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A Comparison of Interventions for Children with Cerebral Palsy to Improve Sitting Postural Control: A Clinical Trial

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1 Abstract

2

3 **Background:** The ability to sit independently is fundamental for function but generally delayed
4 in infants with cerebral palsy (CP). Studies of intervention directed specifically toward the sitting
5 skills in infants with CP have not been reported. **Objective:** Our purpose was to compare the
6 effectiveness of two interventions to improve sitting postural control in infants with CP. **Design:**
7 For this randomized longitudinal intervention study, infants under the age of 2 years who were at
8 risk for CP were recruited for intervention directed toward sitting independence. **Setting:** The
9 intervention was conducted either in the home or at a pediatric outpatient facility. **Patients:**
10 Fifteen typically developing infants were followed longitudinally during sitting development to
11 use as a comparison on postural control variables. Thirty-five infants with risk factors and delays
12 in achieving sitting were recruited for the study. Infants with delays were randomly assigned to
13 either a home program group, or a perceptual-motor intervention group. **Measurements:** The
14 primary outcome measure consisted of Center of Pressure (COP) data taken during sitting, from
15 which linear and nonlinear variables were extracted. The Gross Motor Function Measure
16 (GMFM) sitting subsection was used as an additional clinical outcome measure for the infants at
17 risk for CP (pre-test and post-test). **Results:** There was a main effect of time in the GMFM
18 sitting subscale and in two of the COP variables. Interaction of group by time factors indicated
19 significant differences between intervention groups on two COP measures, in favor of the group
20 with the perceptual-motor intervention. **Limitations:** The small number of infants in the groups
21 limits the ability to generalize the findings. **Conclusions:** Although both intervention groups
22 made progress as measured by the GMFM, the COP measures indicated an advantage for the
23 group with the perceptual-motor intervention. The COP measures appear sensitive to assess
24 developing infant sitting posture control and to objectively quantify intervention response.

1 KEYWORDS: Nonlinear analysis, center of pressure, infant motor development

1 **Introduction**

2 *Selection of diagnostic group and motor task*

3 Children with cerebral palsy (CP) have several fundamental limitations that are pervasive
4 among the varying types and severities of this diagnostic group. Although not all inclusive, the
5 impairments of abnormal movement variability, poor regulation of movement speed, and
6 perceptual deficits related to movement and force production, are common to all types of CP
7 (Olney & Wright, 2006). Children with CP form an extremely heterogeneous group. Differences
8 in severity, distribution of movement dysfunction, and associated impairments complicate the
9 task of comparing these individuals. In addition to the problem of population heterogeneity, the
10 originating pathology differs between individuals, creating difficulties in early diagnosis (Sanger
11 et al, 2003). A diagnosis of CP is often delayed until the child is over 2 years of age because
12 early symptoms may be transient and resolve spontaneously (Palmer, 2004; Nelson & Ellenberg,
13 1984). However, early intervention is thought to be crucial in order to optimize the potential for
14 plasticity of the developing infant's nervous system. Typically, early intervention begins when
15 the child exhibits significant delays in developmental skills or when substantial risk factors for
16 motor impairments are present. The initiation of services often precedes a definitive diagnosis of
17 CP. Because this is the standard of care for early intervention, we investigated intervention for
18 infants with risk factors for, but not yet diagnosed with CP, as well as those who had a diagnosis
19 of CP.

20 In this study we also investigated the development of a specific motor task, sitting, and
21 we explored an intervention targeting this task rather than overall development or general motor
22 skills. Sitting postural control was selected as the targeted skill because sitting is the earliest
23 upright posture achieved in development. More importantly, sitting independence offers the

1 possibility of active arm use, greater potential for functional skills and self-care, and
2 opportunities to orient the self to the environment for improved perception, cognitive growth,
3 and social interaction (Bertenthal & Von Hofsten, 1998; Fogel et al, 1999; Hopkins et al, 2002).

4 *Why we chose to compare these two intervention approaches*

5 Infants who experience delays or who have a diagnosed developmental disability are
6 entitled to early intervention through the Individuals with Disabilities Education Act (IDEA),
7 Part C. Each state regulates Part C service provision, but most states operate under a primary
8 provider model (McEwen, 2000). In this model, a professional member of the early intervention
9 team, possibly a physical therapist, “coaches” a family in developmental activities or
10 environmental strategies that may be incorporated into a child’s daily care routine to promote
11 practice and learning of new skills. As “coaching” is the emphasis, the therapist is less likely to
12 directly treat the infant; instead, routines-based activities or play positions which promote
13 increasing levels of developmental skill are taught to infant caregivers. The caregivers then
14 provide the intervention during daily routine care, and the intervention is family-centered.

15 Reviews of early developmental intervention programs to prevent motor and cognitive
16 impairments in infants born preterm highlight the lack of evidence for early developmental
17 intervention to address motor development (Orton et al, 2009; Spittle et al, 2007). These reviews
18 emphasize that the diversity of approaches and outcome measures used in early intervention.
19 This diversity thus influences the finding that motor intervention yields no significant
20 improvements in developmental outcome. In addition, none of the studies reviewed by Orton et
21 al¹⁰ and Spittle et al¹¹ provided an intervention specifically designed to address postural control.
22 Thus, the early intervention for motor development provided by IDEA Part C is not supported by
23 current evidence. However, other research groups have recently reported improvements in

1 postural control following parent education or caregiver provided interventions.¹²⁻¹⁴ Similarly,
2 Arndt et al¹⁵ reported improvements in postural control following a therapist-guided trunk
3 protocol training. There is also evidence that changes in sitting postural control influence the
4 development of cognitive skills.^{16,17} In addition, there is some evidence that common
5 intervention techniques in pediatric physical therapy are effective in improving postural control
6 in children with cerebral palsy, although the evidence is limited.^{18,19} No study has compared a
7 clearly defined motor intervention targeting a specific emerging motor skill, delivered by a
8 physical therapist versus an intervention delivered by a caregiver following training with a
9 physical therapist. Therefore, we chose to compare a home program intervention, which is the
10 standard of care in early intervention services provided through IDEA guidelines,²⁰ with a
11 medical intervention model described below.

12 In addition to home-based early intervention services, some infants with motor delays
13 receive intervention through a medical model, with direct treatment provided in a clinical
14 facility. These intervention sessions typically consist of direct contact between infant and
15 therapist, and are more child-focused. Depending on the perspective of the therapist and the
16 specific needs of the child, a variety of techniques, approaches and theories may be incorporated
17 into such direct interventions. These approaches may include neurodevelopmental treatment,
18 which is based on the theory originated and taught initially by Bobath²¹; behavioral shaping²²;
19 developmental training²³; sensory integration²⁴; or an eclectic approach²⁵; pulling various
20 techniques from a variety of sources.²⁵

21 The direct intervention used in this study follows guidance principles described by
22 Tscharnuter^{26,27} which we will briefly review here. The cues provided during the intervention
23 guide the infant learner to attend to specific proprioceptive, tactile, and pressure information to

1 accomplish the task, rather than relying on the physical assistance or guidance of the therapist. A
2 critical part of the approach requires the initiation of action by the child, with the therapist
3 guiding in small increments and not directing the movement. The guidance hypothesis states that
4 the benefits of physical guidance (or knowledge of results) are strong during immediate
5 performance of a motor task.²⁸ However, the benefits of physical guidance may be temporary,
6 because the learner easily becomes dependent on the guidance. If guidance is reduced, more
7 permanent learning takes place. This is thought to be due to the learner solving the motor
8 problem and accessing information without external assistance. Thus, information and the
9 perception of information to guide movement become important in building skill. This is why
10 our direct intervention is called perceptual motor intervention.

11 Another aspect of the perceptual motor intervention is touch contact. Touch contact and
12 the importance of informational cues for the perception of orientation also are well established in
13 research examining standing posture in normal adults and adults with balance problems.²⁹ In
14 addition, research in the arena of space travel and artificial gravity research highlights the ability
15 of humans to utilize touch cues to adapt to disorienting forces.³⁰ Infants learn to control their
16 bodies through multiple contexts, errors, and strategies from which successful parameters that
17 are specific to the task are selected.³¹ The adaptation and selection of strategies according to
18 environmental demands is supported by the perception/action and ecological theoretical
19 perspectives,³²⁻³⁵ which add to our understanding of postural control in special populations.³⁶

20 Consequently, the approach utilized in the perceptual motor intervention group
21 emphasizes the mutual interaction of perception and action as they develop in parallel.
22 Movement is used in exploratory functions, to gather information from the environment, as well
23 as performatory in tasks such as sitting and reaching. Goldfield³⁷ describes early accounts of

1 motor development^{38,39} as “air theories” because children’s movements are detailed by describing
2 changes in limb segments with no regard for the support surface in the environment. This air
3 theory is in contrast to “ground theory,” such as that proposed by Gibson,^{33,34} which describes
4 forces supplied reactively by the environment and how the infant’s interaction with the support
5 surface changes movement outcomes.³⁷ The perceptual motor intervention provided to one group
6 in this investigation focused on noting when infants attend to support surfaces for postural
7 control, closely monitoring their adaptation of motor strategies to achieve the targeted sitting
8 goal, as well as reinforcement of a variety of strategies attempted by the infant. Table 1
9 summarizes key differences in the interventions provided to the home program group and the
10 perceptual motor group.

11 *Nonlinear tools for describing postural change*

12 Small changes in postural control are difficult to be quantified using standard assessment
13 tools in infancy. Several problems contribute to this difficulty. The first is that infants are
14 unpredictable and unable to follow instructions. This problem is easily rectified by adapting to
15 the infant’s schedule and interests, and creating a methodology that measures typical activities of
16 the infant. The second problem is that infant movement is extremely “wiggly” and variable.⁴⁰
17 Thus, the measurement tool must account for variability, and measure how this variability
18 changes over time as skill develops. In a perspective article on the value of variability,
19 Harbourne and Stergiou⁴¹ argued that variability is important and actually necessary for the
20 development of skill. Variability creates the adaptability that allows us to respond to changes in
21 the environment around us, and respond differently depending on the situation. More
22 importantly, it is not just the amount of variability or the number of strategies that are needed.
23 The *structure* of variability contributes to postural and movement adaptability in ways that allow

1 greater skill to emerge. Nonlinear tools can quantify the structure of variability, and give us a
2 view into movement generation that is otherwise unavailable.⁴²⁻⁴⁴

3 The use of nonlinear tools in measurement of postural control has expanded our
4 understanding of the development of postural control in sitting.⁴⁵ Examinations of standing
5 postural control in adults have also begun to utilize nonlinear measures to further describe
6 strategies of control.^{46,47} In both sitting development in infants, and adult postural control in
7 standing, linear tools measuring the range, excursion, and standard deviation of the center of
8 pressure have been considered incomplete in describing postural control.⁴² However, nonlinear
9 tools can complete this description by providing reliable measures of constructs such as
10 complexity, dynamic stability, and regularity.⁴⁸ Examination of Figure 1 can assist in
11 understanding the measurement of the center of pressure (COP) time series we will be using in
12 this paper.

13 Figure 1 shows COP tracings from 3 children in sitting: one typical infant, one infant
14 with spastic quadriplegic CP, and one infant with athetoid CP. All three of these children are
15 displaying the same outward behavior. [HERE I NEED A FIGURE OF A TYPICAL INFANT,
16 ONE WITH ATHETOID CP AND ONE WITH SPASTICITY AND THEIR RESPECTIVE
17 COP PLOTS IN PROP SITTING]. However, clinical observations revealed that there is a
18 slightly different quality to the behavior among the 3 children. The infant with typical
19 development is “wiggly” with constant small movements of various body parts. These
20 movements do not actually adjust the posture; nevertheless, the infant is relatively stable while
21 still being dynamic and somewhat adaptive within that posture, but she is unable to move to a
22 completely different posture in a controlled way. The infant with spastic CP is more static,
23 lacking these wiggly movements and seeming to be “stuck” mechanically in the position, unable

1 to adapt in any way or with any body part. The infant with athetoid CP is able to make
2 adjustments, but these movements do not seem adaptive; on the contrary, they threaten the
3 stability of the position. The COP data from these infants informs us about their skill. The linear
4 measure (root mean square [RMS]) measures the amount of variability and shows that the infant
5 with spastic CP has decreased values, indicating less excursion of the path of COP movement.
6 Conversely, the infant with athetoid CP values has increased values, indicating more excursion
7 than the typical infant. However, the nonlinear measure (Approximate Entropy [ApEn]) reveals
8 that even though the infant with athetoid CP has a greater amount of variability, the structure of
9 variability is not complex, indicating a more regular COP pattern and thus fewer strategies of
10 movement compared with the infant with typical development. The nonlinear measures for the
11 infant with spastic CP also show a more regular COP pattern that is coupled with a reduction in
12 the amount of movement. Thus, using the linear and nonlinear measures of the COP can describe
13 the postural control of these infants comprehensively and quantify the somewhat subjective
14 observations that we suspect as we view the infant's attempts to move and stabilize in real time.
15 Therefore, this study utilized both linear and nonlinear measures of postural sway.

16 The specific research question investigated in this study was: Do infants with CP or risk
17 factors for CP respond differently in their development of sitting postural control if they receive
18 a weekly home program versus a twice weekly intervention from a physical therapist using a
19 perceptual motor intervention? We predicted that infants with CP would respond more positively
20 to a perceptual motor intervention than the group receiving a home program for this particular
21 skill.

22

1 **Methods**

2 *Participants*

3 Fifteen infants with typical development and 35 infants with delayed development and at
4 risk for CP were recruited for the study. The infants who were at risk for CP were randomized
5 into the two intervention groups. Five infants with CP or delays withdrew or did not complete
6 the study and were excluded from the analysis. See Figure 2 for the flow chart of recruitment and
7 group assignment. Because not all infants carried a diagnosis of CP, but did have risk factors, all
8 infants who met the entry criteria and did not withdraw were treated and completed data
9 collection for a total of 30 infants. Table 2 lists all infants, and their diagnosis at the end of the
10 study. Fifteen infants were in the home program intervention group and 15 were in the perceptual
11 motor intervention group.

12 All infants were screened for entry into the study using the Peabody Developmental
13 Motor Scale-2.⁴⁹ Inclusion criteria for entry into the study for the typically developing infants
14 were: a score on the Peabody Gross Motor Quotient of greater than 0.5 standard deviation below
15 the mean, age of five months at the time of initial data collection (mean age at entry=5 months,
16 SD=0.5), and beginning sitting skills. Infants who were at risk or diagnosed with CP or
17 diagnosed with CP had the following inclusion criteria: age from five months to two years, a on
18 the Peabody Gross Motor Quotient of less than 1.5 deviations below the mean for their corrected
19 age, and sitting skills as described below for beginning sitting. The mean age for the home
20 program group was 15.5 months (SD=7), and the mean age for the perceptual motor group was
21 14.3 months (SD=3).

22 In the beginning sitting state, the infant's head control is such that when the trunk is supported at
23 the mid-trunk, the head is maintained for over one minute without bobbing, and the infant can

1 track an object across midline without losing head control. The infant may prop hands on floor or
2 legs to lean on arms, but should not be able to reach and maintain balance in the sitting position;
3 when supported in sitting can reach for toy; can prop on elbows in the prone position for at least
4 30 seconds. Beginning sitting stage was not different between the groups of typically developing
5 infants, infants with CP in the home program group, and infants receiving perceptual motor
6 intervention ($F(2, 42) = 2.068, P=0.139$).

7 Exclusion criteria for the sample of infants who were typically developing are: a score on
8 the Peabody Gross Motor Quotient less than 0.5 SD below the mean, diagnosed visual deficits,
9 or diagnosed musculoskeletal problems. Exclusion criteria for the infants with CP or at risk for
10 CP were: age over two years, a score greater than 1.5 SD below the mean for their corrected age
11 on the Peabody Gross Motor Quotient, blindness, or a diagnosed hip dislocation or subluxation
12 greater than 50%, or a diagnosis other than CP or developmental delay. All infants were
13 expected to sit for at least 10 seconds in the prop sitting position for the data collection to begin.

14 In addition to the above entry criteria, the infants at risk or diagnosed with CP were
15 categorized into a severity group based on the Peabody standardized score, the distribution of
16 abnormal muscle tone, and the Gross Motor Function Classification Scale level. The categories
17 mild, moderate and severe were separately randomized for assignment of intervention group. In
18 the final group of children with CP, the individual severity group, GMFCS level, and
19 intervention group assignment are listed in Table 2. The severity score was not different between
20 the two groups ($T(1, 28) = 0.357, P=0.724$).

21 **Outcome Measures**

22 *Postural Control Measures*

1 The COP data was analyzed using both linear and nonlinear tools. The COP is considered
2 a reflection of overall postural control, and as such, contains various components of that control.
3 A previously published factor analysis revealed that linear and nonlinear measures contributed in
4 unique and separate ways to the overall description of postural control (Harbourne et al, 2009).
5 Therefore, different aspects of postural control were defined by the following measures, which
6 were selected from each of the factors previously identified in our initial factor analysis
7 (Harbourne et al, 2009):

8 Root Mean Square AP: Linear measure of overall postural variability, the standard deviation of
9 the length samples in the anterior-posterior (AP) direction or in the forward-backward direction
10 of movement (i.e. sagittal plane).

11 Root Mean Square ML: Linear measure of overall postural variability, the standard deviation of
12 the length samples in the medial-lateral (ML) direction on in the sideways direction of movement
13 (i.e. frontal plane).

14 Sway Path: Linear measure of velocity of the COP. This is the length of the COP path
15 constructed over the 2000 data samples for each trial. Because the time of the trial was held
16 constant, an increase in length of the path means that the COP was moving at an increased
17 velocity.

18 Approximate Entropy AP: a measure quantifying the regularity or predictability of the COP in
19 the anterior-posterior (AP) direction or in the forward-backward direction of movement (i.e.
20 sagittal plane).

21 Approximate Entropy ML: a measure quantifying the regularity or predictability of the COP in
22 the medial-lateral (ML) direction on in the sideways direction of movement (i.e. frontal plane).

23 *Gross Motor Function Measure*

1 In addition to the Peabody, the infants with delays and risk factors were given the Gross
2 Motor Function Measure (GMFM)⁵¹ sitting sub-section, prior to initiating intervention and
3 immediately at the end of intervention. All GMFM testing was videotaped and later scored by a
4 therapist trained in scoring the GMFM to a reliability level of greater than 90% agreement with
5 training tapes. This therapist was blinded to the order of the test and to the intervention group of
6 the child.

7 **Data Collection**

8 For data acquisition infants had the clothes removed. Trunk and pelvis markers were
9 placed on the infant, but the marker data was not analyzed for this study. The infants were placed
10 in the sitting position on an AMTI force plate,* which was interfaced to a computer system
11 running Vicon data acquisition software.+ A small absorbent pad was taped to the force plate for
12 comfort and absorption. COP data were acquired through the Vicon software at 240 Hz, in order
13 to be above a factor of ten higher than the highest frequency that was found by pilot work to
14 contain relevant signal. An assistant sat to the side of the infant during data acquisition, and a
15 parent or relative (typically the mother) sat in front of the infant, for comfort and support, as well
16 as to keep the infants attention focused on toys held in front of the infant. The assistant held the
17 infant until the infant had control of their sitting balance in whatever way possible. When the
18 assistant felt the infant was stable, the support was removed, but the assistant's hands were kept
19 near the infant to support them if they began to fall. Trials were recorded while synchronizing
20 the force plate data and video data from the back and side views. For infants with typical
21 development, COP data were collected at the time of beginning sitting (prop sitting, around 5
22 months of age) and approximately 3 months later when the infants sat independently without
23 propping but prior to initiation of crawling.^{45,48}

1 *Data Analysis*

2 Segments of usable (described below) data were analyzed using custom Matlab software
3 (MathWorks, Nantick, MA). No filtering was performed on the data in order to obtain unaltered
4 nonlinear results.⁵² The person selecting the video segments was blind to the group assignment
5 of the children. Three segments of data with 2000 time steps (8.3 seconds at 240 Hz) were
6 selected. Selection criteria were: no crying or long vocalization, no extraneous items (e.g. toys)
7 on the force platform, neither the assistant nor the mother were touching the infant, the infant
8 was not engaged in rhythmic behavior (e.g. flapping arms), and the infant had to be sitting and
9 could not be in the process of falling.

10 Linear measures were calculated from the selected trials using customized Matlab software
11 from the COP data, using the methodology of Prieto et al,⁵³ and included root-mean-square (RMS)
12 for the AP and the ML directions and the overall length of the path traced by the COP (sway path).
13 These parameters were selected according to Chiari et al (2002), and they are all independent of
14 the effect of biomechanical factors such as weight. Weight changes dramatically during
15 development so it is a possible confounding factor.

16 In addition, a nonlinear measure of variability (ie, the ApEn) was calculated from the selected
17 trials. This variable was also calculated for both the AP and the ML directions. This nonlinear
18 measure was calculated from the COP data as described by Harbourne and Stergiou.⁴² The ApEn
19 was calculated using algorithms written by Pincus⁵⁵ implemented in Matlab. The nonlinear
20 measure characterizes regularity as an indicator of the structure of the variability present in the
21 data by examining the patterns and the time evolving order that exist in the COP time series,
22 evaluating the entire data set point-by-point. Values of this measure range from 0-2, with 0 being
23 completely regular (as in a sine wave), and 2 being completely random and unpredictable.

1 *Statistical Analysis*

2 All statistical analysis was performed with SPSS software (Version 13.0). The alpha level
3 was set at 0.05. The *t*-test for independent groups was used for comparison between intervention
4 groups prior to intervention on the GMFM and severity levels to assure equivalent sitting skills
5 in both groups at baseline. Long-term effects were examined using a general linear model
6 (GLM) repeated-measures procedure for each dependent variable with group (typical, home
7 program and perceptual motor groups) as the between subject variable and time (pre-intervention
8 or beginning sitting versus one month post-intervention/mature sitting for typical group) as the
9 within-subject variable. Significant group by time interactions indicate the presence of
10 intervention effects and were followed by post-hoc analysis using Fisher's Least Significant
11 Difference (LSD) approach or paired contrasts between groups for the post-intervention/mature
12 sitting data.

13 *Intervention*

14 As described above, the 30 infants with cerebral palsy or risk factors were divided into 15
15 infants for the home program group and 15 infants for the perceptual motor intervention group.
16 The home program group was considered the standard of care in early intervention.²⁰ The
17 perceptual motor intervention was conducted twice weekly because this is considered an
18 acceptable frequency for a child working continuously toward established motor goals.⁵⁶ Each
19 group received the selected intervention for 8 weeks. For both groups, the outcome measures were
20 compared prior to the intervention, and at one month follow up after the intervention. If a child
21 missed a scheduled session, the session was re-scheduled as soon as possible.

22 The home program consisted of daily routine activities utilizing handling, play and
23 positioning suggestions provided by the therapist during the eight weeks of intervention. These

1 handling routines consisted of holding or supporting the infant so that trunk support is reduced as
2 much as possible to allow the child practice of trunk control and sitting skills. These handling
3 procedures were suggested for such routine activities as holding the child, bathing, dressing,
4 carrying, playing and feeding. The caregivers were instructed in the handling routines by a physical
5 therapist at each home visit, with updates and changes to the program as needed. The home setting
6 allowed the therapist and caregiver to create activities using the toys, equipment and materials
7 available in the home.^{57,58}

8 Infants in the perceptual motor group received fifty minutes of physical therapy
9 intervention twice weekly for eight weeks. The intervention received by the experimental group
10 was performed by therapists utilizing concepts described by Tscharnuter.^{26,27} Self-initiated goal-
11 directed movements for functional action and postural adaptation were emphasized. The specific
12 techniques used during treatment were dependent on the skill level and interests of the child.
13 Generally, activities were aimed at teaching the child to attend to significant environmental
14 information, such as pressure against the support surface which can be correlated to forces useful
15 for controlling posture and movement. Close interaction between the therapist and child allowed
16 continuous on-line adjustments to assure the child attended to the activity and tried multiple
17 strategies for self-adjustment until the goal of the specific task was attained. The focus was on
18 helping the child explore the variability of forces and body postures needed to obtain a functional
19 goal; thus the task was kept dynamic and the goals were not related to producing a “normal”
20 movement pattern. The Appendix provides further information about the perceptual-motor
21 intervention.

22 Differences in the intervention between the two groups were thus three-fold. First, the child
23 spent more time engaged directly with the therapist in the perceptual motor intervention group.

1 This allowed greater focused problem solving and attention to small changes in strategy by the
2 child, which were reinforced and then scaled to the next level of difficulty more frequently by the
3 therapist. In contrast, during the home intervention the therapist divided time and attention between
4 the caregiver and the child, allowing less time to concentrate on the child's ability to perform or
5 attempt a variety of strategies. Consequently, the home program group was more family or
6 environment focused, and the perceptual-motor intervention was more child-focused. Second, the
7 perceptual motor intervention sessions were more dynamic and variable than the home
8 intervention sessions. Although the overall task might be the same, and the positions similar,
9 during the perceptual motor intervention the therapist focused on the child exploring continuous
10 and slight dynamic changes in the task, or in a component of the task. Lastly, because caregivers
11 were present during all therapy (in both groups), parental observation of the child during a variety
12 of tasks and using variable strategies could have been increased in the perceptual motor
13 intervention group (if the parent attended to all activities), even though home suggestions would
14 be identical in both groups. Parental learning by observation and parent question-asking were not
15 limited in either group except for the frequency of contact. The duration of the home visits and
16 perceptual-motor intervention sessions was the same (ie, 1 hour).

17 Role of the Funding Source

18 This study was funded by the US Department of Education and the National Institute of Disability
19 and Rehabilitation Research.

20

1 **Results**

2 *Gross Motor Function Measure*

3 Baseline scores on the GMFM did not differ between the two intervention groups ($T =$
4 1.144 , $P=0.263$). There was a main effect of time [$F(1,28)=53.292$, $P=0.000$], but no interaction
5 effect [$F(1, 28)=0.634$, $P=0.433$]. Twenty percent of the infants in the home program group
6 crawled by the end of the intervention, while 40% of the infants in the perceptual motor group
7 crawled at the end of intervention. However, because we were not targeting the crawling skill,
8 we did not quantify it by any means other than observation during other data collection.

9 *COP Variables*

10 The typical infants are used as a comparison of normal change over time for the COP
11 sitting variables. Because all the children were developing, the intervention groups were
12 expected to change over time as well, and we wanted to know whether they changed in the
13 direction of the normative values. Thus all variables were examined for a main effect of time
14 (pre versus post values, with a time period of 3 months between measures) and a group X time
15 interaction effect. Figures 3 and 4 demonstrate the changes preintervention and postintervention
16 for all COP variables.

17 For the variable RMS AP there was no significant effect of time [$F(1,42)=2.046$, $P=0.16$]
18 or interaction effect [$F(2,42)=1.195$, $P=0.313$]. However, the typically developing infants and the
19 infants in the perceptual motor group did show increase over time, whereas the infants in the
20 home program decreased over time (Figure 3). For the variable RMS ML there was a main effect
21 of time [$F(1, 42) = 15.547$, $P=0.00$] with all groups decreasing from pre to post. There was no
22 group by time interaction effect [$F(2, 42)=2.908$, $P=0.066$], although both intervention groups
23 showed a decrease over time as compared to the typical infants.

1 Analysis of the velocity variable yielded no main effect of time [$F(1, 42)=0.35, P=0.557$],
2 but there was a significant group by time interaction effect [$F(2, 42) =4.547, P=0.016$]. Pair-wise
3 comparisons indicated a significant difference post intervention between the home program
4 group and the perceptual motor group ($P=0.011$). The perceptual motor group increased in
5 velocity toward the normative levels of the typical infants, and the home program group
6 decreased post intervention further away from the typical normative levels.

7 The nonlinear variable of ApEn in the AP direction showed a main effect of time [$F(1,$
8 $42)=16.066, P=0.00$], with all infants increasing in regularity. There was also a significant
9 interaction effect [$F(2, 42)=3.193, P=0.05$]. Paired comparisons yielded a significant difference
10 between the typical infants and the home program group ($P=0.039$), with the home program
11 group displaying decreased values with greater regularity, and the perceptual motor group
12 approximating the values of the typical infants.

13 ApEn in the ML direction yielded no main effect of time and no interaction effect.
14 However, examination of the mean values prompted us to perform a one-way ANOVA between
15 groups for the post intervention values. This analysis yielded a significant difference between
16 groups [$F(2,42)=3.181, P=0.05$], with a post-hoc significant difference between the two
17 intervention groups ($P=0.011$). The home program group had significantly smaller values
18 exhibiting greater regularity than the perceptual motor group or the typical infants, as it was the
19 case with ApEn in the AP direction.

20

1 **Discussion**

2 The results will be discussed in light of the two main outcome measures: the GMFM
3 sitting subscale and the COP variables. First, we will address the GMFM as a functional
4 outcome.

5 Both the home program group and the perceptual motor group made significant changes
6 in the sitting subscale scores. The average change in the score from pre to post intervention was
7 20 percentage points, which is greater than expected for simple maturation in a child with CP
8 during that time period.⁵⁹ This indicates that targeting the task of sitting during intervention,
9 either using a family-focused home program approach or a child-focused perceptual motor
10 approach guided by a skilled therapist, produces significant changes in the skill. Because both
11 the home program infants and infants receiving perceptual motor intervention made significant
12 functional progress in sitting, we conclude that it was the skilled attention to the specific task
13 rather than the frequency or method of intervention that produced the functional change.
14 However, the GMFM may not be sensitive to small changes in skill, specifically for children
15 with severe motor problems during infancy, and may be inadequate for detecting differences
16 between intervention groups.⁶⁰

17 Mindful that achieving a single function is not the complete story in motor development,
18 we also examined COP variables, which provide an opportunity for evaluating the changes in
19 motor control on a more discrete and objective level of analysis and examining indicators of
20 overall postural control and adaptability. Using both linear and nonlinear measures of postural
21 control, we examined factors that may underlie the functional skill of sitting, and thus provide a
22 window to view strategies for movement that can assist in developing additional skills.

1 Overall the results reveal that infants in the perceptual motor group developed postural
2 control toward normative typical values of the COP measures to a greater degree than the infants
3 in the home program. For all five COP variables, the infants in the perceptual motor group
4 approximated the values of the typical infants post intervention. In contrast, infants in the home
5 program group showed significant differences over time when compared to the infants in the
6 perceptual motor group and the typical infants. These differences between the intervention
7 groups include changes in the amount of variability of the COP, the velocity of the COP, and the
8 structure of the COP as measured from the regularity of the COP path. We will further discuss
9 these changes below.

10 Change over time in the AP direction in the COP variables of the typical infants indicate
11 that amount of variability (RMS) increases, in conjunction with an increase in regularity (ApEn).
12 Functionally, this can be explained as an increased expansion of the infant's control to reach,
13 look, and adjust posture for engagement with the world through reaching what is in front of
14 them, while at the same time decreasing the number of unnecessary weight shifts so postural
15 stability is maintained. The infants in the perceptual motor group followed these trends.
16 However, the infants in the home program group decreased the amount of variability while
17 increasing regularity. Behaviorally, this combination of changes results in less explorative
18 behavior in sitting, but a general maintenance of stability that is not as dynamic.

19 Change over time in the ML direction of the COP variables in typical infants indicates a
20 decrease in the amount of variability over time as sitting is learned. However, typical infants
21 show a corresponding increase in irregularity in the ML direction as sitting develops.
22 Functionally, this may indicate a decreased expansion of the infant's control to adjust posture for
23 engagement with the world as a potential sacrifice for the increased expansion in the AP

1 direction where is the infant's focus. This is coupled with the narrowing base of support because
2 the legs are moving out of the static passive circle sitting position as the child develops.
3 However, the ability to adapt the base of support requires a greater amount of constant weight
4 shifts and dynamic control as depicted by the more irregular movement of the COP. So the small
5 increments of control needed to maintain balance medial laterally are actually quite complex in
6 character. The children in the perceptual motor group mirrored these changes seen in the typical
7 infants, but the home program group did not. Although both groups decreased the overall amount
8 of variability in the medial lateral direction, the home program group did not show greater
9 irregularity; on the contrary, regularity increased, indicating their strategies were not as complex
10 as those of the typical infants or infants in the perceptual motor group.

11 The COP variable measuring velocity of the COP movement indicated that the typical
12 infants did not change over time as they learned to sit. Although both groups of infants in the
13 intervention initially had slightly lower velocity values prior to intervention, post-test results
14 indicated the perceptual motor group increased in velocity over time, becoming more like the
15 values of the typical infants. This indicates that the practice of positioning and carrying
16 suggestions of the home program may fail to address one of the primary problems of children
17 with CP, which is decreased velocity of movement.

18 Although the COP variables are somewhat "invisible" without technology to provide
19 such analysis, they appear to quantify some features of movement or postural control that have
20 been previously termed qualitative. For example "dynamic stability" may be a term that can be
21 quantified by using both the linear measure of the amount of variability, RMS, and the nonlinear
22 measure of regularity, ApEn. As infants learn to sit adaptively, they learn to make small,
23 controlled weight shifts within an increasing range of movement. This allows them to reach and

1 view the world, as well as begin to transition out of sitting and into the crawling position.
2 Notably, 40% of the infants in the perceptual motor group were crawling at the end of the
3 intervention, versus 20% of the home program group. Although this was not a measured
4 variable, it would be of interest to document in future studies of sitting development.

5 It is possible that the use of nonlinear measures of the COP as well as linear measures
6 provides additional fidelity to the description of postural control, which is then better able to
7 describe subtle changes taking place in the children with more significant motor difficulties.
8 Nonlinear measures have been shown to add to the ability to differentiate infants with
9 developmental delays from typically developing infants during sitting postural control.⁶¹ In
10 addition, we have described similar differences in changes in COP variables in case reports of
11 infants with mild motor problems when comparing the home program versus perceptual motor
12 intervention.^{44,62}

13 It may be that infants with cerebral palsy fared slightly better in the perceptual motor
14 group because they are unable to discover solutions to their movement problems on their own,
15 either due to paucity of movement, or because of sensory dysfunction. These children may need
16 more guidance to discover possibilities for movement or for postural control. The perception-
17 action theory would hold that if action is unavailable, such as in a child with CP, perceptual
18 information is inadequate, and a cycle of disuse ensues. Guidance that is sensitive to small
19 attempts at movement, and timed to allow the child to initiate goal-directed movements, may
20 help such a child to find information that can assist in developing postural control.

21 Although some of the children in the study did not have a diagnosis of CP and were included
22 because of risk factors for CP, they had motor delays that were significant enough to warrant
23 early intervention and continuing physical therapy services. Of the 7 children who had risk

1 factors for SP (and no diagnosis of CP), 4 were in the home program group and 3 were in the
2 perceptual-motor intervention group. All of these children were continuing to receive physical
3 therapy services at the end of the study due to motor delays, even though they still did not have a
4 diagnosis. Of this group, 1 out of the 4 children in the home program group and 2 out of the 3
5 children in the perceptual-motor intervention group were crawling by the end of the intervention.
6 Because these “at-risk” children were distributed between both intervention groups, and they
7 appeared to progress in a fashion similar to that of the children with mild CP, we feel that their
8 response to intervention paralleled that of the larger group.

9 *Limitations of the study*

10 The study was limited by small numbers of children with cerebral palsy. A larger multi-
11 site study is warranted to examine early intervention to improve specific motor skills such as
12 sitting. The study was also limited by virtue of the fact that we did not control the amount of
13 practice time or other motor interventions in the home. Although we initially considered tighter
14 controls as a requirement of participation, it was clear from the start that recruitment for the
15 study would be impossible if we demanded extensive changes to the existing routines of the
16 families. We therefore felt that it was important to treat the children in both groups as they would
17 be treated in a normal clinical and home intervention setting, without trying to set controls on the
18 overall environment. In addition, we did not set up any system to document practice in the home
19 because we felt the families were already burdened with many additional responsibilities such as
20 extra appointments and care for the infants with special needs. Experience and skill of the
21 caregiver is another factor that we did not account for in our design of the study or in the
22 analysis. Clearly families bring their own priorities and skills to the table during intervention for
23 skill building, but we did not monitor or document this important factor.

1 Another limitation of the study, or a question that may be raised in terms of the group
2 comparisons, is the issue of dosage. Conceivably, the children in the perceptual-motor
3 intervention group could have fared better because they had twice weekly visits versus the once-
4 weekly visit for the children in the home program group. However, the once weekly home visit
5 was meant to teach the caregivers activities that could extend into the daily routine of the child.
6 As described in the introduction, this focus was meant to mimic the standard of care currently
7 being provided in the United States under IDEA regulation and to increase the dosage of practice
8 activities because the parent would perform the tasks at least twice weekly. The focus in the
9 perceptual-motor intervention group was not on teaching or encouraging the caregiver to do
10 specific activities, although the caregivers were present for all session and obviously absorbed
11 information regarding activities that could be done with their infant. Thus, we feel it is a valid
12 criticism that dosage may be important, although we cannot claim that one group was receiving
13 twice the dose of the other group, because they were distinctly different approaches. Other
14 studies have not shown that merely an increase in frequency of physical therapy visits
15 contributes to better outcomes.^{63,64} We suspect that the type of intervention – that is, what is done
16 during the visit – rather than the frequency of the visits is a critical factor contributing to
17 successful outcomes. Further study is needed to distinguish dosage from type of intervention.

18 *Clinical Implications*

19 Although this study had a small number of participants with CP, it is the largest
20 randomized and controlled study to date which compared motor interventions targeting
21 improvement of postural control in sitting. Therefore, translation to clinicians and suggestions
22 for future study are evident. Home program intervention and direct perceptual motor
23 intervention, both of which target the specific skill of sitting, can facilitate significant changes in

1 sitting behavior. However, the perceptual motor, child-focused intervention appeared to provide
2 greater flexibility and adaptability of the skill, which may translate to ease of further motor
3 development. We conclude that targeting the skill of sitting at a time when the child shows
4 readiness for learning control at that level, and providing more intense perceptual motor training
5 for a short term intervention can provide the optimal care to achieve sitting, and thus should may
6 be considered best practice. This investment of time and effort may have long-lasting
7 implications for learning because of the developmental importance of sitting postural control.
8 We also conclude that nonlinear and linear measures of the COP are important in further
9 elucidating the development of postural control, and can be utilized as markers of change in skill
10 development.

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1 Appendix 1 – Perceptual Motor Intervention Activities

2 The first and primary activity is to set up a task or adjust the environment so the infant can
3 explore and adapt their movement and postural strategies at a slight level of challenge for his or
4 her current skill. During all intervention activities, the therapist should have steady but light
5 contact during any guidance. The contact between child and therapist needs to be light so the
6 therapist can feel any attempts the child makes to initiate movement or actions. If the therapist
7 feels the child is dependent on the therapist support, the contact should be decreased. Most often
8 the therapist goes with the child, but if the child is not moving at all the therapist provides small
9 cues for possibilities of movement, allowing time for the child to process the information. The
10 following are possible activities for each stage of sitting.

11 **Stage 1** (prop sitting): In this stage the child is beginning to sit and may prop on the hands or
12 forearms for at least 10 seconds

13 -Environment set up to allow visual or manual exploration to be optimal when in the sitting
14 position; family member or interesting object on bench or surface above floor level.

15 -Soft support, such as a rolled up blanket, under legs if legs are off the surface. This affords
16 leaning into the surface, rather than pulling away from the surface as many children with CP tend
17 to do.

18 -Child's trunk is leaning forward, resting weight of the trunk/chest/arms on support that is soft,
19 like a pillow.

20 -In sitting, provide steady (as opposed to intermittent) light touch cues that suggest very small
21 changes in weight distribution of the upper trunk on the lower trunk; this is done by touch
22 contact in mid-trunk, along the spine. Can also give touch cues at the shoulder girdle between the
23 trunk and arms, or at the arms in different postures that fit the environmental context.

1 -An opportunity for laying in prone with the therapist providing light touch at trunk leaning
2 slightly into the surface where the child has pressure on the chest; then leaning in small
3 increments away from that point to a variety of points lateral, medial and caudal to that point, as
4 if showing the child a path to different places where weight could be transferred or distributed.

5 -May also work in supine as described above in prone, emphasizing weight distribution caudal
6 towards lower trunk and pelvis (as opposed to head), and some asymmetrical pressure
7 distribution.

8 -Especially in places where the child pulls away from the surface, therapist should gradually
9 work toward the child moving weight distribution closer to that area. Therapist looks for
10 adaptation to the surface first, such as the child allowing that body segment to contact the
11 support surface. Then the therapist should look for the child to actively push against the surface
12 to shift weight. In the severe child with beginning sitting skills, this adaptation and activation is
13 expected in the upper trunk and arms, not in the legs.

14 **Stage 2:** able to prop sit but not able to free both hands for extended play, treatment activities
15 included:

- 16 - Steady light touch to allow/encourage the infant to explore strategies for elevating
17 segments of the upper trunk over the pelvis or for redistribution of pressure either
18 posteriorly or to one side so that one hand could be freed for attempts at reaching.
- 19 - Use of slightly elevated surfaces for taller toys that start to encourage increased spinal
20 extension and dynamic stabilization of the torso over the base of support. The infant can
21 then begin to lean/use their base of support as a point of stability as they start to explore
22 postural control without hand support.

1 - Reaching in a variety of directions while propping with one hand/arm. The therapist
2 provides light guidance for adapting the stable body segment as the child learns to control
3 strategies for shifts of pressure distribution from their pelvis/legs to the propping arm and
4 back.

5 - Prone activities emphasized pushing up with extended arms or reaching from a forearm
6 prop. The therapist may use light touch to assist with dynamically engaging the
7 legs/pelvis during these activities so the child learns they can actively stabilize against the
8 support.

9 **Stage 3:** For infants who are sitting with hands free but not yet transitioning
10 independently in/out of sitting:

11 - Reaching in wider ranges and in a variety of directions with light touch support from the
12 therapist to assist with grading movement and stability. Fluid, efficient transfer from one
13 point of stability (the pelvis and/or legs) to another (the propping hand) is encouraged and
14 the child may actually move into a 4-point position with these exploratory movements.

15 - The therapist uses light touch to guide the infant with activation of the legs against the
16 support surface as their posture changes during self-initiated movement. Such activation
17 allows the infant to learn how to modify their base of support under their center of mass
18 for anticipatory postural adjustments.

19 - Pushing into all fours, rocking in all fours, and beginning to explore how changes in
20 pressure distribution create opportunities for transition into sitting or forward propulsion.

21

1 **Table 1.** Characteristics of home program and perceptual motor program
 2

Home Program	Perceptual Motor Program
1. Family focused; training occurred once weekly in the home	1. Child focused; occurred twice weekly in pediatric outpatient setting
2. Time spent primarily interacting in triad of therapist/parent/child but focused on training parent	2. Time spent primarily in dyad of therapist/child modeling for parent; focus on prompting child to problem solve
3. Setting up child within existing home routines and home equipment	3. Setting up environment that works for small subset of currently available sitting skill, and asking parent to replicate at home
4. Static focus on positioning to decrease errors and re-positioning child with prescribed supports when errors occur	4. Dynamic focus on child-initiated movement within and between positions; errors accepted. Child guided to solve problem with touch cues

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4

1 **Table 2**2 *Subject information for infants included in the intervention groups*

Subject	Diagnosis at 2 years old	Severity	GMFCS
C01	Spastic Quadriplegic CP	Severe	4
C02	Right Hemiplegic CP	Mild	1
C03	Right Hemiplegic CP	Mild	1
C04	Hypotonic, overall delays	Moderate	3
C05	Developmental Delay	Mild	1
C06	Premature (28 weeks), BPD	Mild	1
C07	Premature (28 weeks), BPD	Mild	1
C08	Spastic lower extremities	Moderate	1
C09	Hypotonic, overall delays	Severe	3
C10	Athetoid CP	Moderate	2
C12	Mixed Quadriplegic CP	Moderate	3
C13	Spastic Quadriplegic CP	Severe	4
C14	Spastic Quadriplegic CP	Severe	4
C15	Right Hemiplegic CP	Mild	1
C17	Hypotonia, overall delays	Mild	1
C18	Athetoid CP	Moderate	3
C19	Spastic Hemiplegic CP	Moderate	3
C20	Spastic Quadriplegic CP	Severe	4
C21	Hypotonic; motor delay	Moderate	2
C23	Spastic Quadriplegic CP	Severe	4
C24	Hypotonic, motor delay	Mild	1
C25	Spastic Diplegia	Moderate	2
C26	Motor delay, hearing impaired	Mild	1
C27	Premature, motor delay	Mild	1
C29	Premature, left hemiplegia	Mild	1
C30	Premature, motor delay	Mild	1
C31	Hypotonia, motor delay	Mild	1
C32	Spastic Quadriplegia	Severe	4
C34	Hypotonia, motor delay	Mild	1
C35	Hypotonia, overall delay	Severe	3

3 BPD=Brochial Pulmonary Dysplasia

4 GMFCS=Gross Motor Function Classification Scale

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1 Figure Legends

2 Figure 1. Children at sitting stages 1, and respective center of pressure tracings under each
3 picture. The first picture is a typical infant, in the middle is an infant with spastic quadriplegic
4 CP, and on the right an infant with athetoid CP. Beneath the COP tracings are examples of the
5 linear and nonlinear measures.

6 Figure 2. Flow chart of recruitment and group assignment of children in the study.

7 Figure 3. Graphs of linear COP measures comparing the mean values for typical infants (from
8 beginning sitting to independent sitting), infants in home program group, and infants in the
9 perceptual motor group from pre to post intervention. Bars indicate 95% confidence intervals.

10 Figure 4. Graphs of nonlinear COP measures comparing the mean values for typical infants
11 (from beginning sitting to independent sitting), infants in home program group, and infants in the
12 perceptual motor group from pre to post intervention. Bars indicate 95% confidence intervals.

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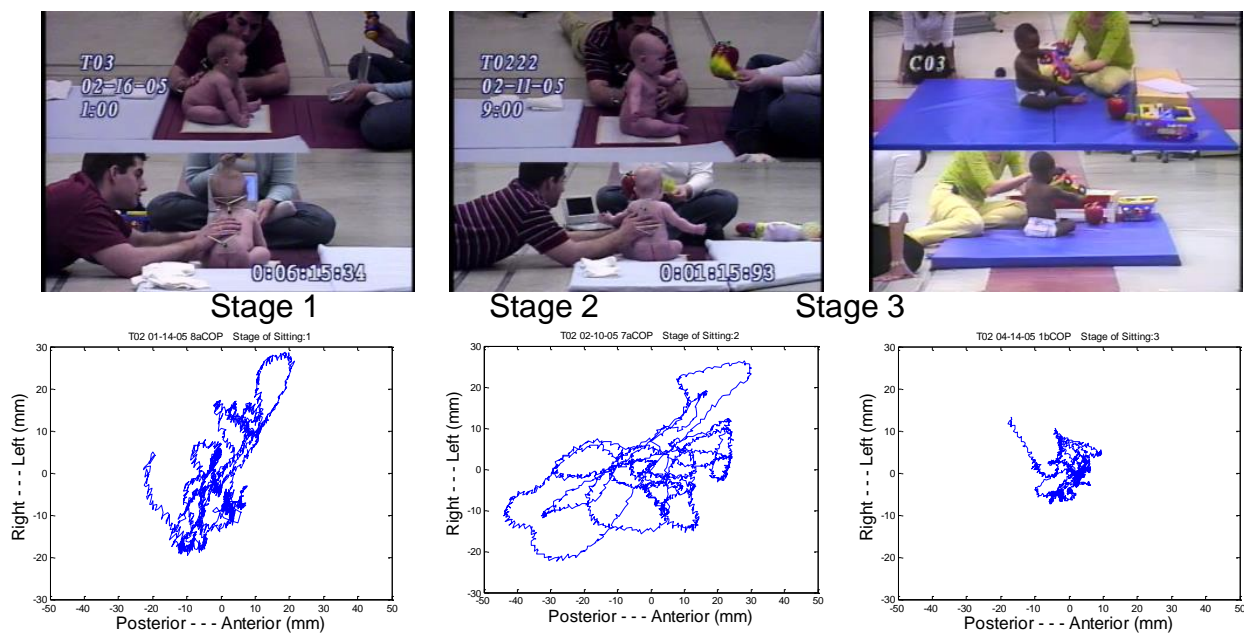
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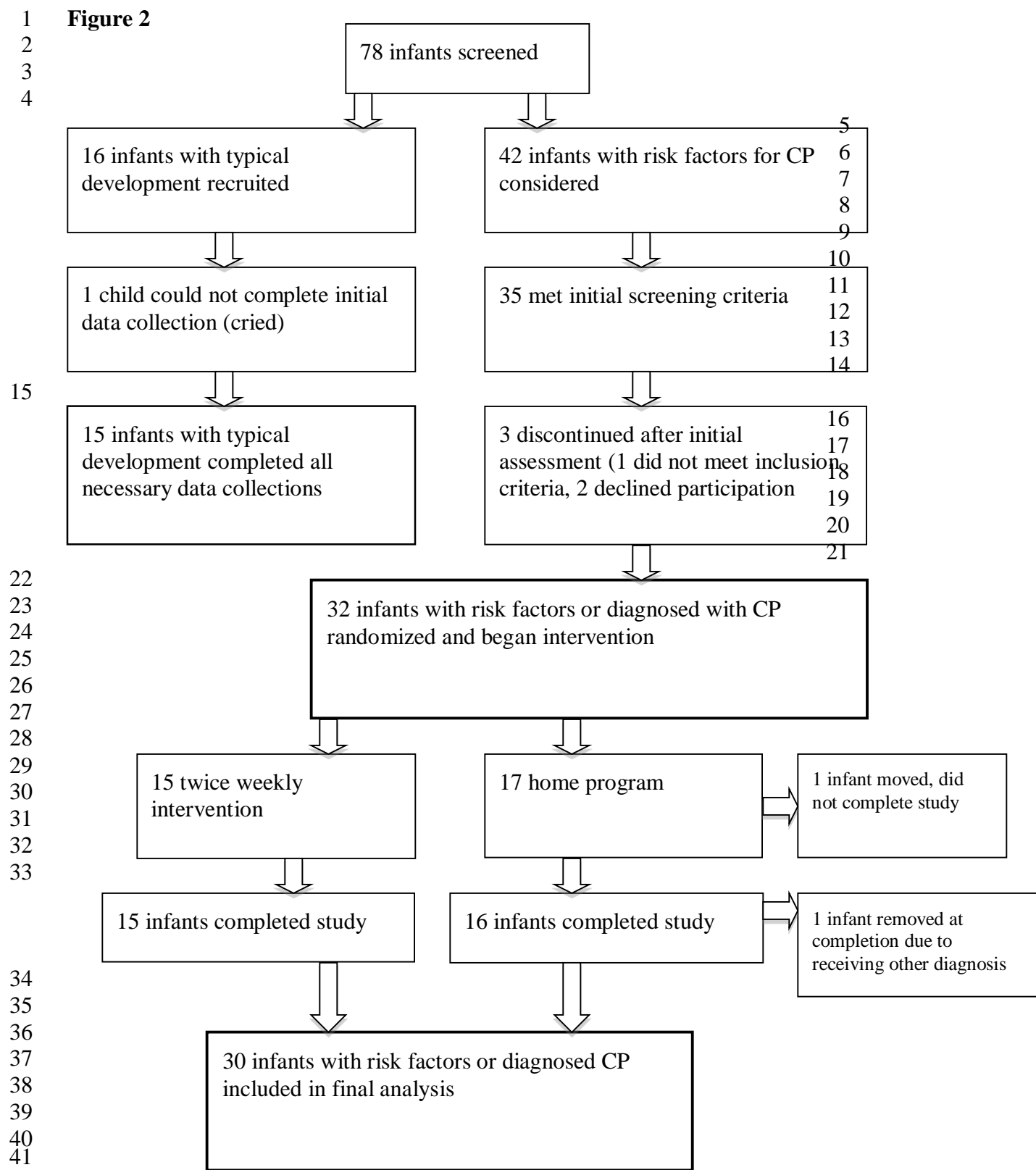
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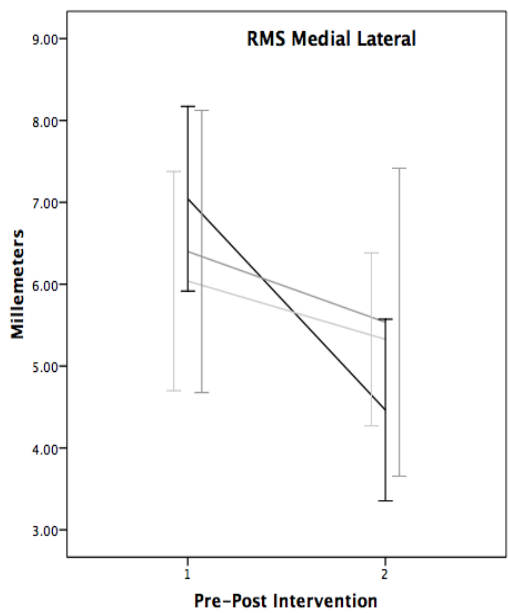
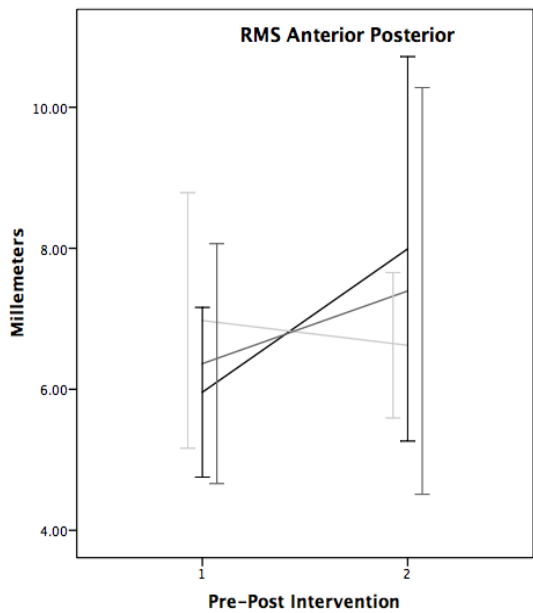
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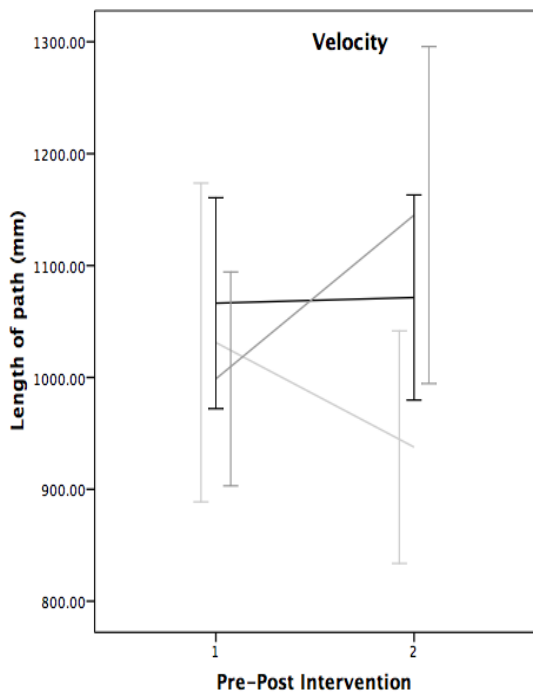
Figure 1. Need help with this figure!!!!



**Figure 3**



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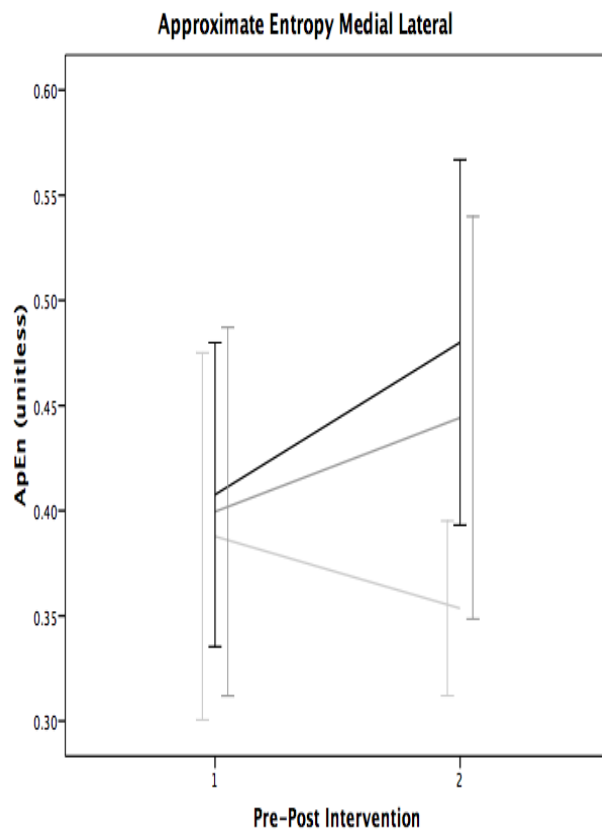
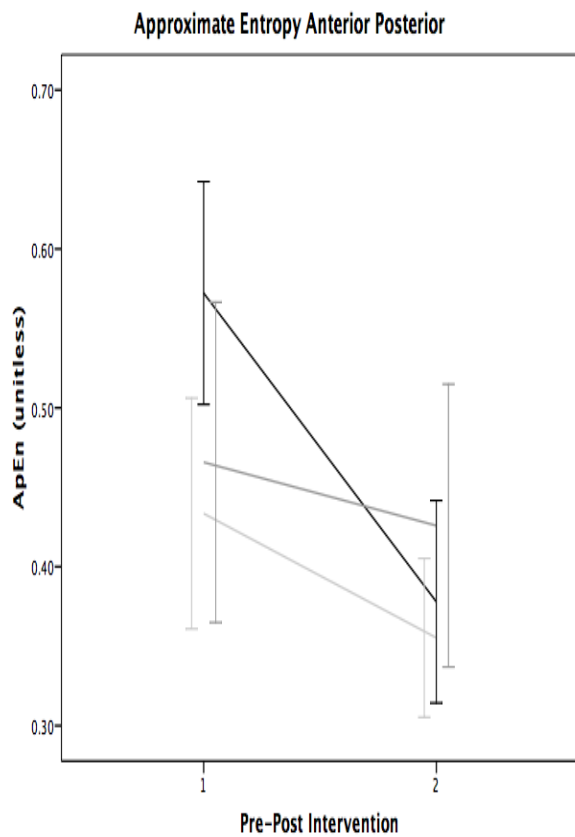


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- 3 Typical
- 4 Home Program
- 5 PerceptualMotor

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7 **Figure 4**



- 1
- 2 Typical
- 3 Home Program
- 4 PerceptualMotor
- 5
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