Research Report

Functional Task Constraints Foster Enhanced Postural Control in Children With Cerebral Palsy

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ABSTRACT:

Background: Postural instability is a classical characteristic of cerebral palsy (CP), but it has not been examined during simultaneous functional play activity. Recent work demonstrates that when motor tasks are made functionally more relevant, performance improves, even in individuals with movement pathology. It may be that in a disease state, the underlying control mechanisms that are associated with healthy physiology must be elicited.

Objective: To explore the utility of the functional play task methodology as a more rich and interpretable approach to the quantification of postural instability in children with CP.

Design: Postural stability measures obtained from a cross sectional cohort of children with CP (n = 30; were compared to stability measures taken from children with typical development (TD; n=30) during a single measurement period.

Methods: Postural stability data were obtained using an AMTI AccuSway PLUS portable force platform system. Postural sway was quantified during a precision manual functional play task. A baseline condition (no task) was also included. Postural sway variability and postural sway regularity were analyzed using analyses of variance.

Results: Children with CP demonstrated an apparent difference in postural control (greater irregularity, greater sway variability) during quiet stance, relative to peers with TD that was mitigated during performance of a functional play precision task.

Conclusions: The findings illustrate flexibility and adaptability in the postural control system, despite the pathological features associated with CP.
INTRODUCTION

Cerebral Palsy (CP) is associated with disruptions in postural control and subsequent postural instability. Postural control during quiet (i.e., unperturbed) stance in CP has also been studied. Compared to control subjects who are typically developing, during quiet stance children with CP typically exhibit a greater amount of postural sway (e.g., greater sway area and path length) and their postural sway is typically more variable.\textsuperscript{1-5} Additionally, children with CP have been described as exhibiting distinct temporal patterns of postural sway compared to children of typical development, reflecting a decrease in postural sway irregularity that is believed to be an indicator of less effective physiological control.\textsuperscript{6}

An inherent assumption underlying the large body of work on postural stability in CP is that during quiet stance a participant’s priority is to reduce postural sway variability to the greatest extent possible. Stance, however, is not achieved and maintained solely for its own sake but rather to facilitate goal-directed tasks that are super-ordinate to (above and beyond) the simultaneous control of posture (functional play or supra-postural tasks).\textsuperscript{7} Examples of functional play (supra-postural) tasks include everyday activities such as standing while holding a lunch tray, writing on a chalkboard, or swinging a baseball bat. Coordination of postural control with a functional play task may require that postural sway is modulated in order to avoid interfering with and in some cases to directly facilitate functional play activity. The postural control system, in the context of functional play task activity, must coordinate the physical demands of posture with the functional requirements of the task.\textsuperscript{8} The success of postural control can therefore be defined in terms of its impact on the achievement of functional play goals\textsuperscript{9}. As such, no singular description of postural control can be used to characterize a “healthy” system or one that deviates from it.
Because functional play tasks are everyday activities, studying postural activity during functional play task performance may be a way to achieve the functional context necessary to develop a more applicable and valid understanding of postural control. This is an especially critical consideration when studying the movement behavior of children with impairments given that differences between controls and neurologically impaired patients could indicate in part a change in postural control strategies or constraints rather than simply a decline in the postural control system. In populations with established motor deficiencies, although the pattern of movement used to successfully complete a task may be atypical, it may not be ineffective.

Recent work by Volman, Wijnroks, and Vermeer illustrates the influence of functional context on motor behavior in CP. Children with CP reached to (a) press a light switch to turn on a light (functional task context), (b) press the light switch without turning on a light (semi-functional task context), or (c) reach to a marker (non-functional task context). The functional task context improved reaching kinematics; when a task is functionally more relevant, motor performance will be more precise and less variable, even for individuals with a movement pathology. These findings are buttressed by other clinical studies manipulating task context by varying object availability and object affordances. For example, persons after a cerebrovascular accident produced smoother, faster, and more forceful movements when reaching for their favorite food or for an active telephone instead of a spatial location or a stick. Additionally, mimicking in an impoverished condition (pretending to eat food with a saucer and a spoon) resulted in motor performances that were less efficient and kinematically different than actual task performance (eating applesauce in a saucer, with a spoon) in patients with multiple sclerosis.
Comprehensively, these studies illustrate that different motor behaviors can emerge in task-relevant conditions. The purpose of this study was to investigate postural stability in children with CP during performance of a functional play task that engendered a more functional context for balance control than quiet stance. Specifically, we evaluated postural control during a functional play task that required precision control of manual activity in a cohort of children with CP and age-matched peers who are typically developing (TD). We hypothesized that if the functional play task context employed in the present study promoted a dynamic functioning of the postural control system, the change in postural sway irregularity associated with CP and other differences in postural behavior between children with CP and children who are TD would be attenuated during performance of a functional play task. Modulating control strategies in response to supra-postural task constraints could reflect a system with adaptability—a response to the constraints imposed by functional play tasks, despite pathological state. Such a response exposes aspects of motor control that might remain intact in children with CP.

METHODS

Design and Participants

Cross-sectional measures of postural stability during supra-postural task performance were taken in a cohort of 60 children (n = 30 children with CP, mean age = 8.30 years, SD = 2.26 years; n = 30 children with TD, mean age = 9.20 years, SD = 1.98 years). Children with CP were referred for participation in this study from a large, nonprofit academic pediatric medical center in the midwest. Children with TD were invited to participate through convenience sampling methods. This study was approved by both academic and hospital Institutional Review Boards.
To be included in the study, all children were required to be between 5 and 12 years of age and able to stand independently for one minute. None of the participants in the study had additional medical comorbidities known to impact postural stability. In order to minimize musculoskeletal effects of interventions on stability measures, children with CP qualified for participation in this study only if they had not undergone surgical intervention 12 months prior to the test date or botox injections within 3 months of the test date. All children with CP were characterized by spasticity. Sample descriptors are summarized in Table 1.

Procedure

All participants began the study by completing six 20 s quiet stance trials. In these trials, no supra-postural task was performed. These trials were conducted in order to identify any baseline postural control differences between children who are TD and children who have CP.

In order to facilitate the engagement of children participating in the study, animal puppets were mounted to a steadiness tester. Their mouths surrounded five differently sized circular copper tubes, each one 1.25 cm larger than the next (smallest diameter = 3.175 cm). Participants were informed that the animals on the device did not feel well and that, as the doctor in this study, they could help to determine if a specified animal was sick by checking its temperature. This was accomplished by asking the children to position a 12.7 cm (length) × 2.5 cm (width) × 1.9 cm (depth) wooden thermometer with a 5 cm metal tip (stylus length) in the animal’s mouth and to maintain the thermometer’s position in the center of the mouth for the duration of the trial. If the stylus inadvertently contacted the perimeter of the copper tube, a low-voltage circuit was completed and a feedback light in the center of the tester illuminated; the device functions like the children’s game Operation™, but uses a light in lieu of a buzzer. The device was vertically oriented on a height-adjustable table so that each participant performed the task while standing
with 90° of shoulder flexion, full elbow extension, and neutral forearm/wrist alignment. In order to examine postural control during functional activity, the supra-postural task was performed while the children were standing on the force platform (see Figure 1).

A within-subject manipulation of functional play task difficulty (easy versus hard) was included to vary the demands placed on postural control by the functional play task. Prior to data collection, participants were asked to position the stylus of the thermometer in a tube on the steadiness tester without touching the perimeter for 10 s. The smallest “animal mouth” for which each child was able to successfully perform the task was used in “hard” task conditions. An animal two sizes larger was used in “easy” task conditions. This procedure established relative task difficulty for each child participating in the study. All children were minimally able to complete this task in the 5 cm tube for 10 s without error.

Easy and hard functional play task conditions were repeated three times, yielding a total of 6 randomly ordered 20 second trials for each participant (in addition to the quiet stance trials). All children demonstrated task awareness, followed instructions, and were able to complete all trials of the precision task within a 10-minute period.

Outcomes

Postural data were obtained using an AMTI AccuSway PLUS portable force platform system (Advanced Mechanical Technology, Inc., Watertown, MA). The accuracy and reliability of ground reaction force data collected using static posturography in children with CP has been well documented. Data were sampled at 100 Hz, in 20 second trial periods, in order to ensure that each times series was represented by an adequate number of points for the proposed analyses. Balance Clinic software (Advanced Mechanical Technology, Inc., Watertown, MA) was used to acquire force and moment data sampled by the force platform and to calculate the
center of pressure (COP), the point location of the resultant ground reaction forces acting at the
feet, in both the AP and ML axes. Standard assessments of postural stability included measures
of the within-trial standard deviation of the AP and ML COP. Higher values of those COP
variability measures are widely assumed to reflect reduced postural stability. Sample entropy
(SampEn)\textsuperscript{19} was used to provide a measure of order and regularity in the COP data. SampEn is
the negative natural logarithm of an estimate of the conditional probability that a subseries that
repeats itself for m points will also match at the next point (m + 1). Accordingly, smaller
SampEn values reflect self-similarity or regularity in the time series: an indication that the data
did not arise from a random process. SampEn has been utilized to quantify r in COP times series
and has proven to be a useful tool for the studying the dynamics of postural stability.\textsuperscript{20} Balance
Clinic and custom Matlab (MathWorks, Inc., Natick, MA) routines were used to compute those
COP metrics from the recorded COP time series. All static posturography trials were
conducted in barefoot conditions, without the aid of ankle-foot orthoses.

Statistical Analysis

Preliminary exploration of the data using Levene’s test\textsuperscript{21} indicated that samples of
children with CP and children with TD did not reflect an equality of variance. Subsequently,
data in this study were subjected to a monotonic, variance-stabilizing square-root transform.

Postural sway measures collected during static trials and the supra-postural task were
averaged over repeated trials of the same experimental condition for each participant to yield one
average value for each dependent measure, in each experimental condition. These values were
submitted to repeated measures analyses of variance (ANOVAs) for each dependent variable
( sway variability and SampEn in both the AP and ML planes) in order to examine the
fundamental impact of the functional play task. The effects of quiet stance (group), task
performance (group, task/no task performance), and the task modifier of difficulty (group, easy
task/difficult task performance) were analyzed separately. For all analyses, an alpha level of .05
was used to establish statistical significance.

RESULTS

Quiet Stance Trials

Baseline postural variability and regularity analyses from the quiet stance trials indicated
significant group differences in both the standard deviation of the COP and in SampEn, in all
planes tested. In the AP plane, the standard deviation of the COP was significantly higher for
children with CP than for children with TD, \( F(1, 29) = 58.53, p < .05 \). The ML COP standard
deviation was also significantly higher for children with CP than children with TD, \( F(1, 28) =
85.75, p < .05 \). In quiet stance, children with CP demonstrated greater irregularity in the AP
plane than children with TD, \( F(1, 28) = 28.04, p < .05 \). This group difference was also observed
in the ML plane, \( F(1, 28) = 44.77, p < .05 \).

Functional Play Task: SD of the COP

Two-way mixed ANOVAs revealed main effects of group \( [F(1, 28) = 53.11, p < .05] \) and
task \( [F(1, 28) = 40.73, p < .05] \), and a group by task interaction for COP standard deviation \( [F(1,
28) = 31.02, p < .05] \) in the ML plane. Similar main effects were found for group \( [F(1, 28) =
78.91, p < .05] \) and task \( [F(1, 28) = 6.57, p < .05] \) in the AP plane but the interaction was not
significant in this plane \( (p > .05) \). Simple-effects analysis of the ML interaction revealed a
functional play task effect (reduced sway during task performance compared to the no-task
condition) that was significant for children with CP \( (p < .05) \), but not peers with TD \( (p > .05) \).
Moreover, a group difference in SD of the COP existed in the no-task condition where the SD
was higher for children with CP than children with TD \((p < .05)\), but the difference was attenuated during the precision-task condition \((p > .05)\). See Figure 1.

The analysis of task difficulty (easy vs. hard) revealed main effects of group \([F(1, 28) = 3.65, p < .05]\) and task difficulty \([F(1, 28) = 12.49, p < .05]\), and a group by task difficulty interaction for COP standard deviation \([F(1, 28) = 9.49, p < .05]\) in the ML plane). A main effect of group was only found in the AP plane, \(F(1, 28) = 43.41, p < .05\). Simple-effects analysis of the ML interaction indicated that children with TD altered their sway variability as a function of task difficulty \((p < .05)\)—in difficult conditions, sway variability decreased relative to easy conditions. This trend was not observed in children with CP, who demonstrated relatively stable sway variability across conditions \((p > .05)\). A difference between children with CP and peers with TD (higher SD for children with CP) was only detected in hard conditions \((p < .05)\). See Figure 2.

*Functional Play Task: SampEn of the COP*

Two-way mixed factor ANOVAs also revealed main effects of group \([ML: F(1, 28) = 33.19, p < .05; AP: F(1, 28) = 17.97, p < .05]\) and task \([ML: F(1, 28) = 75.97, p < .05; AP: F(1, 28) = 41.78, p < .05]\), and a Group by Task interaction \([ML: F(1, 28) = 24.07, p < .05; AP: F(1, 28) = 13.56, p < .05]\) for SampEn of the COP in both planes. Simple effects analysis indicated that participants in both groups produced a spatiotemporal profile with lower SampEn (greater regularity) during functional play task performance than they did in the absence of concurrent activity. The groups remained statistically different in either functional play task condition (children with CP exhibited greater irregularity), although when performing the functional play task, differences between the groups was reduced (mean difference ML: no task: 0.09 bits, task: 0.02 bits, \(p > .05\); mean difference AP: no task: 0.13 bits, task: 0.01 bits, \(p > .05\)). See Figure 3.
The analysis of task difficulty (easy vs. hard) revealed a main effect of group only, with children with CP exhibiting greater SampEn (more irregular COP patterns) in both the ML \(F(1, 28) = 3.65, p < .05\) and AP \(F(1, 28) = 19.86, p < .05\) planes. See Figure 4.

DISCUSSION

We proposed that functional play task performance would create a functional context for postural control and a subsequent postural sway profile that differed markedly from measures of quiet-stance postural control in children with CP. The hypothesis that differences between children with TD and children with CP would be attenuated during the functional play task was supported. Group by task interactions demonstrated sway variability (CP > TD) and regularity (TD > CP) group differences in the no-task condition, but these were attenuated when participants performed the functional play task. Functional play task performance was accompanied by an increase in the regularity (CP and TD) in both the AP and ML planes and a decrease in the variability (CP) of postural sway in the ML plane. Like the findings of Riley and colleagues,\(^{22}\) differential axis effects may be explained by task-specificity of the postural control system; in this study, successful aiming performance by optimization of stability in ML axis. Manipulations of task difficulty magnified variability differences between the two groups (TD with decreased sway in difficult conditions), but did not change the overall pattern of results.

The results were in part, consistent with previous studies of postural control and functional play tasks. They validate findings of greater sway variability in children with CP during quiet stance trials\(^1-5\) and a flexibility of postural control during functional play task performance\(^7, 8, 22, 23\). The SampEn findings in this study were unanticipated. CP was expected to be associated with a greater regularity of the COP profile, in alignment with the well-documented theory that disease is accompanied by predictably stereotypical physiological
The hypothesis was also in alignment work by Donker and colleagues, who reported that COP profile of 5-11 year old children with hemiparetic CP was associated with low SampEn\(^6\). In our study, children with CP instead demonstrated higher SampEn (greater irregularity) during quiet stance trials. Moreover, the functional play task condition, which was expected to elicit a more typical physiological COP profile (greater irregularity), instead resulted in COP profiles of increased regularity in both children with CP and their peers with TD.

Vaillancourt and Newell\(^{25}\) argue, however, that depending on the interaction between task constraints and the constraints intrinsic to a given individual, disease-related changes in the physiological and behavioral dynamics can occur in either direction—regularity can increase in some cases but decrease in others. They thus advocate for a “change in regularity” approach over a “loss of irregularity” approach.

This study presents a compelling base of evidence to support the dynamic nature of the postural control system, in children with a diagnosis widely associated with poor motor adaptability. It is, however, not without limitations. The sample of children with CP included in the study was characterized by a heterogeneity of presentation (i.e., gross motor function, development), and not strategically sampled to ensure a correlation to population characteristics. The study was also inadequately powered for a priori subgroup analyses. It is hypothesized that wide variability within this group would have masked unique findings associated with different levels of disease severity or clinical presentation.

Despite unexpected baseline SampEn findings, the study clearly demonstrated greater similarity between children with CP and peers with TD during performance of a functional play task. The demonstration of flexibility in postural performance by children with CP in this study challenges the notion that people have one, fixed, singular postural control system that either
works well or does not. Instead, the findings support the theoretical position that control systems are assembled and disassembled to match current circumstances and constraints.8

The finding that children with CP within our sample demonstrated a functional play task effect is of great clinical significance, to the extent that levels of functioning between groups during task performance were nearly equivalent.26 Accordingly, the assertion that poor postural control in CP is the catalyst for later motor deficiencies is challenged by the present results, which instead suggest that dynamic aspects of the postural control system and its relations to other sensorimotor behaviors are preserved in CP, allowing children with CP to function in ways that do not differ significantly from children with TD under some situations. In populations with established motor deficiencies, although the pattern of movement used to successfully complete a task may be atypical, it may not be ineffective.12, 13, 17 The modulation of postural control in order to facilitate performance of this functional play task illuminates aspects of pathological motor control that have been previously misunderstood.

Findings indicating that concurrent functional play tasks result in a modulation of postural control in some children with mild hemiparetic CP will have significant implications for future research. A related, additional implication of the present findings is that quiet stance may not be an appropriate task protocol for comparing clinical and typical participant groups. Postural control and functional play tasks are tightly intertwined. Studies employing quiet stance may not accurately describe the pragmatic characteristics of postural control, and greater attention to the influence of experimental method would be paramount in studies linking deficient postural control to subsequent disruptions in motor development in CP. Examining postural control in the context of functional play tasks should render a more interpretable picture
of existing postural deficiencies associated with CP. More importantly, it may also expose
aspects of motor control that remain intact in children with CP.
Acknowledgments

All authors provided concept/idea/research design. Dr J. Schmit, Dr Riley, and Dr Shockley provided writing and data analysis. Dr J. Schmit provided data collection. Dr J. Schmit and Dr Riley provided project management. Dr Riley provided facilities/equipment. Dr Riley, Dr Cummins-Sebree, Dr L. Schmitt, and Dr Shockley provided consultation (including review of manuscript before submission).

REFERENCES


Table 1

*Characteristics of the Sample (Percentage of Group).*

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Participants in the study completed a functional play aiming task while postural sway data was collected on a force platform.
Figure 2. SD of the COP ± 95% CI, Functional Play Task Analysis

Significant ML (top) and AP (bottom) main effects of task and group. Significant ML (top) group by task interaction. During precision task performance, sway variability decreased in children with CP, but not peers with TD. Significant group differences that existed during no task conditions were mitigated during precision task performance.
Children who are typically developing demonstrated less sway variability during hard conditions. Sway variability for children with CP was not altered as a function of task difficulty. Significant TD and CP group differences were detected only during hard conditions.
Figure 4. SampEn of the COP ± 95% CI, Functional Play Task Analysis

Significant ML (top) and AP (bottom) main effects of task and group. Significant ML (top) and AP (bottom) group by task interactions. Relative to no task conditions, during performance of the precision task, SampEn decreases (becomes more regular) for both children with CP and peers with TD. Group differences in no task conditions remained significant but were mitigated during precision task performance.
Figure 5. SampEn of the COP ± 95% CI, Difficulty Analysis

*Significant ML (top) and AP (bottom) group by task interaction. SampEn was higher (more irregular) in children with CP relative to peers with TD, regardless of precision task difficulty.*