9-2013

Center of pressure and the projection of the time-course of sitting skill acquisition

Joshua L. Haworth
University of Nebraska at Omaha

Regina T. Harbourne
University of Nebraska Medical Center

Srikant Vallabhajosula
University of Nebraska at Omaha

Nicholas Stergiou
University of Nebraska at Omaha, nstergiou@unomaha.edu

ORIGINAL ARTICLE

Center of pressure and the projection of the time-course of sitting skill acquisition

Authors, w/affiliation:

Haworth, Joshua L[1,3], Harbourne, Regina T[2], Vallabhajosula, Srikant[1], Stergiou, Nicholas[1,3]

[1]Nebraska Biomechanics Core Facility, University of Nebraska at Omaha, Omaha, Nebraska, USA

[2]Munroe Meyer Institute, University of Nebraska Medical Center, Omaha, Nebraska, USA

[3]College of Public Health, University of Nebraska Medical Center, Omaha, Nebraska, USA

Acknowledgements:

This work was supported by National Institutes of Health (grant no. K25HD047194), National Institute of Disability and Rehabilitation Research (grant numbers H133G040118, H133G080023), the Nebraska Research Initiative, a Pre-doctoral Fellowship from University of Nebraska Medical Center, NASA Nebraska Space Grant Fellowship, and a Dennis Weatherstone Pre-doctoral Fellowship from Autism Speaks (grant number 7070).

Corresponding Author

Correspondence to

Nicholas Stergiou, PhD

Nebraska Biomechanics Core Facility

School of Health, Physical Education and Recreation

University of Nebraska at Omaha

6001 Dodge Street, Omaha, NE 68182.

Phone: 402.554.3247, Fax: 402.554.3693

Email: nstergiou@unomaha.edu

Word Count:
Total (Abstract, Intro - Conclusion) = 2997/3000 (limit) Abstract: 181/250 (limit)

Abstract

A normal time-course for the acquisition of sitting is essential. A delay in sitting may affect other developmental milestones, resulting in deficiencies in overall skill. Therefore, our aim was to identify variables whose measures at the very beginning of sitting would allow for the projection of the evolution of the sitting skill. Center of pressure data were collected from the postural sway of twenty-six typically developing infants while sitting on a force platform with a beginning ability to sit upright. Spatial, temporal and frequency variables of postural sway were obtained from both the medial/lateral and anterior/posterior directions of sway. Discriminant function analysis was conducted to identify potential predictors of the duration between onset and fully independent sitting. Gender (p=0.025), Median Frequency (p=0.006), and Correlation Dimension (p=0.002) were identified to be predictive of grouping with 73.1% correct classification of the participating infants into short, mid, and long delay groups. In conclusion, measures taken at the earliest stage of sitting may allow the projection of the time-course to achieve independent sitting for typical infants. This approach may be useful for monitoring typical development.

Keywords: postural control, nonlinear analysis, motor development, infants, posture

1. Introduction

Sitting is a critical motor skill for infants, setting the stage for development of nearly all other subsequent motor actions; e.g. reaching, visual searching of the environment, standing, and walking[1-3]. These skills inevitably contribute to development of perceptual, cognitive, social and emotional processes[4,5]. Proper development of these skills may play decisive roles in determining the long range success of individuals in social, academic, and professional settings. Hence it is critical to monitor that a normal time-course in the acquisition of sitting occurs, such that prompt and appropriate interventions may be offered to promote healthy development and reduce secondary developmental delays[6,7].

Methods for monitoring development are pervasive within pediatric clinical settings, where several scales for evaluation of motor development are used; including the Peabody, Alberta motor scale, and Gross Motor Function Measure[8-10]. Although each of these identifies large discrepancies in onset and mastery of functional motor skills, they lack ability to measure small increments of postural performance[11]. Typical development is quite variable, manifesting different trajectories toward skill acquisition. Alternative options for monitoring progression of development should include attention to the vast individual differences found among children, offering heightened discrimination among this group of typical developers.

Posturography is suggested for evaluating center of pressure (COP) at the base of support, measured via force platform, providing finer measures of postural performance; posing this methodology as a more effective diagnostic tool of postural control[12]. Posturography is considered an adequate evaluator of the changes in postural performance resulting from development, as well as those that occur through the effects of therapies[12-14]. Many metrics

are developed for evaluating COP motion during sitting, and have been shown reliable[12] and useful for indication of potential active control mechanisms being utilized during typical[15] and atypical[16,17] posture. These measures consider many aspects of the motion of the COP including amount (sway path and range), variance (root mean square), and frequency characteristics (median frequency and frequency dispersion)[18-20], with nonlinear analyses temporal structural components such as complexity and regularity (via approximate entropy, correlation dimension, and lyapunov exponent)[15,21].

However it is unknown whether any of these measures forecast the time-course of sitting acquisition, making it possible to more directly identify children taking longer to reach sitting independence. Objective diagnostic metrics of this type may add to information gained from standardized clinical tests, potentially leading targeted and effective skill development activities to children most in need.

Therefore, our investigation sought to determine a predictive model of postural development. Discriminant function analysis was applied to a set of measures including infant demographics (i.e. age, mass, gender) and measures of COP taken at onset of sitting acquisition. We hypothesized that this approach would identify specific individual characteristics that effectively identify the time-course between sitting onset and full, independent sitting.

2. Methods

2.1 Participants

Twenty-six typically developing infants (age 150±16.6 days) were recruited, based on their expression of early sitting skills, prop sitting; labeled Stage 1 sitting[11]. Following informed consent procedures, screening included a parent interview for health history and a standardized test of developmental skills (Peabody Gross Motor Scale II [22]). All infants scored within 0.5 standard deviations of the mean and thus were deemed typically developing. The exclusion criteria included a score on the Peabody Gross Motor Scale II greater than 0.5 SD below the mean, or diagnosed visual or musculoskeletal deficits; met by none of the recruited infants. Infants were followed until able to sit fully independently (Stage 3 sitting[11]; typically under 4 months); determined by physical therapist's evaluation. Characteristics of participating infants can be found in Table 1.

2.2 Procedures

Infants' sitting ability was measured across four months. Data was collected via posturography during the initial visit, and again within a maximum of one week. This design was selected to allow evaluations of reliability of measures within data collection sessions[12]. Additional posturography and therapist's evaluation of sitting stage were conducted twice per month to monitor progression of sitting development. Infants were followed in this fashion until able to sit fully independently. For the current investigation, posturographic measures collected during the initial visit were submitted to a discriminant function analysis to identify which

variables could effectively predict the time-course of sitting development (days between onset and full acquisition).

2.3 Data processing

COP data were collected using a force platform (AMTI, Watertown, MA; 240Hz) while the infant's attention was held by watching an age-appropriate video or looking at toys held by the mother or investigator (Figure 1). Infants were guarded from falling while three minutes of COP data (with minimal support) were collected. From this 3 minute trial, shorter segments (length 8.3s@240Hz=2000 data points) were identified *a posteriori* during which the infants were sitting according to criteria previously described in similar studies; including lack of external support or expression of rhythmic movements such as arm flapping and vocalization, as well as consistent positioning of propping arm and the base of support[11]. Data length was deemed sufficient to perform both linear and nonlinear analyses[11]. Previous work[12] confirms trial-by-trial reliability within data collection sessions. We therefore sought to avoid introduction of error, due to averaging, by selecting only the first segment from each participant for subsequent analysis[23]. Importantly, however, it should be noted that each data point was verified to be fairly representative of the infant's sitting posture; falling within one standard deviation of the mean of the three trials. For each selected trial, anteroposterior(AP) and mediolateral(ML) components of COP were calculated using custom Matlab (Mathworks Inc., Natick, MA) routines. Measures of COP (sway path, range, root mean square, median frequency, frequency dispersion, approximate entropy, correlation dimension, and largest lyapunov exponent[24]), along with

descriptive characteristics (age and gender), provided a comprehensive set of measures for discriminant function analysis.

Median frequency and correlation dimension are found to provide discriminative power (described later) and are thusly further described here. To find median frequency, the frequency distribution of infants' COP was computed using power spectrum density, Hanning window, over 0 to 10 Hz. Median frequency is the frequency above/below which 50% of the total power is found. Full detail of calculation for correlation dimension (as well as entropy and lyapunov) can be found in previous publications[24]. For the current study, it is important to note that a value of 6 was used for embedding dimension (multi-dimensional expansion of the data) parameter for the calculation of correlation dimension ('smallest' dimension that contains the complexity of the analyzed system).

2.4 Statistical Analysis

Using PASW Statistics v.18 (Predictive Analytic Software; International Business Machines, Armonk, NY), stepwise discriminant analysis was conducted to identify functions from a set of independent variables (COP, age, mass, gender) which could predict the time-course of development of sitting ability in infants from initial stage to full acquisition of sitting (Stage 1 to 3).

2.4.1 Identification of Groups

Three groups (short, mid, and long delay) were identified based on naturally appearing cut-offs selected from a plot of the time between sitting onset at Stage 1 and acquisition of fully

independent sitting at Stage 3 (Figure 2). Initial consideration of this study thought to pursue only two groups, short and long delay, to attempt to identify early sitters from the group. Upon viewing the distribution of delay values (Figure 2), it was noted that identifying a clear threshold for short versus long delay would be challenging. In order to alleviate this challenge, as well as take advantage of the strength of discriminant analysis, in classifying amongst multiple groups, it was decided to consider the three groups described in this study. Visual inspection was followed by test of heterogeneity to ensure that the groups were significantly different from one another ($F=65.337$, $p<0.001$); indicating that our sample contained three distinct subgroups. Within PASW, prior probabilities for grouping were computed accounting for differences in group sizes, as the short delay group had eight members with mid and long delay each having nine.

2.4.2 Identification of Predictors

Prior to conducting discriminant analysis, the entire set of independent variables was tested for heterogeneity. AP Median frequency ($p=0.006$), AP correlation dimension ($p=0.002$), and gender ($p=0.025$) were identified to vary significantly between the three outcome groups (Table 2). The outcomes of the heterogeneity test reflect the likelihood that a variable will have discriminative power, in that if the variable has the same value for each of the three groups it would not be able to identify any particular group. We conducted a stepwise discriminant analysis, so this test is redundant relative to the F-value criteria for entry and removal of potential predictor variables (procedure for stepwise analysis; probability of F, entry = 0.05 and removal = 0.10). Procedurally similar to stepwise regression, the stepwise discriminant analysis iteratively selects the most discriminant variable through multiple 'steps' through the potential predictor

variable pool. This procedure was chosen to ensure that only the most relevant predictor values were selected, keeping the outcome functions concise.

2.4.3 Discriminant Function Analysis

Discriminant analysis tests whether the function coefficients derived from the stepwise assessment of predictor variables are able to account for the variance in group placement and accurately predict group placement for individuals. To this end, the functions are used to reclassify the individuals, and the predicted placement is compared with the 'true' placement. The *percent of variance explained* by each function indicates the relative value of the predictor variable more strongly represented in the particular function (largest magnitude of coefficient). Validity of the functions is evaluated via the Wilk's lambda and significance values (Table 3), whereas confidence is ultimately determined from the *percent of cases correctly reclassified*. Additional confidence is gained using a "leave one out" operation provided by PASW; wherein each case is deleted in turn from the sample and is then classified by the functions established on the remaining observations. Again, percent of cases correctly reclassified indicates the value of the derived discriminant functions.

3. Results

Analysis produced two functions, showing three predictor variables, median frequency, correlation dimension, and gender to be successful at predicting group placement by 73.1%.

This indicates a much greater than chance probability of correctly predicting categorical time delay between Stage 1 and Stage 3 sitting for each infant. Accounting for direction of misclassified cases, only two of these were detrimentally predicted (expected to achieve sitting earlier than actually occurred); thus gross error rate was only 7.7% for the discriminant functions. The "leave one out" approach resulted in 65.4% correctness in group prediction, with four cases of detrimental classification. This shows high retention of strength of the functions (Table 3), suggesting high generalizability to wholly new data sets.

Discriminant analysis resulted in two functions of three variables, coefficients in Table 3, interpreted much like multiple regressions. Function coefficients indicate the relationship of the independent variables as they predict outcomes. Each function is characterized by the 'strength' of the variable with the largest magnitude coefficient, and is generally better at discriminating a particular outcome group from the set of three. However, it is common to discuss the pair of functions together for interpreting their ability to accurately reclassify cases into outcome groups. In our case, function 1 was characterized by median frequency, which scaled linearly with increased delay in sitting skill acquisition; with larger values associated with a longer time period prior to Stage 3 sitting (Table 2). Function 2 was characterized by correlation dimension; smallest in the short delay group, but not differing between mid and long groups. Gender was a moderate

factor in both functions, lending discriminability between the three groups; with more females comprising the short and mid delay groups, while most long delay infants were males.

4. Discussion

Our results confirm that specific individual characteristics allow for prediction of the time delay between initial sitting performance and fully competent sitting in infants. Predictive characteristics include median frequency, correlation dimension, and gender of the infants. These factors are measurable at initial onset of sitting skill, and allow for projection of an individual child's developmental progress using the presented discriminant functions (Table 3). The power of such a tool is that the approach lends to a simple and effective objective means for monitoring typical development, using relatively simple force-platform technology and posturography.

Previously, median frequency of COP during standing has been shown to increase with increased muscle fatigue in healthy adults[25]. Interestingly, also observed in upper extremity muscular activity (measured using electromyography) as a result of robotic surgical training[26]. Wurdeman et al[27] found that in patients with multiple sclerosis, median frequency of ground reaction force during walking was lower than that of healthy adults. This decrease was suggested to indicatedecreased flexibility in firing rate resultant from disease, leading to diminished variation of behavior across the normal frequency range. Our results associate higher median frequency with longer delays between Stage 1 and Stage 3. We doubt that, with three minute collections, fatigue affected expression of COP behavioral variation across a given frequency range. Additionally, neuromuscular deficiency is not expected, as all infants passed evaluation for healthy typical development to enter the study. We propose that median frequency of COP reflects some other quality of infants' overall ability to control sitting posture. Differences in

frequency of COP movement indicate that each group of infants accommodated fluctuations of COP differently. Sitting being a novel task for these infants, these results could indicate a general difference in how the infants approach learning, specifically how to counter the effects of gravity to maintain sitting posture. These results are consistent with previous findings that show decreases in sway variability as infants develop into more advanced sitters, arguably through the gain of tighter control of the many degrees of freedom available in their control of upright sitting[16].

Results also indicated that AP correlation dimension is predictive of the time-course of sitting development. Particularly, AP correlation dimension was smallest in the short delay group and similar between the other two groups. Previous researchers have proposed the strategy of freezing degrees of freedom to promote learning in dynamically unstable environments[28]. In the current study, infants demonstrating fewer degrees of freedom (lower correlation dimension values, short delay group) appear to be primed for constraining degrees of freedom; necessary for mastering the skill of independent sitting. These infants appear to begin their quest for sitting acquisition with either inherently constrained movement behavior, or a more readily adaptable postural control. However tempting it may be to suggest innateness of control strategy to be the culprit; it is important to note that correlation dimension values are known to fluctuate throughout the life-span, as individuals acquire new postural skills and accumulate experience within novel environments[21]. Accordingly, we contemplate if the relationship found in the present study (lower dimensionality related to accelerated sitting acquisition) is suggestive of a neuromuscular system primed to learn, and not one with an innate tendency to resist the use of many degrees of freedom in the face of novel tasks. We speculate that lower correlation

dimension and smaller COP median frequency in this short delay group suggest a more readily adaptable postural control system that is learning to counter the effects of gravity.

Finally, although gender has not commonly been found to be a discriminating variable regarding postural performance, our data suggests that for the case of the speed of sitting skill acquisition, females demonstrate a significant advantage. A growing base of literature has begun to identify developmental differences based on gender; however, these sources are focused specifically on analyses related to visual search and object identification tasks[29,30]. It is possible that gender differences in sitting development identified in the current investigation are related to more general differences in the development of coordinative behaviors between males and females. It may even be resultant simply to a purely mechanical factor; body mass. We found in our data that males (n=11, mass=8.37±0.79 kg) tended to be more massive than the females (n=15, mass=7.23±0.71 kg). However, this result was not significant (p=0.368). When entered into the discriminant function analysis, this factor did not improve predictability of the time-course of sitting skill acquisition. Future research may pinpoint causative factors behind this finding. We would like to emphasize from this finding, however, that our concept of typical developmental milestone acquisition should include more consideration for individual differences for interpretation of healthy development. In our case, it is suggested that a heavier male child would be expected to take a bit longer for sitting skill acquisition than his female counterpart, whom is otherwise characteristic matched. Therefore, if this is found to be the case, in the home or clinical setting, it may be advisable to permit additional time for skill acquisition prior to concerns being raised.

Limiting the present study is that the sample size of typically developing infants may not be large enough to generalize usage of the discriminant functions presented. Albeit, the leave-one-out cross-checking does add validity to the presented functions; and our sample size (26 infants) is actually quite large for the motor development literature.

Participating infants all satisfied the criterion for typical development. This lends to question whether the discriminant functions presented here would generalize to infants who are at *severe* risk of developmental delay. To this end, it is not the goal of the proposed approach to supplant clinical assessments of deficits in children which would be available to the trained eye, but to provide a refined tool for assessment of children on a typical developmental course. For these children, early intervention may yet be advisable on a case-by-case basis to ensure proper development of motor, and later cognitive, development. Further work is necessary to determine whether this approach may be extended to development of such an approach to discriminating typical from atypical sitters.

5. Conclusion

Our analysis showed the time-course of sitting acquisition for typically developing infants can be predicted from postural and demographic measures taken at the earliest signs of sitting emergence. This information could benefit parents and clinicians during evaluation of typical development and recommendation of at home exercises useful in promoting sitting acquisition when needed. Future studies are recommended, such that the present results can be expanded to a larger generalization across a wider potential population of infants.

References

1. Soska KC, Adolph KE, Johnson SP. Motor skill acquisition facilitates 3D object completion. Dev Psychol 2010;46(1):129-38.
2. Corbetta D, Snapp-Childs W. Seeing and touching: The role of sensory-motor experience on the development of infant reaching. Infant Behav Dev 2009;32:44-58.
3. Rochat P, Goubet N. Development of Sitting and Reaching in 5- to 6- Month-Old Infants. Infant Behav Dev 1995;18:53-68.
4. Bremner, J G. Motor abilities as causal agents in infant cognitive development. In: Advances in psychology: Vol. 97. The Development of Coordination in Infancy. G. Savelsbergh (Ed.). Elsevier Science: San Diego, CA; 1993
5. Campos JJ, Anderson DI, Barbu-Roth MA, Hubbard EM, Hertenstein MJ, Witherington D. Infancy 2000;1:149-219
6. Campbell SK. The infant at risk for developmental disability. Decision Making in Pediatric Neurologic Physical Therapy. Ed: Campbell SK; Churchill Livingstone, Philadelphia, PA; 1999.
7. Hadders-Algra M. Evaluation of motor function in young infantsby means of the assessment of general movements: a review. Pediatr Phys Ther 2001;13:27-36.
8. Palisano R, Rosenbaum P, Walter S, Russell D, Wood E, Galuppi B. Development and reliability of a system to classify gross motor function in children with cerebral palsy. Dev Med Child Neurol 1997;39:214–23.
9. Provost B, Heimerl S, McCain C, Kim NH, Lopez BR, Kodituwakku P. Concurrent validity of the Bayley Scales of Infant Development II Motor Scale and the Peabody Developmental Motor Scales-2 in children with developmental delays. Pediatr Phys Ther 2004;16(3):149-56.

10. Snyder P, Eason JM, Philibert D, Ridgway A, McCaughey T. Concurrent Validity and Reliability of the Alberta Infant Motor Scale in Infants at Dual Risk for Motor Delays. Phys Occup Ther Pediatr 2008;28(3):267-82.
11. Harbourne R, Stergiou N. Nonlinear analysis of the development of sitting postural control. Dev Psychobiol 2003; 42(4):368-77.
12. Kyvelidou A, Harbourne RT, Stuberg WA, Sun J, Stergiou N. Reliability of center of pressure measures for assessing the development of sitting postural control. Arch Phys Med Rehabil 2009;90(7):1176-84.
13. Riach CL, Hayes KC. Maturation of postural sway in young children. Dev Med Child Neurol 1987:29:650-58.
14. Dusing SC, Kyvelidou A, Mercer VS, Stergiou N. Infants born preterm exhibit different patterns of center-of-pressure movement than infants born at full term. Phys Ther 2009:89(12):1354-62.
15. Harbourne RT, Deffeyes JE, Kyvelidou A, Stergiou N. Complexity of postural control in infants: linear & nonlinear features developed by principal component analysis. Nonlinear Dynamics Psychol Life Sci 2009;13(1):123-44
16. Deffeyes JE, Harbourne RT, Kyvelidou A,Stuberg WA, Stergiou N. Nonlinear analysis of sitting postural sway indicates developmental delay in infants. Clin Biomech 2009;24(7):564-70.
17. Molloy CA, Dietrich KN, Bhattacharya A. Postural stability in children with autism spectrum disorder. J Autism Dev Disord 2003;33(6):643-52.
18. Yamada N. Chaotic swaying of the upright posture. Hum Movement Sci 1995;14:711-26.
19. Chiari L, Rocchi L, Cappello A. Stabilometric parameters are affected by anthropometry and foot placement. Clin Biomech 2002;17(9-10):666-77.
20. Palmieri RM, Ingersoll CD, Stone MB, Krause BA. Center-of-pressure parameters used in the assessment of postural control. J Sport Rehab 2002; 1:51-66.

21. Newell KM. Degrees of freedom and the development of center of pressure profiles. In KM Newell and PMC Molenaar (Eds) Applications of nonlinear dynamics to developmental process modeling, pp. 63-84, Hillsdale, NJ: Erlbaum; 1997.
22. Folio, MR, Fewell, RR. Peabody Developmental Motor Scales, 2nd Edition. Austin, TX: Pro-ed, Inc.; 2000.
23. Bates BT, James CR, Dufek JS. Single-Subject Analysis. In: Innovative Analyses of Human Movement. N. Stergiou (Ed.) Human Kinetics: Champaign, IL; 2003
24. Stergiou N, Buzzi UH, Kurz MJ, Heidel J. Nonlinear tools in human movement. In: Innovative Analyses of Human Movement. N. Stergiou (Ed.) Human Kinetics: Champaign, IL; 2003
25. Corbeil P, Blouin JS, Begin F, Nouger V, Teasdale N. Perturbation of the postural control system induced by muscular fatigue. Gait Posture 2003;18(2):992-100.
26. Judkins TN, Oleynikov D, Narazaki K, Stergiou N. Robotic surgery and training: electromyographic correlates of robotic laparoscopic training. Surg Endosc 2006;20(5): 824-9.
27. Wurdeman SR, Huising JM, Filipi M, Stergiou N. Multiple sclerosis affects the frequency content in the vertical ground reaction forces during walking. Clin Biomech 2011;26:207–12.
28. Konczak J, Vander Velden H, Jaeger L. Learning to to play the violin: motor control by freezing, not freeing degrees of freedom. J Mot Behav 2009;41(3):243–52.
29. Wilcox T. Event-mapping tasks: investigating the effects of prior information and event complexity on performance. Inf Behav Dev 2003;26:568-87.
30. Wilcox T. Sex differences in infants' mapping of complex occlusion sequences: further evidence. Infancy 2007;12(3):303-27.

TABLES

Table 1: Characteristics of the participating infants

				Peabody Gross Motor Scale II			Stage 1		Stage 3	
Delay Stage 1 to 3				Standard Scores			age	mas	age	mass
Group	# days	Subject	Gender	Reflexes	Stationary	Locomotion	(days)	(kg)	(days)	(kg)
Short	*33*	s1	M	10	10	10	158	6.77	191	7.63
	55	s2	F	10	11	10	130	7.20	185	7.65
	56	s3	F	10	11	10	128	7.29	184	8.06
	56	s4	F	10	11	10	155	7.15	211	8.08
	56	s5	F	9	10	9	191	7.69	247	8.08
	56	s6	M	10	11	10	139	8.27	195	8.66
	62	s7	F	10	11	10	147	7.33	209	8.37
	70	s8	F	10	10	10	156	7.38	226	8.08
Mid	*82*	s9	F	11	11	10	147	5.63	229	6.14
	83	s10	F	9	10	9	128	7.37	211	7.84
	83	s11	M	10	11	10	161	9.23	244	9.81
	83	s12	F	10	10	10	164	7.24	247	8.32
	84	s13	F	10	11	10	142	7.88	226	8.70
	84	s14	F	10	11	10	156	6.95	240	8.10
	84	s15	F	10	11	10	168	8.19	252	8.95
	84	s16	F	10	11	10	182	8.41	266	9.63
	84	s17	M	10	10	10	148	7.53	232	8.46
Long	*86*	s18	F	8	10	9	125	6.25	211	7.33
	90	s19	M	9	10	9	151	7.55	241	9.20
	91	s20	M	11	10	9	160	8.97	251	9.18
	91	s21	M	10	11	9	159	8.03	250	8.76
	98	s22	M	10	10	10	123	8.19	221	8.91
	98	s23	M	10	11	9	138	8.95	236	9.72
	98	s24	M	10	10	10	150	8.15	248	10.09
	105	s25	M	9	10	9	142	9.56	247	11.03
	112	s26	F	9	10	9	156	6.63	268	7.59
			mean	*9.81*	*10.50*	*9.65*	*150.15*	*7.68*	*229.54*	*8.55*
			SD	*0.63*	*0.51*	*0.49*	*16.57*	*0.92*	*23.86*	*1.01*

Table 2: Stage 1 values of demographic and COP variables used in discriminant analysis. Significant differences indicate discriminability of group by the particular variable.

	Time between Stage 1 and Stage 3 sitting (in days)			Heterogeneity
	short (55)	mid (83)	long (97)	*Sig.*
Median Frequency AP	0.480 ± 0.287	0.707 ± 0.236	0.987 ± 0.498	*0.028**
Correlation Dimension AP	4.094 ± 0.355	4.502 ± 0.237	4.304 ± 0.277	*0.028**
Gender (% of group female)	0.750 ± 0.463	0.778 ± 0.441	0.222 ± 0.441	*0.025**

* = significant difference across the three groups, $p < 0.05$

Table 3: Standardized Canonical Discriminant Function Coefficients

	Function	
	1	2
Anterior-Posterior Median Frequency	0.763	-0.047
Anterior-Posterior Correlation Dimension	0.523	0.825
Gender	-0.733	0.417
Percent of variance explained by this function (=1)	*74.9*	*25.1*
Wilk's Lambda (1 through 2, and 2; respectively)	*0.379*	*0.752*
Significance (p=)	*0.002*	*0.043*

Figure Captions:

Figure 1: Infant engaged in independent sitting upon the force platform.

Figure 2: Scatter-plot of days until Stage 3 sitting for each infant. Three groups were found statistically unique from each other when examining the time delay (in days) between onset and fully independent sitting.

Figure 1

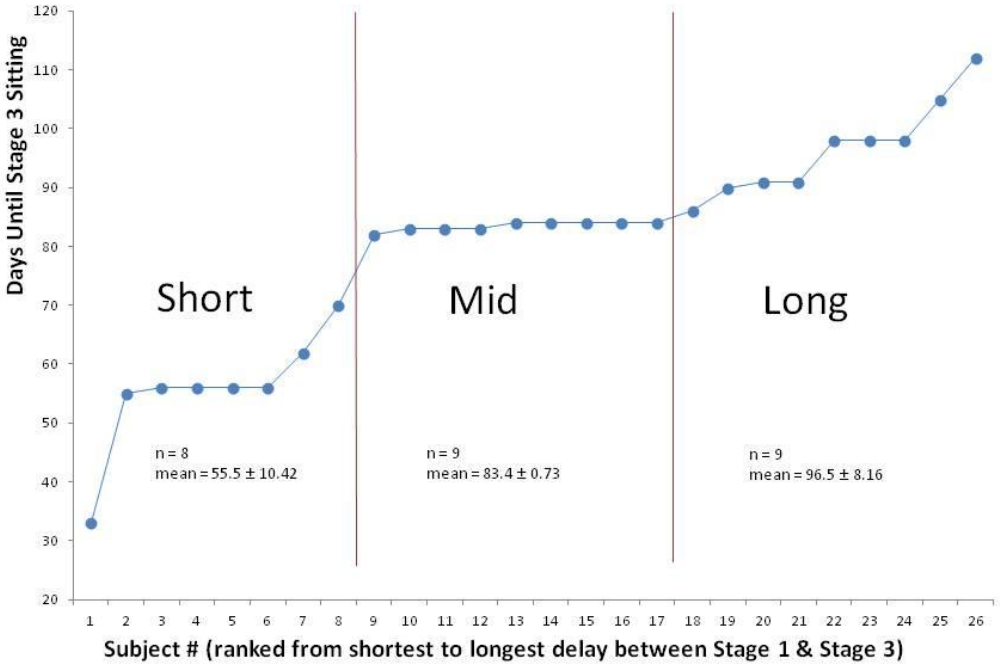
Days Until Stage 3 Sitting
120
110
100
90
80
70
60
50
40
30
20
Short
Mid
Long
n = 8
mean = 55.5 ± 10.42
n = 9
mean = 83.4 ± 0.73
n = 9
mean = 96.5 ± 8.16
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
Subject # (ranked from shortest to longest delay between Stage 1 & Stage 3)

Figure 2