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ABSTRACT

Purpose: Determine sitting postural control changes for children with cerebral palsy (CP), using a perceptual-motor intervention and the same intervention plus stochastic vibration through the sitting surface. Methods: Two groups of children with moderate or severe CP participated in the 12 week interventions. The primary outcome measure was center of pressure data from which linear and nonlinear variables were extracted and the gross motor function measure (GMFM). Results: There were no significant main effects of intervention or time or an interaction. Both treatment groups increased the Lyapunov exponent values in the medial–lateral direction three months after the start of treatment as well as their GMFM scores in comparison with baseline. Conclusions: The stochastic vibration did not seem to advance the development of sitting postural control in children between the ages of 2 and 6 years. However, perceptual-motor intervention was found beneficial in advancing sitting behavior.

KEYWORDS Biomechanics; developmental disabilities; motor development; posture

Introduction

Dynamic postural control in the sitting position is necessary for the control of function in today's world for most individuals, with or without a physical disability. Learning at school, functioning in the workplace, and engaging in social activities are primarily done when seated. Achieving sitting postural control for children with cerebral palsy (CP) is a significant milestone, with great potential to affect overall function and success. Sitting prior to the age of two is considered a prognostic indicator of future walking capability. Inability to sit by age two is taken as an indicator that a child will need an assistive device such as a wheelchair for functional mobility and additional

assistance in daily activities.[1] Research has linked the ability to sit independently to greater success in reaching and maintaining contact with objects and improved eye–hand coordination during reaching.[2] Indeed, postural control is at the root of attention, exploration, and perception during development and may be critical during childhood for learning to occur.

Postural control in children with CP has been studied by examining patterns of muscle activity after a platform perturbation in the standing position[3,4] and in infants when supported in the sitting position or during reaching while sitting.[5] It has been determined that children with CP employ atypical patterns of muscle activation such as excessive co-contraction of opposing muscles or delayed muscle activation in comparison with typical peers. However, these variables have been measured at one point in time, without consideration of change that may occur over time as development progresses or as the child practices the skill. In addition, these studies emphasize the child's reaction to a perturbation, not self-initiated control of movement or activities related to that control. Longitudinal studies in children with CP are lacking in the literature, resulting in many questions regarding the natural progression of movement control, or differences in development that occur with therapeutic intervention. Consequently, questions remain regarding the necessary intervention time, the type of intervention that is most appropriate, and the prediction of skill attainment for children with CP when developing functional movement skills and postural control.

There are few studies that have investigated the development of sitting postural control over time in children with CP. Although some research has followed the gross motor function of children with CP over time, few studies have documented a longitudinal effort to quantify sitting development.[6] The majority of sitting posture intervention studies in children with CP examined external seating devices[7] or positions[8] and did not focus on the development of dynamic postural control or learning of new strategies for sitting. Our research has examined the development of sitting postural control in infants with or at risk for CP via analyses of the center of pressure (COP) time series.[9,10–12] Specifically, we compared two interventions for improving sitting posture in infants with or at risk of CP. We found that a perceptual-motor intervention is advantageous in comparison with a home therapy program.[9] However, intervention studies for children that are older than 2 years of age with severe or moderate CP who are still developing sitting postural control are not available.

The prevailing handling method in physical therapy intervention of children is the neurodevelopmental treatment.[13] This method relies heavily on precise, graded, handling skills that guide the child to ultimately develop and achieve postures essential for functional activities.[14] Normal postural alignment is emphasized in this approach. A review of the body of evidence regarding this intervention approach found little support for its effectiveness in promoting normal motor milestones in any type of condition.[15] More recent findings provide conflicting evidence with regard to the effectiveness of this approach on gross motor function.[16,17] For this reason, we have chosen a different

intervention for the present project. One approach that is based on perception-action coupling is the perceptual-motor intervention.[18,19] This method emphasizes the ecological approach and spontaneous movement based on environmental affordances. Self-initiated, functionally directed movement is the focus of intervention. Intervention consists of activities that include handling, which gently calls the child's attention to the support surface, and sets up the environment for small increments of movement that the child can utilize to solve a movement problem. Increased variability of active movement is encouraged, and movements that are considered abnormal in other approaches are not blocked or discouraged. This perceptual-motor approach has been used as one of the interventions for infants with or at risk for CP with evidence of effectiveness over and above a home program.[9,20]

For a group of children with moderate-to-severe CP, longterm application of intensive physiotherapy or collaborative goal-setting intervention has been shown to have short-term effectiveness, but the focus was on overall motor skills and not on postural control in sitting.[21,22] Despite suggestions that postural control is one of the areas of motor control in children with CP that is responsive to intervention and calls for further research in this area,[23] evidence to guide intervention is lacking. Intervention techniques/approaches need to be investigated for effectiveness to broaden the range of appropriate intervention for children with CP.

It has long been known that sensory deficits coincide with the motor dysfunction of CP. Sensory deficits of children with hemiplegia were documented in up to 70% of individuals.[24,25] In addition, imaging studies confirm damage to the sensory cortex related to the motor areas of deficit.[26] McLaughlin and colleagues confirmed sensory deficits in children with spastic diplegic CP consistent with dorsal column sensory modalities.[27] In spite of widespread awareness of sensory problems in children with CP, there are no interventions available that address both the sensory and postural issues. Since the perceptual-motor intervention has been found to improve sitting postural control, an additional component that would address their sensory problems could be beneficial. In fact, there is one technique that can be used in addition to a physical therapy regimen that has been utilized in adults who have postural and sensory problems.

The technique of using stochastic vibration to improve postural reactions in the standing position in adults with decreased sensation or decreased balance is relatively new. Collins and colleagues[28–30] have used small, non-detectable vibrations in the insoles of shoes to improve standing postural control. The idea is that the "noise" of the mechanical vibrations, although not noticed by the subject, raises the sensory threshold so that the individual can detect the need for a balance reaction. This technique has been used to decrease abnormal amount of sway variability with adults with stroke, elderly people with balance problems, and people with diabetic neuropathy.[29] The premise of this approach is that it can improve the detection of sensory information both consciously (to detect a slight tactile input) and to detect information necessary for

gauging postural responses.[30] Early animal work has suggested that introducing stochastic “noise” signals to a physiological system could possibly improve the sensitivity of the sensory systems and thus the detection of weak signals.[31,32] In humans, the effect of enhancing actions by the use of stochastic vibration is a phenomenon that is being investigated in a variety of systems, but particularly with the nervous system.[33] A recent Cochrane review[34] on the effect of whole body stochastic vibration on neurodegenerative diseases has found inconclusive evidence on the benefits of this approach. In contrast, one study that involved adults with cerebral palsy presented advantageous effects of the whole body stochastic vibration treatment on strength, walking speed, and spasticity.[35] Most studies involving interventions with some type of whole body vibration for children with CP suggest that spasticity decreased, motor performance, gait speed, and postural function improved.[46–50] However, most of these studies involved older children with CP close to 10 years of age. In young toddlers with CP, whole body vibration was not associated with improvements in gross motor function.[51] The premise behind whole body stochastic vibration is that muscular and neural components are stimulated by the vibrations, which in turn will initiate a muscle contraction.[52]

The significance of addressing sensory deficits in children with CP is related to perceptual-motor development. Without the ability to adequately gather information from the lower extremities, it becomes impossible to perceive imbalance in posture or differences in pressure sensation from the base of support. Intervention that would enhance or improve the ability to perceive the support surface may serve posture and movement control related to the lower extremities, such as in sitting or standing. It is for this reason that we have chosen the use of stochastic vibration at the support surface as an intervention in this study.

Therefore, the purpose of this study was to determine sitting postural control changes for children with moderateto-severe CP and comparing this intervention group to a group receiving the same intervention plus stochastic vibration through the sitting surface. We chose to use as the treatment basis the perceptual-motor intervention, since from our previous study,[9] we have established that this type of intervention is advantageous in comparison with a home program. Moreover, the addition of stochastic vibration in one of the treatment groups was selected due to the improvement in standing postural control shown in neuromotor deficits.[29] We hypothesized that children with moderate-tosevere CP would show changes on the COP measures of postural control over the duration of the intervention. We further hypothesized that the group receiving the additional stochastic vibration during the intervention would have greater changes in postural control.

Methods

Participants

Thirty-six children with CP were recruited; 35 parents signed the parental consent form, one opted to not participate. Three children dropped out within the first month—one due to surgery for shunt malfunction and two due to poor overall health. Two children ended up being mild and were not included in this final analysis. Therefore, thirty children between the age of two and six years diagnosed with CP and unable to sit independently participated in the study (Table 1). A parental consent form was signed from all parents/caregivers. Exclusion criteria were as follows: age under two years or over six years; a diagnosis of blindness; a diagnosed hip dislocation or subluxation of the hip over 50%; and an additional diagnosis that affects the neuromuscular system such as Down syndrome or spina bifida. Additionally, beginning sitting skills were required for entry into the study. The operational definition for beginning sitting includes the following: the ability to prop sit while on the floor sitting for at least 10 seconds when placed; the ability to hold the head in line with the body (not falling forward) while prop sitting; and the ability to move the arm toward a person or toy, but not need to grasp the toy, when supported by another person in the sitting position. The above sitting skill was the least amount of skill required for entry into the study. A child would not qualify for the study if sitting skills were mature. Mature sitting is operationally defined as: the ability to sit independently without using the arms for support for five minutes or more without falling; reaching for toys using both hands at once without disrupting balance; moving in and out of the sitting position independently. Children, who have greater skill than the beginning sitting skills, but less skill than listed for mature sitting, were eligible for the study. Parents provided informed consent. Children with CP were randomly assigned to the two intervention groups (Table 1). In order to guarantee equal distribution of children with similar CP severity levels in the two groups, a severity scale[9] was used.

Experimental protocol

Data were collected at four different times during the child's participation in the study. The first session was a baseline testing, prior to the child receiving any intervention sessions, and included the sitting subsection of the gross motor function measure (GMFM) and center of pressure (COP) assessment. We used the GMFM version 88. One of the authors (RH) either performed or supervised the GMFM assessments done by other therapists for every child. The subsequent sessions were after the completion of every eight intervention sessions, approximately one month apart. A fourth and final session was one month after the final data collection as a follow-up after the child has stopped receiving the intervention sessions (Figure 1). The follow-up session included GMFM and COP assessment.

Data collection process

For all data collection sessions, the children were allowed time to get used to the laboratory setting and were at their parent's side or on their laboratory for preparation. Children were provided with a standard set of toys according to age and cognitive level for distraction and comfort. All attempts were made to maintain a calm, alert state by

allowing the child to eat if hungry, be held by a parent for comforting, or adapting the temperature of the room to the child's comfort level. The children wore light clothing when sitting on the force platform.

Table 1. Participant information.

Participant #	Diagnosis	Severity	Treatment group
C01	Spastic Bilateral	GMFCS III/IV	1
C02	Dyskinetic CP	GMFCS III/IV	1
C03	Dystonic CP	GMFCS III/IV	0
C04	Spastic Bilateral	GMFCS III/IV	0
C05	Dystonic CP	GMFCS III/IV	1
C06	Spastic Bilateral	GMFCS II/III	0
C07	Spastic Bilateral	GMFCS III/IV	1
C08	Spastic Bilateral	GMFCS III/IV	0
C09	Dystonic CP	GMFCS II/III	1
C10	Spastic Bilateral	GMFCS III/IV	1
C11	Dystonic CP	GMFCS III/IV	0
C12	Spastic Bilateral	GMFCS III/IV	0
C13	Spastic Bilateral	GMFCS III/IV	0
C14	Spastic Bilateral	GMFCS II/III	1
C15	Dystonic CP	GMFCS III/IV	1
C16	Spastic Bilateral	GMFCS III/IV	0
C17	Spastic Bilateral	GMFCS III/IV	0
C18	Spastic Bilateral	GMFCS II/III	0
C19	Dystonic CP	GMFCS III/IV	1
C20	Spastic Bilateral	GMFCS II/III	1
C21	Spastic Bilateral	GMFCS II/III	0
C22	Spastic Bilateral	GMFCS II/III	0
C23	Dystonic CP	GMFCS II/III	1
C24	Spastic Bilateral	GMFCS III/IV	0
C25	Spastic Bilateral	GMFCS II/III	1
C26	Spastic Bilateral	GMFCS II/III	0
C27	Non-classifiable	GMFCS III/IV	1
C28	Non-classifiable	GMFCS II/III	1
C29	Spastic Bilateral	GMFCS III/IV	1
C30	Spastic Bilateral	GMFCS II/III	1

Diagnosis: definitions are based on the surveillance of cerebral palsy in Europe; Severity: GMFCS II/III (gross motor function classification system level 2 and 3), GMFCS III/IV (gross motor function classification system level 3 and 4); treatment group: 0 = no vibration; 1 = with vibration

Data were collected in a specifically designed laboratory space that simulates a common living room to provide a soothing environment. Center of pressure analysis in sitting was done using a force plate, which was embedded in the floor of the laboratory. Data were collected for 10 seconds, while the child attempted to maintain sitting postural control without being touched by the experimenter. If the child became irritated, the session was halted for comforting by the parent or to meet the child's needs and then resumed only when the child was again in a calm state. The time of data collection on the force platform was videotaped from the back and side views for behavioral and qualitative postural analysis. The back and side views were combined onto one screen

view by a video mixer. An event marker with a light was in the view of the cameras to synchronize the videotape record with the time series collected from the force platform.

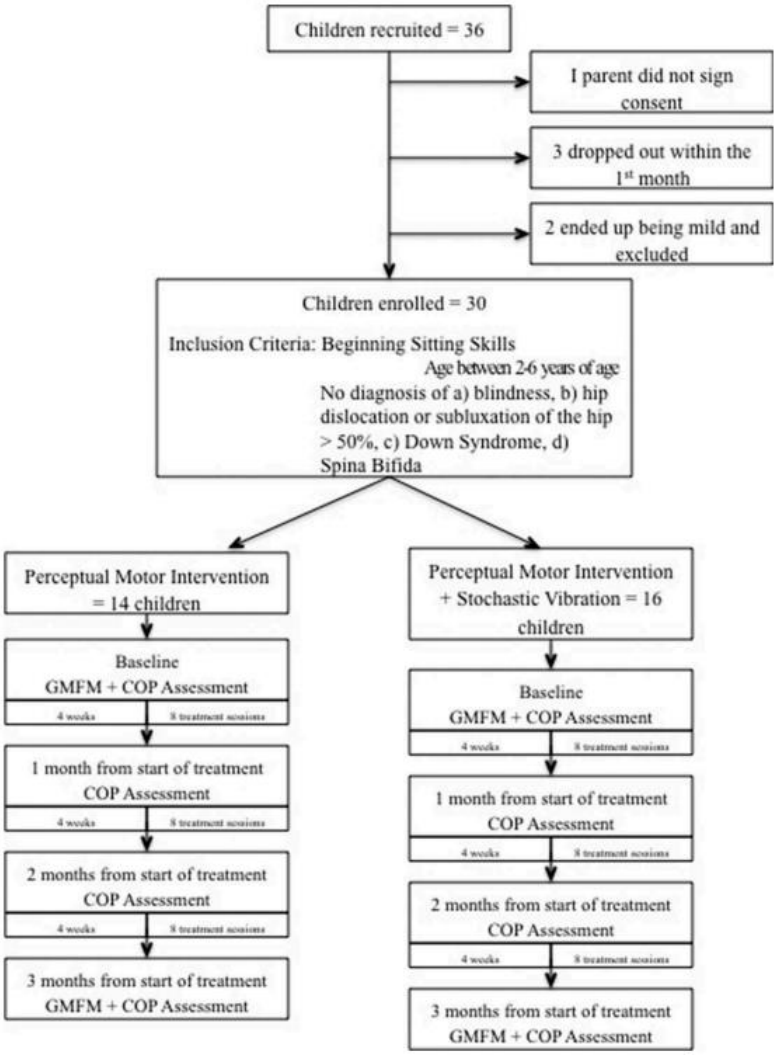

Figure 1. Flow diagram showing the progression of participants through the study. (GMFM—gross motor function measure; COP—center of pressure).

The first three acceptable trials at each session were analyzed. Acceptable trials were those, in which the child was not being held, crying, or vocalizing, was not in the process of falling, and was not flapping the arms or kicking the legs. However, for some children, we were able to collect only two trials.

Instrumentation

Data were collected at the Munroe-Meyer Institute for Genetics and Rehabilitation Infant Laboratory at the University of Nebraska Medical Center using an AMTI force platform (Advanced Mechanical Technology Inc, USA). The force platform was mounted to a sub-floor concrete slab to prevent vibration interference. Component forces (Fx, Fy, Fz) and moments (Mx, My, Mz) were each sampled at 200 Hz. Each data collection was videotaped using two Panasonic video cameras (Model 5100 HS)

interfaced with a Panasonic Digital AV Mixer (Model WJ MX30) positioned to record both sagittal and frontal views of the infant.

The intervention instrumentation for the group receiving stochastic vibration was as follows: a custom-made device from Engineering Acoustics, INC, which was a portable unit that could be affixed to any bench, chair, or mat. The tactor control unit (ATC3.0) connected to a Mini Pal Pad (Adaptivation, Inc) was used to manipulate the amplitude of the 6 C-2 vibrotactile actuators in an viscoelastic pod array, mounted within an approximately 16 × 18 × 2.5 inch height medical grade (water resistant and cleanable) cushion embedded in the vibrating mat (Figure 2) The therapist adjusted the amplitude of the tactors. Specifically, the therapist increased or decreased the amplitude of the tactors while observing the facial expressions of the child until the vibrations were not noticeable.

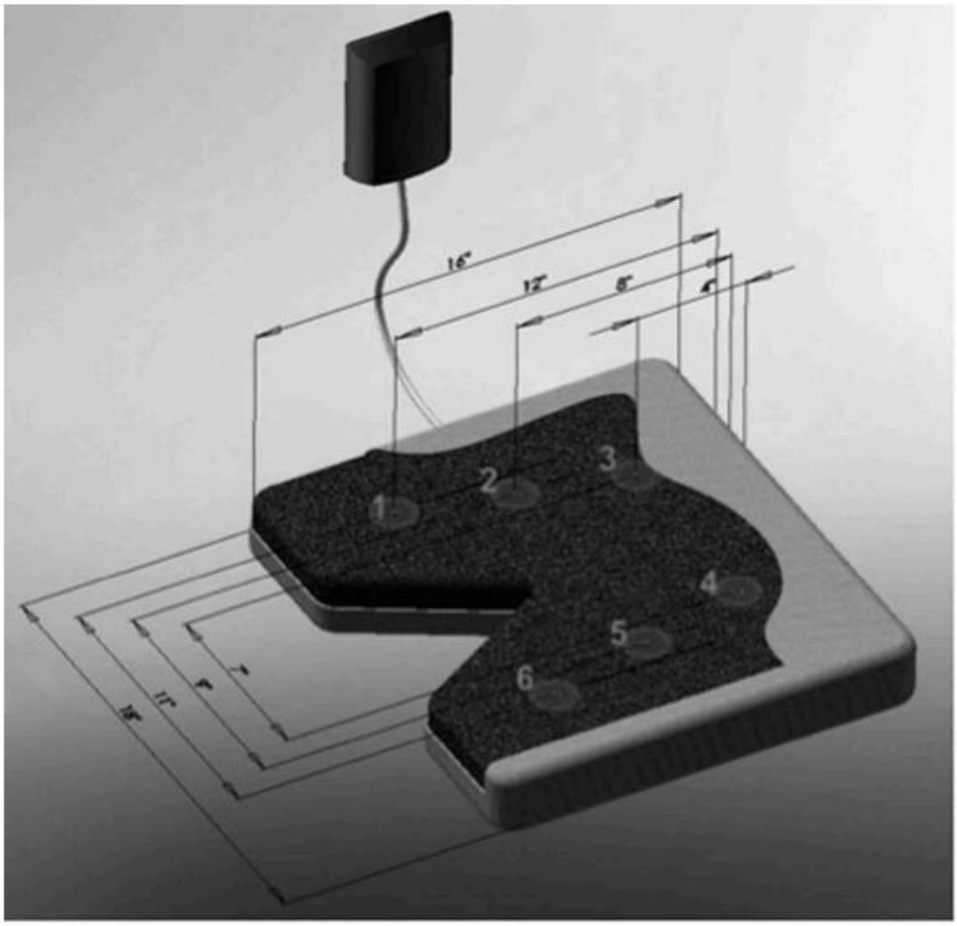

Figure 2. The custom made stochastic vibration device that was used during the intervention for only one of the groups.

Intervention

The interventions between groups were identical except that one group received, in addition to the perceptual-motor therapy, the stochastic vibration to the seating

surface during the therapy. The therapists could not be blinded to group assignment as the one treatment included the vibrating pad, which was obviously there for some and not for others. Children in both groups received sixty minutes of physical therapy intervention twice weekly for twelve weeks in addition to the standard of care they received at home or school setting. Standard of care on average includes consultative physical therapy once per week, which focuses on equipment management, training for functional activities, such as transfers and wheelchair mobility, and training of staff to manage positioning and adaptive equipment. The intervention received by the children was performed by therapists trained in the perceptual-motor therapy.[9] This intervention approach was chosen because is based on dynamic theories, is an ecological approach, and focuses on the child's ability for self-organization relevant to environmental forces. The approach utilizes environmental forces during self-initiated goal-directed movements to change function and postural control. The specific techniques used during intervention were dependent on the skill level of the child. Generally, activities were aimed at teaching the child to attend to significant environmental information, such as pressure against the support surface, which can be correlated with forces useful for controlling posture and movement. Very small increments of change were expected, but the expectation was that the child would choose the movement strategy rather than the therapist. The therapist presented a small movement or postural challenge to the child and waited for the child to solve the problem, giving very light cues or assistance. The focus was on helping the child utilize forces to obtain a functional goal, which may not necessarily lead to producing a "normal" movement pattern. This intervention was found to be advantageous in infants with or at risk for CP in our previous study,[9] which was one additional reason for comparing this type of therapeutic approach in addition to stochastic vibration.

For the children in the group receiving stochastic vibration at the support surface in addition to the perceptual-motor therapy, a small vibrating device attached to a bench, chair, or mat was used during the therapy session. The voltage was varied to provide stochastic vibration to the seating surface. The vibrations were small and not detectable by the child.

Outcome measures and data analysis

The videos of the GMFM assessments (only the sitting subsection) were scored by one therapist certified in the GMFM who was blinded to group assignment. For the present study, we used the total points scored on the items of the sitting subsection. Those scores where then converted to percentages.

Customized MatLab software was used to calculate the linear measures from the COP data from the selected trials by using the methodology of Prieto et al.[36] and included the root mean square (RMS), range (maximum minus minimum) for the anterior-posterior (AP), and the medial–lateral (ML) directions and the sway path (length of the path traced by the COP). These parameters are all independent of the effect of

biomechanical factors such as weight,[37] which may change rapidly during development. These linear measures characterized the amount of sway variability present in the data.

Furthermore, two nonlinear measures of variability were calculated from the selected trials: approximate entropy (ApEn) and the largest Lyapunov exponent (LyE) for both the AP and the ML directions. These nonlinear measures characterized the temporal structure of sway variability present in the data and have been found reliable tools to assess sitting development.[11] Calculation of the nonlinear measures of the variability present in the postural sway was performed as presented by Harbourne and Stergiou.[9,38]

Statistical analysis

We conducted a two (Intervention) by four (Time) mixed way ANOVA on the dependent variables derived from the COP data and a two (Intervention) by two (Time) on the GMFM scores. To adjust for the analysis of multiple outcome measurements, a two-sided critical value of 0.01 was used. A single-subject analysis[42] was also performed to detect differences at the inter-individual level that could have been undetected by the group analysis. In this procedure and for each subject, the difference between two subject means (baseline vs. last data collection) was compared with the product of the mean standard deviation and a criterion test statistic based on number of trials.[42]

Results

There were no significant main effects of intervention or time or an interaction between intervention and time for all the COP variables examined. LyE in the ML direction was significant at the 0.05 level but not in our adjusted 0.01 level ($F_{1,28} = 4.12$; $p = 0.0163$; Figure 3) for the main effect of time. Post hoc analysis revealed that both treatment groups increased the LyE values in ML direction three months after the start of treatment in comparison with baseline. Group mean data of all COP variables examined are presented in Table 2.

Table 2. Mean group data for root mean square (RMS), range, sway path, Lyapunov exponent (LyE), and approximate entropy (ApEn) in the anterior–posterior (AP) and medial–lateral (ML) directions. None of the measures was statistically significant different between the groups.

						F-ratios		
		Baseline	1 month from start of treatment	2 months from start of treatment	3 months from start of treatment	Intervention (1,28)	Time (3,26)	Interaction (3,26)
RMS	**AP**	6.637	6.763	6.457	6.639	0.18	0.65	0.63
	ML	6.425	5.621	4.553	5.518	0.42	2.37	0.52
Range	**AP**	38.798	38.034	35.961	36.658	0.41	1.42	1.13
	ML	35.493	28.323	26.527	29.741	0.98	1.05	0.78
Sway Path		599.6	564.778	525.608	611.68	0.61	1.99	0.5
LyE	**AP**	0.215	0.203	0.216	0.205	1.65	1.57	1.02
	ML	0.203	0.203	0.214	0.212	1.18	4.12	0.93
ApEn	**AP**	0.425	0.400	0.484	0.415	0.01	1.69	1.01
	ML	0.453	0.400	0.484	0.417	0.15	0.98	1.17

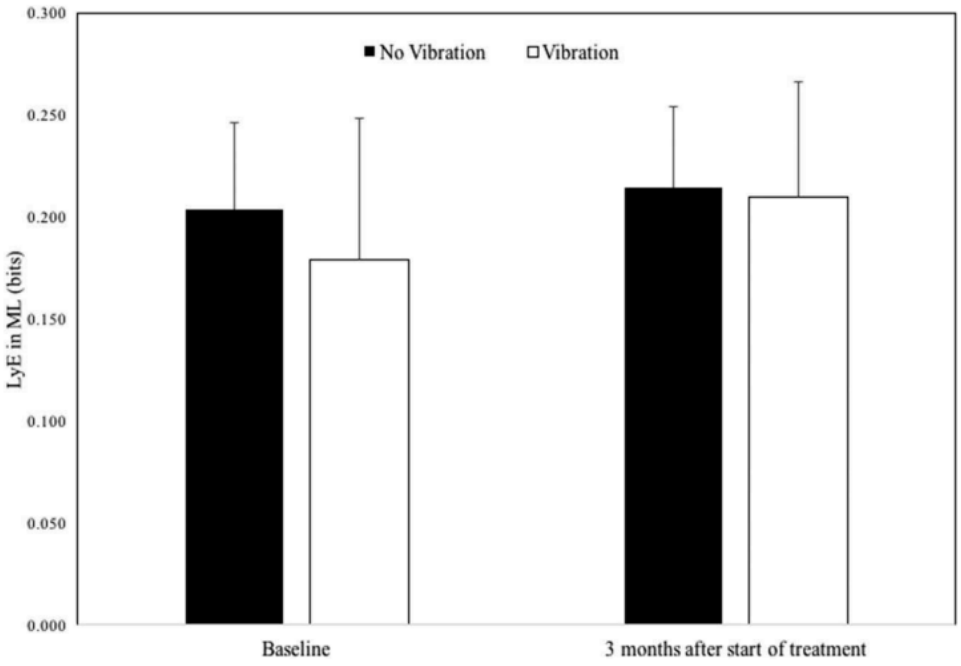

Figure 3. Lyapunov exponent (LyE) in the medial–lateral direction pre- and post-intervention.

There were no significant main effects of intervention or an interaction between intervention and time for the GMFM scores. GMFM scores presented statistical significant differences ($p<0.001$) for the main effect of time. Specifically, three months after the start of treatment GMFM scores were significantly greater than baseline GMFM scores in all children (Figure 4)

It should be mentioned that in the no vibration group, 53% of the children improved their stage of sitting, while in the vibration group, 46% of the children improved their stage of sitting from baseline to one-month follow-up assessment. We also performed a single-subject analysis that revealed significant differences not previously detected by the group analysis. Specifically, the single-subject comparisons for RMS AP and ML showed that 38% of the baseline subject means comparisons were significantly different, as well as 33% for the Range in AP and ML, ApEn in ML and LyE in AP. Moreover, sway path and ApEn in AP showed that 57% of the baseline subject means comparisons were significantly different. The use of single-subject analysis revealed further evidence that baseline measures changed for more than 30% of the children for all COP measures with the exception of LyE in ML direction. This change in baseline measures was similar to both groups of children.

Discussion

The purpose of this study was to determine sitting postural control changes for children with moderate-to-severe CP, using a perceptual-motor intervention in comparison with the same intervention in addition to stochastic vibration through the sitting surface. We did not find any significant main effects for intervention or time in the

COP measures of sitting postural control, as well as for the interaction between intervention and time. Only LyE in the ML direction nearly reached statistical significance for the main effect of time ($p = 0.0163$; not significant due to the adjusted 0.01 level of significance). However, when considering the changes in the GMFM scores at baseline and three months after the start of treatment, all children made significant improvements regardless of group assignment. In addition, single-subject analysis revealed that 30% of the children changed significantly at the end of the treatment in comparison with the baseline.

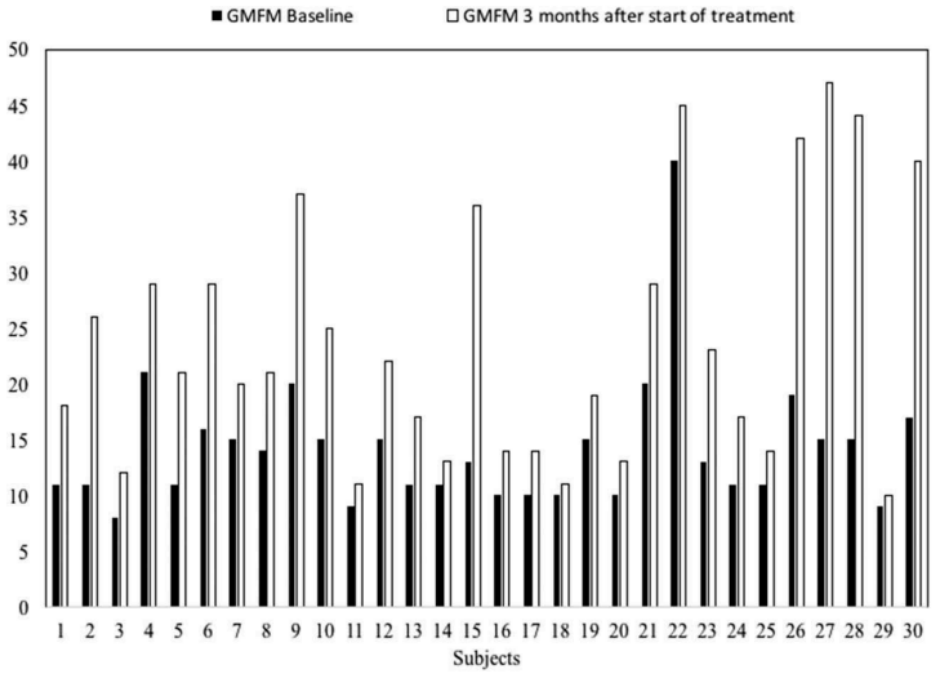

Figure 4. GMFM scores pre- and post-intervention for all subjects.

Taking these findings into account, it may be suggested that older children with moderate-to-severe CP did benefit from a perceptual-motor treatment protocol, but not all the children benefited the same way from the same protocol in addition to stochastic vibrations. Compared to the results of our previous work, we did not find significant differences in the other variables derived from the COP data. This may be due to the fact that different characteristics of population may respond differently to the treatment based on the perceptualmotor approach. For the current study, we recruited children with only moderate-to-severe CP (but not with mild CP). In our previous study, with infants with or at risk for CP,9 we had mildly, moderately, and severely affected infants, and those in the perceptual-motor treatment group developed postural control toward the values of infants with typical development to a greater degree than the infants in the home program group. When we took into account the level of severity, the results were the same. Another possible explanation maybe the fact that older children diagnosed with CP between two and six years of age have already “selected” the movement strategies that are functionally relevant for them regarding sitting postural control; thus,

it is more difficult now to change their neuromuscular organization to a different state. However, the improvement in the GMFM scores indicates positive gross motor function changes as a result of the perceptual-motor treatment but not due to the addition of stochastic vibration.

If we take into consideration the increasing value of LyE in ML direction for both treatment groups, we can conclude that sitting postural sway in children with CP became less rigid and more flexible in this direction. LyE is a measure of the rate at which nearby trajectories in state space diverge. This result may support the fact that children with moderate-tosevere CP are trying to escape from the attracted behavioral state of postural control that they have developed and are exploring new movement solutions, within their limitations. Thus, it may be suggested that older children with moderate to-severe CP have locked into a preferred neuromuscular state of postural control and therefore the lack of differences in COP measures, but are able to find other more general functional solutions and hence the improvement in GMFM scores.

Adding stochastic vibration stimulus during intervention did not appear to have an effect on the development of the sitting skill. Two possible explanations can be drawn here. First, our participants were exposed to the stochastic vibration only during intervention, while elderly adults from previous studies were assessed while exposed to vibrating insoles[30] or in general to stochastic mechanical input vibration while performing a task.[28] More recent work on whole body vibration shows no advantageous effect in patients with Parkinson's disease and multiple sclerosis,[34] although adults patients with CP do see improvements with whole body stochastic vibration.[35] Moreover most studies in children with CP that utilize stochastic vibration declare positive effects on muscle tone, strength, and coordination.[46–50] It can be interpreted that the stochastic vibration may not possess a retention effect on the regulation of postural control. Our pilot data had shown that the postural sway measures of children's sitting postural control were reduced right after the exposure to the stochastic vibration surface. However, the current results suggest that the exposure to stochastic vibration with treatment possibly provides only an acute effect to improve postural sway, while it eliminates the possibility of transfer to natural sitting posture. In addition, the type of vibrotactile signal may also be of importance. Given that a temporally organized structure of postural sway is considered as healthy,[9,43,44] to develop postural control may not benefit from entrainment to a stochastic signal. Rather, a signal that has a temporally organized structure (such as one exhibiting chaos or has a fractal structure or is pink noise) may provide a better stimulation to initiate neuromuscular changes in sitting postural control. A proof of concept study has shown that elderly individuals may alter their gait patterns depending on the temporal structure of an auditory signal.[45] Similarly, infants and children could entrain differently to proprioceptive signals of varying complexities. However, future studies are needed to compare the effect of different vibrotactile signals (e.g., white vs. pink noise) on sitting postural control. Lastly, the fact that single-subject analysis revealed that 30% of the children did alter significantly their postural control measures, could imply that the level of proprioceptive

deficit in this population is very variable, and should investigate issues of frequency and amplitude of the vibration stimulus before use.

Limitations

There are few limitations that should warrant caution in the interpretation of our findings. First, there are small numbers of children with CP. A larger multisite study could provide more robust results with respect to the effect adding a stochastic vibration component during the perceptual-motor intervention in developing the sitting skill. Second, another limitation is the the absence of another group of children as a control group that would receive only the standard of care. It is possible that the improvement in the GMFM sitting scores is due to the standard of care and not due to the perceptual-motor intervention per se. However, in another group of younger infants with or at risk of cerebral palsy, the perceptual-motor intervention was superior to the standard of care services.[9] Finally, we did not examine possible important covariates such as cognitive level, overall health status, or family engagement in the protocol at home. These other factors may play an important part in the individual responses of children to an intervention program.

Conclusions

Although both groups made similar progress in sitting stages and the variability of the postural sway, the stochastic vibration stimulus did not advance the development of sitting postural control. However, the significant changes noted in sitting scores and single-subject analysis support the use of the perceptual-motor therapy that was used in both groups as a means of advancing sitting postural control in children with moderate or severe CP who are between the ages of 2 and 6 years and promote the continuation of this line of research.

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