of standing reach when compared to typically developing children. We found that children with DS took a significantly longer time, but demonstrated comparable CoP displacement to complete the APA phase in all three standing reach conditions when compared to typically developing children (Table 1, Fig. 1a and d). This finding was supported by previous studies which hypothesized that children with DS utilized alternative temporal or spatial APA strategies prior to the forthcoming self-induced postural perturbation. That is, children with DS likely traded mechanical efficacy of motor patterns for safety, in order to preserve equilibrium (Aruin & Albertini, 1997).

APA is a feed forward program and has been used to initiate the forthcoming movement as well as to provide postural stability (Girolami, Shiratori, & Aruin, 2010; Kaminski & Simpkins, 2001; Liu, Zaino, & McCoy, 2007). APA, in terms of its amplitude and duration, was reported to be affected by the perturbation induced by this forthcoming movement (Aruin & Albertini, 1997; Girolami et al., 2010; Huang & Brown, 2013; Kaminski & Simpkins, 2001; Liu et al., 2007). Comparable posterior CoP displacement with a longer time used in children with DS, who may gain less forward momentums to move the body toward the reaching target, may be an inefficient dynamic postural control strategy. However, slower postural sway in children with DS may increase safety margin for preventing loss of balance. When facing farther reaching targets, greater anterior momentum was needed for both DS and TD groups. To obtain this momentum, strategy of increasing posterior CoP displacement with unchanged duration was adopted for both groups during APA phase. It seems that during standing reach, task difficulty affected APA amplitude but not duration (Table 1).

Inefficient but safer postural control strategies were also observed when children with DS executed reaching task, especially in more challenging task conditions. That is, compared to typically developing control group, children with DS in our study demonstrated not only significantly increased reaching phase duration time in all test conditions, they also demonstrated significantly smaller A–P CoP displacement for the most difficult task, when they reached a task that was set at a 120% of arm length. This finding was supported by other investigators (Tucker, Kavanagh, Morrison, & Barrett, 2010; Wang et al., 2012). The researchers concluded that individuals with poorer postural control would have reduced CoP amplitude and slower reaction time. We assumed that our sample children with DS adopted a trunk stiffening strategy to compensate their poor postural control. Since reaching a target beyond one's arm length and maintaining postural stability in standing requires controlling and organizing higher degrees of freedom (DOF) (Kelso & Schoner, 1988; Saltzman & Kelso, 1987), freezing the trunk segment would simplify the inter-segmental coordination necessary to complete the task (Haddad et al., 2012; Newell, 2014). The reduction of A–P CoP amplitude during the reaching phase was probably a result of this strategy. We also observed that the amplitude of M–L CoP increased significantly in reaching phase for the most difficult task in both children with DS and typically developing children. We suspected that M–L CoP displacements increased during the most challenging condition (reaching distance set at a 120% of arm length), possibly to accommodate changes in dynamic postural stability in A–P direction. Other studies had made observations and reported that greater M–L postural sway was associated with poor postural control (Wang et al., 2012). However, our study was unable to support these performance differences between typically developing children and children with DS.

Group differences were found in the spatial domain of dynamic postural control but not in the temporal domain during the returning phase (Table 1, Fig. 1). In the spatial domain, similar to the results of the reaching phase, a group difference was found only in the condition of beyond the arm's length reaching. Children with DS were able to return to upright standing position with comparable time as their typically developing counterparts. We suspected that it was because moving center of mass back to the body center was an easier and safer task for children with DS to perform, therefore, they did not need to adopt any special accommodation in the temporal domain in the returning phase.

4.2. Reaching performance

In this study, we found that children with DS demonstrated smaller PV and lower PPV than typically developing children during the standing reach. Similar findings were reported by other studies that investigated reaching while sitting, in children with DS (Charlton, Ihsen, & Oxley, 1996; Vimercati, Galli, Rigoldi, Ancillao, & Albertini, 2013a; Vimercati, Galli, Rigoldi, Ancillao, & Albertini, 2013b). Smaller PV indicated that children with DS had poor reaching force generation, and lower PPV suggested that children with DS may use less preplanned control of the reaching movements (Elliott et al., 2010), and consequently relied more on sensory feedback to control the reaching movement (Vimercati et al., 2013a,b). Slowing down arm movements during reaching were thought to be the strategy that children with DS used not only for postural stability, but also to benefit reaching performance. Even though speed and accuracy were both emphasized in the test instruction, children with DS seemed to adopt a conservative strategy, in terms of slower movements, to achieve the requirement of reaching accuracy.

Altered dynamic postural control and reaching kinematics for children with DS may also be reflected in the results of the coordination of reaching and postural control between DS and TD groups. A trend of smaller arm–CoP coordination difference ($p = 0.05$) was found in children with DS, compared to that in children with TD. According to Haddad's reports (2012) on their study of the development of coordination between posture and manual control, smaller PPV differences indicated poorer and immature posture and reaching coordination. Our results extended the knowledge of posture–manual coordination. We propose that the value of arm–CoP coordination obtained from the paradigm of postural–suprapostural task can be used not only to investigate developmental trajectory of posture–manual coordination but can also be considered as a discriminate indicator between children with TD and DS.

5. Conclusions

The demands of the standing reach task affected both dynamic postural control and reaching performance in children with DS, especially in the condition of beyond arm's length reaching. More postural adjustment strategies were recruited when reaching distance was beyond arm's length. Children with DS tended to use inefficient and conservative strategies for postural stability and reaching. That is, children with DS performed standing reach with increased reaction and execution time, and decreased the amplitudes of the center of pressure displacements. Standing reach resembled functional balance that is required in daily activities. It is suggested that it be considered as part of strength and balance training program with graded task difficulty.

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