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Reliability of Center of Pressure Measures for Assessing the Development of Sitting Postural Control in Infants With or at Risk of Cerebral Palsy

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2 Title: Reliability of center of pressure measures for assessing the development of sitting postural
3 control in infants with or at risk of cerebral palsy.

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58 **Abstract**

59 *Objectives:* To establish the test-retest reliability of linear and nonlinear measures, including intra-
60 and inter- session reliability, when used to analyze the center of pressure (COP) time series during
61 the development of infant sitting postural control in infants with or at risk for cerebral palsy (CP).

62 *Design:* Longitudinal study

63 *Setting:* University hospital laboratory

64 *Participants:* Eighteen infants with or at risk for CP (mean age at entry in the study \pm standard
65 deviation, $13.1.7 \pm 3.6$ months).

66 *Interventions:* Not applicable

67 *Main Outcome Measures:* Infant sitting COP data was recorded for three trials at each session (two
68 sessions for each month within one week) for four consecutive months. The linear COP parameters
69 of root mean square (RMS) and range of sway for both the anterior-posterior (AP) and the medial-
70 lateral (ML) directions, and sway path, were calculated. In addition, the nonlinear parameters of
71 approximate entropy (ApEn), Lyapunov exponent (LyE), and correlation dimension (CoD) for
72 both directions were also calculated. Intra-session and inter-session reliability was computed by
73 the intraclass correlation coefficient (ICC).

74 *Results:* Regarding nonlinear measures, LyE showed high intra-session and inter-session ICC
75 values in comparison to all other parameters evaluated. Intra-session and inter-session reliability
76 increased overall in the last two months of the data collections and as sitting posture improved.

77 *Conclusions:* Our results suggested that the methodology presented is reliable way of examining
78 the development of sitting postural control in infants with or at risk for CP, and the reliability

79 results generally parallels values found in sitting postural behavior in typical infants. Therefore,
80 this methodology may be helpful in examining efficacy of therapy protocols directed at advancing
81 sitting postural control in infants with motor developmental delays.

82 Key Words: Posture; Nonlinear dynamics; Reproducibility of Results; Cerebral palsy;
83 Developmental Disabilities

84

85 Abbreviations:

86 COP – Center of pressure

87 CP – Cerebral palsy

88 RMS – Root mean square

89 AP – Anterior/posterior

90 ML – Medial/lateral

91 ApEn – Approximate entropy

92 LyE – Lyapunov exponent

93 CoD – Correlation dimension

94 ICC – Intra class correlation coefficient

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100 **Introduction**

101 Cerebral palsy (CP) is defined as a nonprogressive disorder of posture and movement, which
102 is caused by damage to the motor control centers of the developing brain, and can occur pre-,
103 peri- and post-natally¹. Children with CP have several fundamental limitations in postural control
104 of static and dynamic tasks, such as sitting, standing and walking². In particular, a delay in
105 achieving the first milestone of postural control, which is independent sitting, is one early sign
106 that a child's development is not following a normal course³. Disruptions in sitting postural
107 control significantly affect the development of a child, and can limit the ability to develop
108 eventual independent movement⁴⁻⁶.

109 A diagnosis of CP is often delayed until the child is over 2 years of age. Initial identification
110 of a developmental problem during early infancy is difficult since current clinical testing
111 methods are not highly specific or sensitive, and some early neurological symptoms may be
112 transient and resolve spontaneously⁷. On the other hand, early intervention is considered
113 essential to take advantage of the plasticity of the developing infant's nervous system for optimal
114 development⁸. Thus, there is a need to identify a quantifiable method that will assess the
115 developing mechanisms of sitting postural control in children with early postural control
116 problems, describe and identify the types of problems to target in early intervention, and help to
117 determine early intervention efficacy.

118 Postural control can be described using a simple paradigm of sitting and standing on a force
119 platform to measure the center of pressure (COP) to quantify body sway. The organization of
120 posture has been described repeatedly in the literature by the COP⁹. COP data have been used in
121 investigations of postural control during standing in healthy adults during a dual task paradigm¹⁰
122 and Parkinson's disease patients¹¹, as well as in healthy young children¹² and children with
123 cerebral palsy¹³. The reliability of this methodology has been examined thoroughly during

124 standing for both healthy and unhealthy populations. Intraclass correlation coefficient (ICC),
125 which is a statistical method of evaluating reproducibility of results, revealed that COP measures
126 in general produced poor to fair reliability (0.3 to 0.75) under static and dynamic balance tasks¹⁴⁻
127 ¹⁷.

128 Furthermore, in the past few years new concepts and methods for studying postural
129 control have been introduced. Currently, COP data have been evaluated not only with
130 conventional linear measures, which provide an “average” picture and lose the temporal aspect
131 of sitting, but also with nonlinear measures, which describe the temporal organization of the
132 postural sway pattern of sitting¹⁸. Nonlinear measures can provide new insights in the ways that
133 the nervous system controls the complexity of dynamic balance^{19, 20}. Moreover, nonlinear
134 measures unveil different features of the COP data. For example, range and the length of path
135 traced by the COP, which are traditional linear measures, evaluate the quantity of movement
136 variations of the COP during a specific task independently of their order in the distribution. On
137 the other hand, Lyapunov Exponent (LyE) and Approximate Entropy (ApEn), which are
138 nonlinear measures, they are able to capture the temporal component of the movement variation
139 in COP regarding how motor behavior emerges in time. Temporal organization or “structure”
140 can be measures by the extent to which values of COP data emerge in a predictable way¹⁹⁻²². The
141 usage of these measures has increased recently because they allow the quantification of
142 constructs such as regularity, complexity, and stability²⁰. Thus, nonlinear analyses of the COP
143 data as sitting develops can provide a window into the neurological status of the infant with CP,
144 and allow insight into the multifaceted strategies these infants utilize to organize movement and
145 posture.

146 Recently, the COP methodology has also been utilized to investigate sitting postural
147 control^{19,20,23,24}. However, the reliability of COP measures for the evaluation of infant sitting
148 postural control has been identified only for typically developing infants²⁵. Specifically,
149 Kyvelidou et al.²⁵ found that COP measures for the evaluation of infant sitting postural control is
150 a fairly reliable methodology. They examined both linear and nonlinear measures of COP during
151 the development of sitting posture in typically developing infants. They found that both types of
152 measures presented inter-session and intra-session ICC values ranging from poor to good
153 reproducibility, with the last two months of data collection presenting consistently fair to good
154 ICC values²⁵. However, the reliability of this methodology for infants with cerebral palsy is
155 currently unknown.

156 Therefore, the purpose of this study was to establish the reliability of linear and nonlinear
157 measures, including intra- and inter- session reliability, when used to analyze the COP data during
158 the development of sitting postural control in infant with or at risk of CP. Based on the previous
159 reliability data on typical development of infant sitting²⁵, we hypothesized that the nonlinear tools
160 will be more reliable in assessing development of infant sitting postural control and that reliability
161 measures will increase with development. The identification of the reliability of linear and
162 nonlinear tools from COP data is necessary in order to validate the reliability of the procedure, so
163 that it can then used in the future to assess efficacy of treatment and increments of change over
164 time in children with or at risk for CP. Once this procedure is established, comparisons of the
165 sitting behavior of infants with typical development and infants with cerebral palsy can be made,
166 and be certain that our results are not measurement artifacts but true differences.

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168 **Methods**

169 *Participants*

170 For the present study we recruited 30 infants with or at risk for CP (mean age at entry in the
171 study \pm standard deviation, $13.1.7 \pm 3.6$ months; gender, 10 males 8 females). The infants were
172 referred from local early intervention programs. The infants were followed from the age where
173 they could exhibit at least 10 sec of independent sitting and for four months after that time. Infants
174 were recruited from employee announcements at the campus of the university. The parents of the
175 infants provided informed consent that was approved by the university human research ethics
176 committee before data collection initiation. The inclusion criteria for entry into the study for the
177 infants with or at risk for CP as well as the exclusion criteria are presented in Table 1. Furthermore,
178 the Gross Motor Function Classification Scale (GMFCS) level as well as the diagnosis that the
179 infants with or at risk for CP received after two years of age is presented in Table 2.

180 -----Place Tables 1 and 2 around here-----

181 *Experimental design*

182 Each infant participated in nine sessions. The first session and was used to perform the Peabody
183 Gross Motor Scale²⁶ which is a standardized clinical test³⁷. In addition, the child was tested to
184 determine adequate prop sitting skills to begin the study, and to familiarize the family with the
185 procedures used in the study. The other eight sessions were dispersed over a time period of four
186 months. To assure that inter-session measures captured the infants at the same stage of sitting
187 development, the infants were tested twice in one week at each of the four months of the study.
188 Three trials per session were used to determine intra-session reliability (Figure 1). The repeat
189 testing within one week of each month's testing was utilized for the estimation of the inter-session
190 reliability (Figure 1).

191 -----Place Figure 1 around here-----

192 *Protocol*

193 For all sessions, the infants and the parents were given time to get used to the laboratory
194 environment. Subsequently, they sat on the force platform with their parent in front of them for
195 the data collection. The sessions lasted approximately 30 minutes to one hour. After the force
196 platform was covered with an absorbent pad, which was securely adhered with tape, infants were
197 positioned by their parent on the top of the force platform. The infant was in the sitting position in
198 the middle of the plate when calm (Figure 2). For safety reasons, the investigator and the parent
199 remained at one side and in front of the infant respectively during all data collection. When the
200 child was ready, and was not held by the examiner, COP data were collected continuously while
201 the child attempted to maintain the sitting position control without falling. Once we had collected
202 three trials that were acceptable for our criteria (see below), or until the infants were indicating
203 that they were done, data collections were completed.

204 -----Place Figure 2 around here-----

205 From the videotape record we selected three acceptable trials (8.3 seconds each) based on the
206 following criteria: a) infant did not move the arms (not reaching, holding an object, or flapping
207 their arms), b) infant did not vocalize or cry, c) infant was not in the process of falling, d) trunk
208 was not inclined more than 45 degrees to either side, e) not being touched, f) the arm position
209 (propping or not propping) of the infants was noted during the entire trial and only trials that have
210 the infant using a consistent base of support was used.

211 For the collection of the COP data, infants sat on an AMTI force platform (Advanced
212 Mechanical Technology Inc., Model OR6-7-1000, Watertown, MA), interfaced to a computer

213 system running Vicon data acquisition software (Lake Forest, CA). The force platform
214 simultaneously measures three force components F_x , F_y , and F_z and three moment components
215 M_x , M_y , and M_z . The forces and moments are measured by strain gauges attached to load cells at
216 the four corners of the platform. The force plate has a 4450 N (1000 lb) capacity for F_z and a 2225
217 N (500 lb) capacity for F_x and F_y . The F_z channel has a natural frequency of 480 Hz and F_x and
218 F_y have a natural frequency of 300 Hz. COP data in both the anterior-posterior (AP) and the
219 medial-lateral (ML) directions were acquired through the Vicon software at 240 Hz, in order to be
220 above a factor of ten higher than the highest frequency contained in the signal. No filtering was
221 performed on the data because such a procedure can affect the nonlinear results. Furthermore,
222 video of each trial was collected using two Panasonic recorders (Model 5100 HS) interfaced with
223 a Panasonic Digital AV Mixer (Model WJ-MX30). The cameras were positioned to record a
224 sagittal and a frontal view of the subject. Segments of acceptable (described below) data were
225 analyzed using custom MatLab software (MathWorks, Nantick, MA). The COP data selected
226 allowed for the examination of 2000 data points (8.3 sec times 240 Hz) for each COP direction for
227 each trial. This number is considered adequate for nonlinear analysis^{27,28}.

228 *Data analysis*

229 Customized MatLab software was utilized to calculate the linear measures from the COP data
230 from the selected trials, using the methodology of Prieto et al.²⁹ and included root-mean-square
231 (RMS), maximum minus minimum (range) and length of the path traced by the COP (sway path)
232 for the AP and the ML directions. These parameters are all independent of the effect of
233 biomechanical factors such as weight³⁰, which may changed rapidly during infancy. These linear
234 measures characterized the amount of variability present in the data¹⁸.

235 Furthermore, three nonlinear measures of variability were calculated from the selected trials:

236 the approximate entropy (ApEn), the largest Lyapunov exponent (LyE), and the correlation
237 dimension (CoD) for both the AP and the ML directions. Calculation of the nonlinear measures of
238 the variability present in postural sway was performed as presented by Harbourne and Stergiou¹⁹.
239 Chaos Data Analyzer Professional software³¹ was used to calculate the Lyapunov Exponent and
240 the Correlation Dimension. In order to precisely compute these measures, the embedded dimension
241 must be chosen with extreme care. We estimated the embedded dimension by performing the
242 Global False Nearest Neighbor (GFNN) analysis³², with the Tools for Dynamics software. The
243 embedded dimension is a depiction of the number of dimensions needed to unfold the attractor of
244 a dynamical system in state space³³. For the analysis of all COP traces, the same embedding
245 dimension (6) was used even if they had a dimension lower than six. Lastly, for the calculation of
246 the ApEn custom written MATLAB code was used based on the Pincus³⁴ algorithms.

247 *Statistical Analysis*

248 Intra-session and inter-session reliability was quantified by the intraclass correlation
249 coefficient³⁵ (ICC). Specifically, a one-way ANOVA model with a random subject effect was
250 used to estimate the intra-session reliability based on data from the first visit of the month for each
251 child (ICC[1,1] in the notation of Shrout and Fleiss³⁵). To estimate the inter-session reliability, the
252 averages of the three measurements during each session are analyzed using a one-way ANOVA
253 model with a random subject effect similar to the model for intra-session reliability. In the results
254 section ICC findings are reported based on Rosner³⁶. Specifically, an ICC of less than 0.4 indicates
255 poor reproducibility while an ICC between 0.4 and 0.75 indicates fair to good reproducibility.
256 Lastly, an ICC over 0.75 indicates excellent reproducibility.

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279 **Results**

280 *Linear Parameters*

281 Inter-session ICCs for the linear parameters were between 0.25 and 0.78 (Table 3). The RMS
282 in the AP direction presented the highest ICC value. All linear parameters presented ICC values

283 ranging from poor to fair to excellent reproducibility. The highest mean ICC value across months
284 was observed for RMS in AP direction. However, the last month of data collections presented
285 consistently fair to good ICCs with the exception of the sway path parameter (Figure 3). RMS and
286 mean range in AP direction showed consistently increasing values in ICCs across months of sitting
287 postural development. However, sway path presented consistently decreasing values in ICCs
288 across months of sitting postural development.

289 -----Place Table 3 around here-----

290 -----Place Figure 3 around here-----

291 Intra-session ICCs for linear parameters were between 0.19 and 0.75 (Table 4). RMS in the
292 AP direction presented the highest ICC value, which suggests excellent reproducibility. All linear
293 parameters presented ICC values ranging from poor to fair to excellent reproducibility. The highest
294 mean ICC value across months was observed for RMS in AP direction. However, the last three
295 data collections, which are included in the third and fourth month sessions, presented consistently
296 fair to good ICCs (Table 4, Figure 4). We can observe that RMS, range and sway path presented
297 consistently increasing values in ICC's across data collections. The above findings are in
298 agreement with the inter-session reliability with the exception of sway path.

299 -----Place Table 4 around here-----

300 -----Place Figure 4 around here-----

301 *Nonlinear Parameters*

302 Inter-session ICCs for nonlinear parameters were between 0.16 and 0.78 (Table 5). LyE in the
303 AP direction presented the highest ICC value, which suggests excellent reproducibility. All

304 nonlinear parameters presented ICC values ranging from poor to fair to excellent reproducibility.
305 The highest mean ICC value across months was observed for LyE in AP direction. However, the
306 last two months of data collections presented alternating fair to good reproducibility (Table 4,
307 Figure 5).

308 -----Place Table 5 around here-----

309 -----Place Figure 5 around here-----

310 Intra-session ICCs for nonlinear parameters were between 0.05 and 0.70 (Table 6). Overall,
311 nonlinear parameters presented ICC values ranging from poor to fair to good reproducibility. The
312 highest mean ICC value across months was observed by ApEn in the AP direction. Furthermore,
313 with the exception of CoD all other nonlinear parameters present fair to good reproducibility across
314 data collections (Figure 6).

315 -----Place Table 6 around here-----

316 -----Place Figure 6 around here-----

317

318 **Discussion**

319 The goal of the present study was to establish the reliability of linear and nonlinear measures,
320 including intra- and inter- session reliability, when utilized to examine the COP data during the
321 development of sitting postural control in infants with or at risk for CP. Based on our previous
322 study²⁰, we hypothesized that the linear and nonlinear measures will present different reliability
323 values because they are quantifying different features of the COP data.

324 Reliability assessment of all linear parameters during sitting posture in infants with or at risk
325 for CP presented inter- and intra- session ICC values ranging from poor, to good, to excellent
326 reproducibility. Similarly to our previous study in the development of sitting postural control in
327 typically developing infants²⁰, the last two months of data collections presented consistently fair
328 to good ICCs. In contrast the sway path parameter presented decreased values of inter-session
329 reliability across development, while the intra- session ICCs were increased across development.
330 Similarly, reliability assessment of all nonlinear parameters during sitting posture in infants with
331 or at risk for CP presented inter- and intra- session ICC values ranging from poor to good
332 reproducibility. However, the last two months of data collections did not present increased ICC
333 values but were consistently fair to good across development with the exception of CoD in both
334 anterior-posterior and medial-lateral directions. Overall, RMS and LyE presented the highest ICC
335 values compared to all other parameters examined, while the rest of the linear and nonlinear
336 parameters presented acceptable values with the exception of CoD which showed low
337 reproducibility.

338 Reliability of linear parameters during sitting posture in infants with or at risk for CP paralleled
339 the results of a reliability study of typical infants during the development of sitting²⁵. Specifically,

340 RMS in both directions showed fair to good ICC inter- (0.59 in AP and 0.55 in ML) and intra-
341 session (0.57 in AP and 0.54 in ML) values in infants with or at risk for CP while typical infants
342 showed also fair to good ICC values inter- (0.44 in AP and 0.41 in ML) and intra- session (0.51 in
343 AP and 0.49 in ML)²⁵. Similar results were observed in range and sway path in the infants with or
344 at risk for CP and typical infants. Furthermore, standing posture studies in healthy adults¹⁴ and
345 elderly individuals^{15, 37} showed similar reliability findings with sitting posture in infants with or at
346 risk for CP. Particularly, the nonlinear measure RMS in AP and ML directions presented fair to
347 good intra-session reproducibility (0.58) during a standing task of healthy elderly individuals³⁷.
348 Moreover, intra-session ICC values for the range of COP during standing in healthy adults were
349 fair to good for both the AP and ML directions¹⁶. However, inter-session reproducibility of linear
350 measure during a standing task of healthy adults presented fair to poor reliability¹⁴. In addition,
351 children without disabilities exhibited similar ICC values of linear parameters during standing
352 balance tasks to those infants with or at risk for CP during the development of sitting¹⁶. Intra-
353 session reliability of the Smart Balance Master System, which examines standing posture under
354 different sensory conditions, presented ICC values with a wide range between 0 and 0.79¹⁶. Lastly,
355 inter-session reliability of Smart Balance Master System ranged between 0.08 to 0.68¹⁶. Therefore,
356 our present findings are parallel to those reported in the literature from standing posture studies.

357 With regards to the reproducibility of the nonlinear measures during sitting posture in infants
358 with or at risk for CP presented here, we observed fairly similar results as the reliability data from
359 sitting postural control of typically developing infants²⁵. In typical infants, ApEn presented the
360 highest ICC values, while in infants with CP or at risk for CP, LyE presented the highest ICC
361 values. CoD presented poor to moderate ICC values in both groups of infants. In a recent study, a
362 different nonlinear measure, fractal dimension, presented most of the times higher intra-session

363 reliability than linear measures from COP data during standing in young healthy people, and
364 overall fair to good to excellent reliability values³⁸. Analogous to the findings of the present study,
365 ApEn, which is a measure of complexity in the time series, demonstrated fair to good intra-session
366 (>0.50) reproducibility of COP during development of sitting in infants with or at risk for CP.

367 It is important to note that intra- and inter- session reliability of sitting posture in infants with
368 or at risk for CP improved on the last two months of data collections, especially with the linear
369 measures. Similarly, younger children showed lower ICC values than older children when their
370 COP sway index was investigated during a standing task.

371 It should be mentioned that inter-subject variability may have influenced our results. Possibly,
372 when infants with CP or at risk for CP entered the study, their sitting behavior was not at the same
373 level. For example, some infants may have entered the study while being able to prop sit, while
374 other infants may did not use the help of their hands at the onset of the study. Presumably, this
375 may be one reason why we observed differences in the sitting behavior in the first two months of
376 sitting development. The usage of stages of sitting instead of months could be used as an alternative
377 to describe sitting postural development. Moreover, the rapid physiological, neuromuscular and
378 psychological changes that infants undergo early on may be the reason why inter-session reliability
379 did not show consistently excellent reproducibility. Therefore, multiple repeated testing distributed
380 across the months of sitting development may allow us to describe more accurately sitting postural
381 control in both typically developing infants and infants with or at risk of CP, since infants are
382 going through a period of rapid growth and change along many interwoven line

383 In conclusion, we determined that linear and nonlinear description of COP data is a reliable
384 method for assessing the development of sitting postural control in infants with or at risk of CP.

385 Our results from our linear and nonlinear parameters were similar to those reported in the
386 literature from sitting and standing posture studies. Regarding the linear tools, RMS presented
387 the highest intra- and inter- session ICC values among all other parameters. Regarding the
388 nonlinear tools, LyE presented the highest intra- and inter- session ICC values among all other
389 parameters. In contrast, CoD presented the lowest intra- and inter- session ICC values in
390 comparison to all other parameters examined. Therefore, the presented methodology is not only a
391 reliable tool for the evaluation of sitting postural control using linear and nonlinear tools of COP
392 data, but also a tool to quantifying small amounts of change in the variability patterns of COP
393 data during the development of sitting postural control in infants with or at risk for CP. The
394 present study is extremely important because we can use the presented methodology to assess
395 efficacy of treatment and increments of change over time in children with or at risk for CP. Once
396 this procedure is established we can compare infants with typical development and infants with
397 cerebral palsy and be certain that our results are not measurement artifacts but true differences..
398 The next step is to determine the validity of these measures in explaining differences in these
399 parameters between infants with typical development and infants with neuromotor disorders.
400 Changes in developing postural control due to learning, maturation and intervention for children
401 with neuromotor disorders can then be examined using measures that better quantify small
402 increments of improving or decreasing motor control. Furthermore, in our future research we
403 plan to explore how COP measures relate with other functional tasks during infant sitting.

404 *Clinical Implications*

405 Infant assessment is notoriously unreliable, with the results being that most testing requires
406 either a scale with many items to obtain a reliable overall picture of the function or behavior of
407 interest, or examination over time to determine problems needing intervention. Because of the

408 variability in the reliability of the many measures described in this paper, it is likely that a scale
409 using a composite of the variables will better represent the postural behavior of the child reliably.

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543 **Legends**

544 Table 1. Inclusion and exclusion criteria of the study

545 Table 2. Gross Motor Function Classification Scale scores for all infants.

546 Table 3. Inter-session (within a week per month) reliability, as expressed with the Intra-class
547 correlation coefficient (ICC), for all linear parameters.

548 Table 4. Intra-session (within each session) reliability, as expressed with the Intra-class
549 correlation coefficient (ICC), for all linear parameters.

550 Table 5. Inter-session (within a week per month) reliability, as expressed with the Intra-class
551 correlation coefficient (ICC), for all nonlinear parameters

552 Table 6. Intra-session (within each session) reliability, as expressed with the Intra-class
553 correlation coefficient (ICC), for all nonlinear parameters.

554 Figure 1. Schematic representation of inter and intra-session reliability. This procedure was
555 repeated for each month of data collections.
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557 Figure 2. Position of infant during data collection.

558 Figure 3. Inter-session reliability (ICC) for linear parameters of COP across months. Most linear
559 parameters ICCs are averaging around 0.5 and there is an increasing trend as the infant develops.
560 This is not true for Mean Sway Path where ICC are presenting a decreasing trend across
561 development.

562 Figure 4. Intra-session reliability (ICC) for linear parameters of COP across data collection
563 sessions. All linear parameters ICCs are averaging around 0.5 and there is an increasing trend as
564 the infant develops

565 Figure 5. Inter-session reliability (ICC) for nonlinear parameters of COP across months. All
566 nonlinear parameters ICCs are averaging lower than 0.5 except of LyE in both directions.

567 Figure 6. Intra-session reliability (ICC) for nonlinear parameters of COP across data collection
568 sessions. All nonlinear parameters ICCs are averaging around 0.5 except of CoD in both
569 directions.

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585 Table 1.

Inclusion Criteria

Age from five months to two years

Score less than 1.5 SD below the mean for their corrected age on the Peabody Gross Motor Scales

Sitting skills

- a) Head control such that when trunk is supported at the mid-trunk, head is maintained for over one minute without bobbing
- b) Infant can track an object across midline without losing head control
- c) Infant may prop hands on floor or legs to lean on arms, but should not be able to reach and maintain balance in the prop sit position
- d) When supported in sitting can reach for toy
- e) Can prop on elbows in the prone position for at least 30 seconds

Exclusion Criteria

Age over two years

Score greater than 1.5 SD below the mean for their corrected age on the Peabody Gross Motor Scale

Diagnosed visual impairment

Diagnosed hip dislocation or subluxation greater than 50%

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587 Table 2.

Subject	Diagnosis at 2 years old	Severity	GMFCS
C01	Hypotonic, overall delays	Moderate	3
C02	Developmental Delay	Mild*	
C03	Premature (28 weeks), BPD	Mild*	
C04	Athetoid CP	Moderate	2
C05	Mixed Quadriplegic CP	Moderate	3
C06	Spastic Quadriplegic CP	Severe	4
C07	Right Hemiplegic CP	Mild	1
C08	Noonan's Syndrome	Mild*	
C09	Spastic Hemiplegic CP	Moderate	3
C10	Spastic Quadriplegic CP	Severe	4
C11	Hypotonic; motor delay	Moderate	2
C12	Hypotonic, motor delay	Mild	1
C13	Spastic Diplegia	Moderate	2
C14	Motor delay, hearing impaired	Mild	1
C15	Premature, motor delay	Mild*	
C16	Premature, left hemiplegia	Mild	1
C17	Premature, motor delay	Mild*	
C18	Hypotonia, motor delay	Mild	1

*Diagnosis of CP excluded; children considered to have developmental delay and not CP

BPD=Brochial Pulmonary Dysplasia

GMFCS=Gross Motor Function Classification Scale

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590 Table 3.

Variables	ICC's				Mean
	1 st Month	2 nd Month	3 rd Month	4 th Month	
RMS AP	0.44	0.44	0.72	0.78	0.59
RMS ML	0.58	0.70	0.25	0.67	0.55
Range AP	0.40	0.49	0.65	0.69	0.56
Range ML	0.61	0.64	0.35	0.68	0.57
Sway Path	0.46	0.57	0.46	0.25	0.43

Abbreviations: RMS = root mean square, AP = anterior-posterior, ML = medial-lateral

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593 Table 4.

Variables	ICC's								Mean
	1 st Month		2 nd Month		3 rd Month		4 th Month		
	1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd	
Sessions									
RMS AP	0.51	0.42	0.68	0.45	0.59	0.53	0.75	0.61	0.57
RMS ML	0.52	0.20	0.67	0.55	0.71	0.50	0.62	0.57	0.54
Range AP	0.53	0.20	0.64	0.47	0.62	0.32	0.70	0.58	0.51
Range ML	0.50	0.19	0.65	0.52	0.71	0.35	0.66	0.64	0.53
Sway Path	0.44	0.52	0.37	0.65	0.40	0.57	0.57	0.48	0.50

Abbreviations: RMS = root mean square, AP = anterior-posterior, ML = medial-lateral

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596 Table 5.

Variables	ICC's				Mean
	1 st Month	2 nd Month	3 rd Month	4 th Month	
ApEn AP	0.57	0.21	0.52	0.44	0.43
ApEn ML	0.56	0.53	0.42	0.28	0.45
LyE AP	0.62	0.60	0.67	0.78	0.67
LyE ML	0.61	0.72	0.31	0.72	0.59
CoD AP	0.69	0.15	0.43	0.29	0.39
CoD ML	0.39	0.43	0.31	0.34	0.37

Abbreviations: RMS = root mean square, AP = anterior-posterior, ML = medial-lateral

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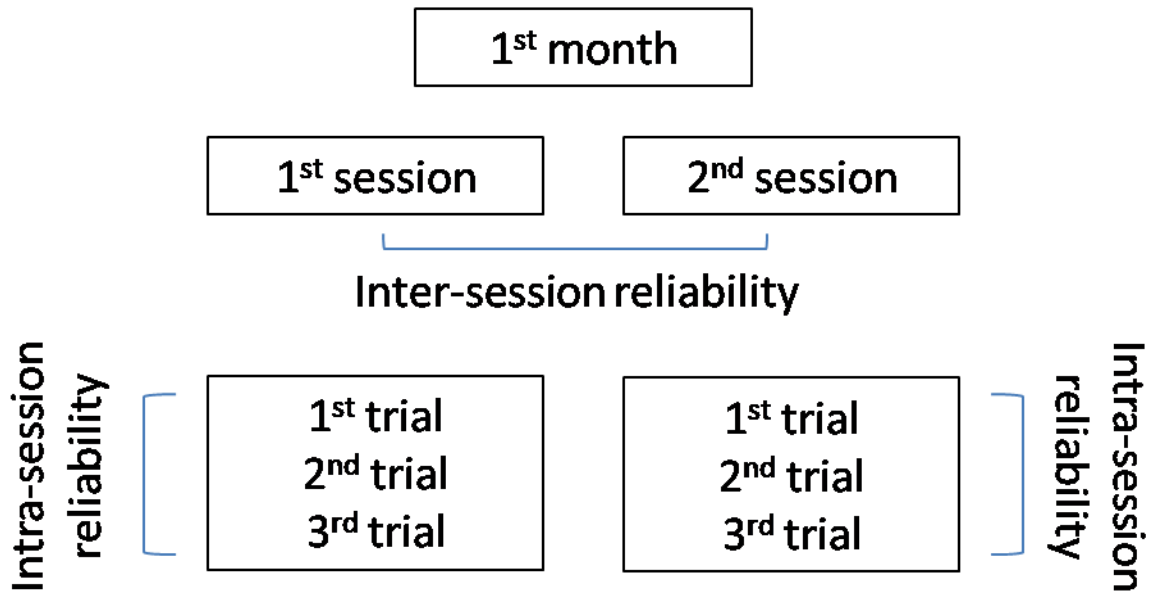
600 Table 6.

Variables	ICC's								Mean
	1 st Month		2 nd Month		3 rd Month		4 th Month		
Sessions	1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd	
ApEn AP	0.70	0.63	0.60	0.54	0.63	0.35	0.52	0.65	0.58
ApEn ML	0.54	0.49	0.55	0.57	0.57	0.27	0.59	0.57	0.52
LyE AP	0.64	0.38	0.53	0.29	0.49	0.63	0.58	0.62	0.52
LyE ML	0.48	0.45	0.57	0.57	0.13	0.54	0.49	0.56	0.47
CoD AP	0.47	0.24	0.09	0.42	0.17	0.44	0.42	0.13	0.30
CoD ML	0.42	0.05	0.31	0.44	0.44	0.46	0.43	0.22	0.35

Abbreviations: RMS = root mean square, AP = anterior-posterior, ML = medial-lateral

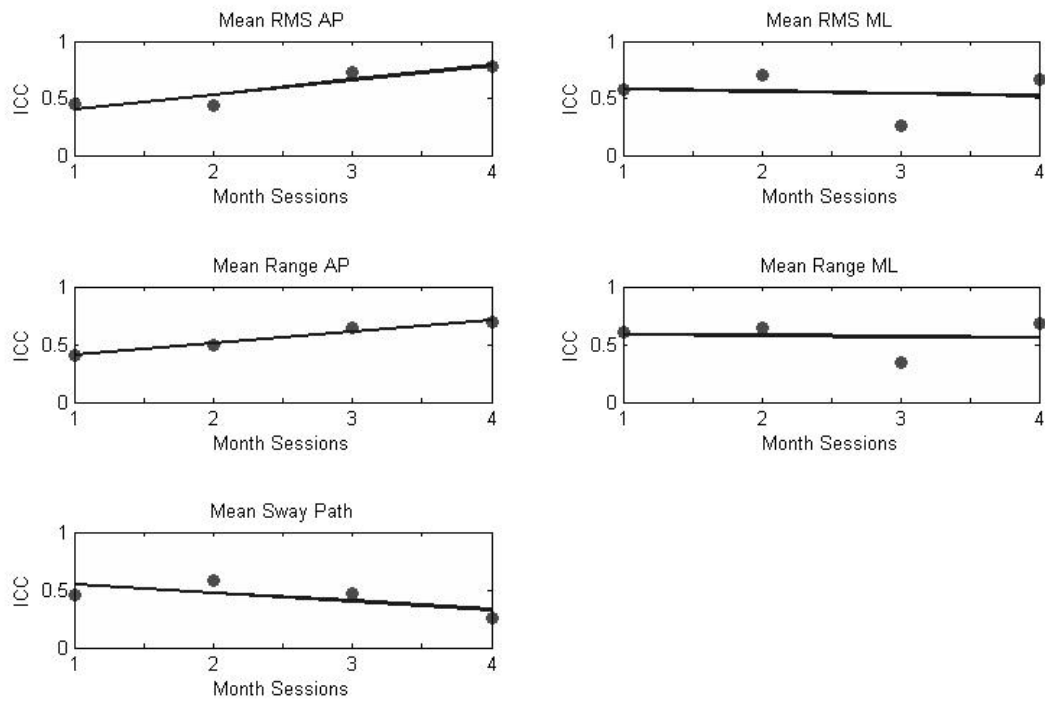
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619 Figure 1.



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636 Figure 3.



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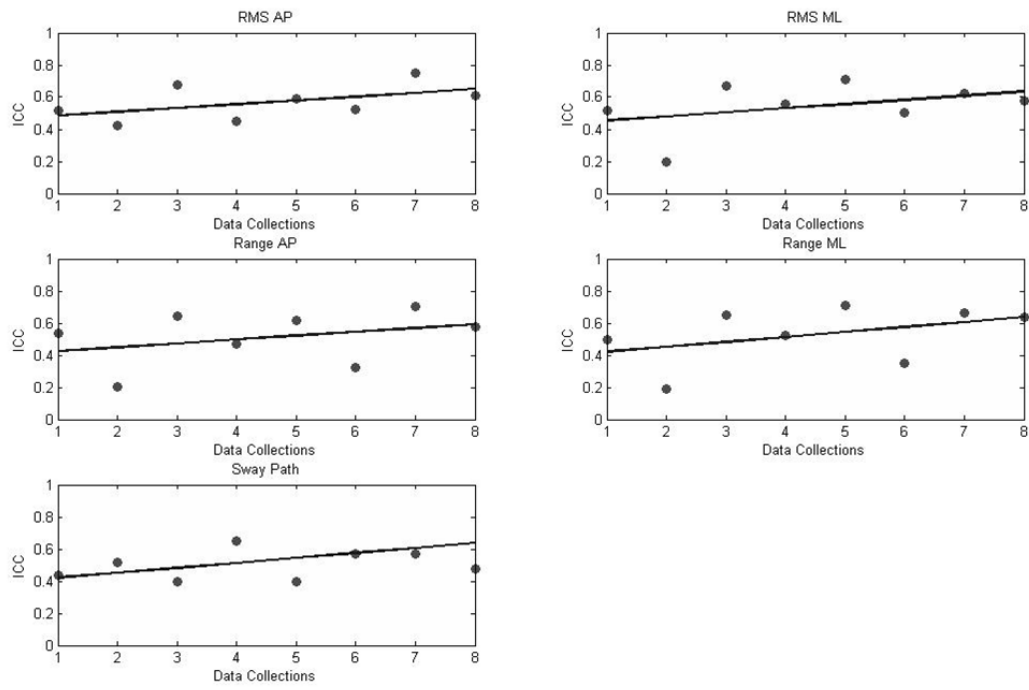
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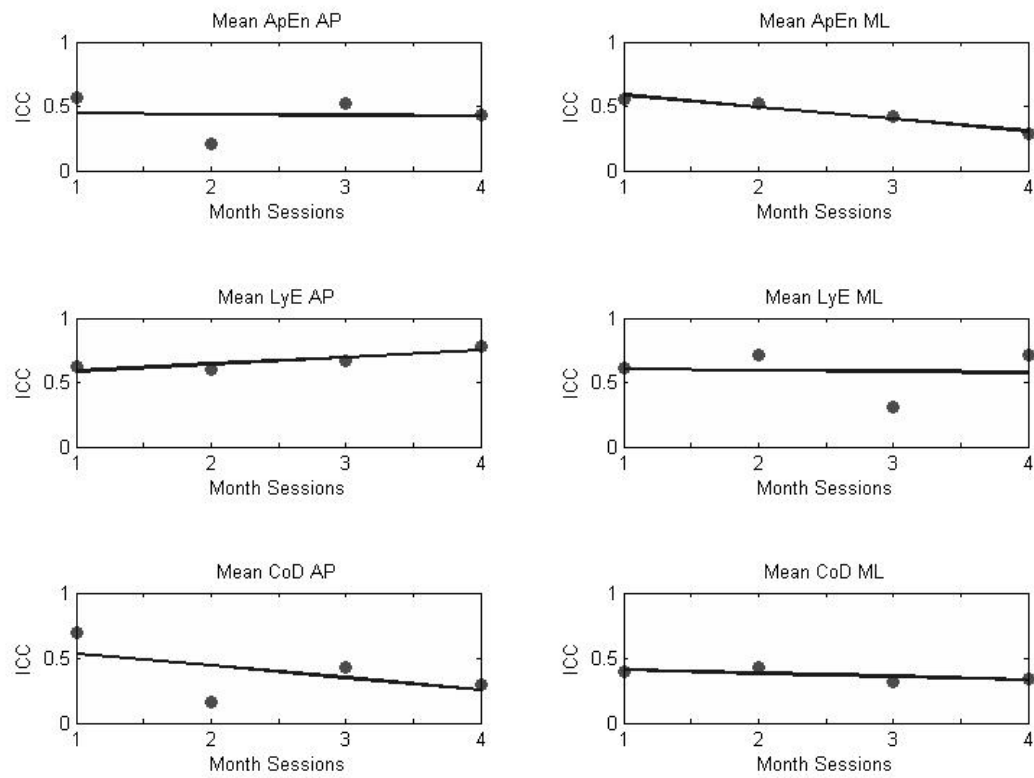
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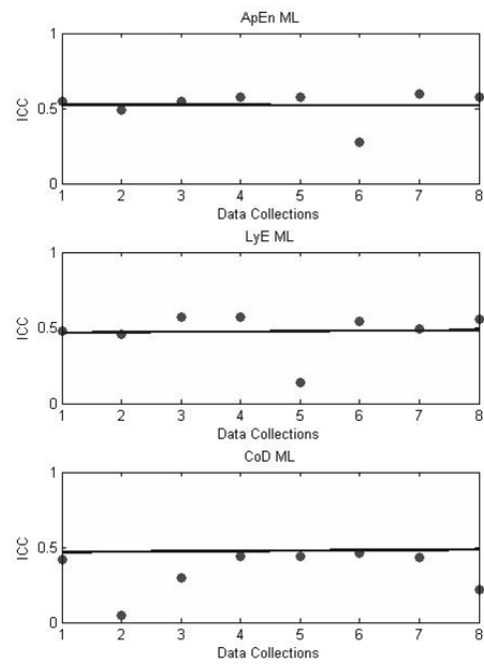
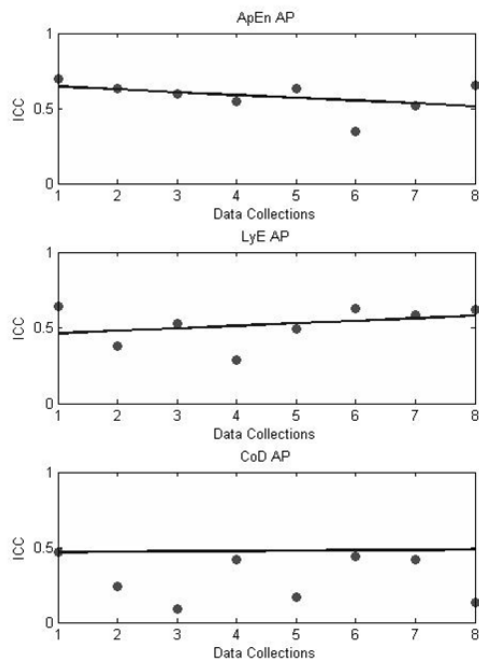
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669 Figure 6.



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