

Developmental trajectory of physical activity and its relationship to rate of gain in weight, subcutaneous fat, and motor skill development during the first six months of life

by

Janet Lynn Hauck

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Kinesiology)
in The University of Michigan
2012

Doctoral Committee:

Professor Dale A. Ulrich, Chair
Professor Karen E. Peterson
Professor Beverly D. Ulrich
Associate Professor Julie C. Lumeng

© Janet L. Hauck

All rights reserved

2012

This dissertation is dedicated to Mom, Dad, Paul, Teddi, and Emma. Without your unquestionable and withstanding support, inspiration, and love, this would not have been possible. I love and thank you!

Acknowledgements

It is my pleasure to thank those who made this dissertation possible. I have had the distinct opportunity of working with a significant network of outstanding academic and personal supporters, each making their own unique contribution to my dissertation.

I owe my deepest gratitude to the infants and their families who participated in these studies. It was a delight to meet and work with each of them. They are the true difference makers.

To Dale I am grateful for a lifetime of lessons, guidance, and passion that he has provided me in just four short years. More than ever I am motivated to continue to affect the lives of individuals with disabilities, mentor and teach young professionals entering the field, and contribute to this chosen field of study.

To my lab mates Leah, Irully, Phil, Megan, and Andy, it was an honor and a privilege to have learned, worked, and sweat by your sides for so many years. I am confident that our collaborative efforts will continue for many years to come.

To the research assistants who worked endless hours on these studies, may their dedication and intelligence provide them with platform of success as they continue to graduate school and promising careers.

Thank you to Rackham Graduate School and Blue Cross Blue Shield of Michigan for funding these research studies.

Lastly, thank you to my remarkable family. You were each a source of inspiration and motivation to me throughout this journey and I am eternally grateful for your love and support throughout the past four years. I am blessed to belong to such a humorous, loving, and intelligent group. Mom, Dad, Paul, Teddi, and Emma, I love you.

Table of Contents

Dedication.....	ii
Acknowledgements.....	iii
List of Figures.....	vii
List of Tables.....	x
List of Appendices.....	xiii
Abstract.....	xx
Chapter	
1. The developmental relationship between physical activity and changes in weight status and subcutaneous fat in young infants.....	1
Specific Aims.....	5
Method.....	6
Participants.....	6
Procedures.....	7
Measurement.....	7
Anthropometric Measurement.....	8
Physical Activity.....	9
Data Reduction.....	11
Statistical Approach.....	11
Results.....	13
Discussion.....	14
References.....	23

2. The developmental relationship between physical activity and change in motor skill development during the first six months of life	38
Specific Aims.....	41
Method.....	42
Participants.....	42
Procedures.....	43
Measurement.....	43
Anthropometric Measurement.....	44
Motor Development.....	45
Physical Activity.....	45
Data Reduction.....	46
Statistical Approach.....	47
Results.....	48
Discussion.....	50
References.....	55
3. Does the amount of time an infant spends in a infant positioning device influence changes observed in weight status, subcutaneous fat, physical activity and motor skill development?.....	66
Specific Aims.....	70
Method.....	71
Participants.....	71
Procedures.....	72
Measurement.....	73
Anthropometric Measurement.....	74

Motor Development.....	75
Physical Activity.....	75
Data Reduction.....	76
Infant Positioning Device.....	77
Statistical Approach	77
Results.....	79
Discussion.....	81
References.....	87

List of Figures

Chapter 1

Figure 1.1	Physical activity (PA) at the ankle from one to six months of age.....	33
Figure 1.2	Physical activity (PA) at the wrist from one to six months of age.....	34
Figure 1.3	Change-in subcutaneous fat from two to six months of age.....	35
Figure 1.4	Subcutaneous fat from one to six months of age.....	36
Figure 1.5	Change-in ponderal index from one to six months of age.....	37

Chapter 2

Figure 2.1	Change-in motor skill development from two to six months of age.....	64
Figure 2.2	Motor skill development from one to six months of age.....	65

Chapter 3

Figure 3.1	Infant positioning device (IPD) use during a 24 hour period from one to six months of age.....	96
Figure 3.2	Change-in ponderal indices from one to six months of age.....	97
Figure 3.3	Change-in subcutaneous fat from two to six months of age.....	98
Figure 3.4	Subcutaneous fat from one to six months of age.....	99
Figure 3.5	Physical activity (PA) at the ankle from one to six months of age.....	100
Figure 3.6	Physical activity (PA) at the wrist from one to six months of age.....	101
Figure 3.7	Change-in motor skill development from two to six months of age.....	102
Figure 3.8	Motor skill development from one to six months of age.....	103
Figure 3.9	Use of an upright sitting device from one to six months of age BY physical activity (PA) group.....	104

Figure 3.10 Use of a jumping device from one to six months of age BY
physical activity (PA) group.....105

List of Tables

Chapter 1

Table 1.1	Characteristics of participants and their families as percentage of the total sample.....	29
Table 1.2	Physical activity (PA) group differences (means \pm standard deviations) in PA, maternal BMI, and infant growth status from one to six months of age.....	30
Table 1.3	Estimated fixed effects (standard errors in parenthesis) in linear models incorporating physical activity (PA) at the ankle as a predictor.....	31
Table 1.4	Estimated fixed effects (standard errors in parenthesis) in linear models incorporating physical activity (PA) at the wrist as a predictor.....	32

Chapter 2

Table 2.1	Characteristics of participants and their families as percentage of the total sample.....	59
Table 2.2	Physical activity (PA) group differences (means \pm standard deviations) in PA at the ankle and motor skill development from one to six months of age.....	60
Table 2.3	Physical activity (PA) group differences (means \pm standard deviations) in PA at the wrist and motor skill development from one to six months of age.....	61
Table 2.4	Estimated fixed effects (standard errors in parenthesis) in linear models incorporating physical activity (PA) at the ankle as a predictor.....	62
Table 2.5	Estimated fixed effects (standard errors in parenthesis) in linear models incorporating physical activity (PA) at the wrist as a predictor.....	63

Chapter 3

Table 3.1	Characteristics of participants and their families with average IPD use in minutes.....	92
Table 3.2	Infant positioning device (IPD) use group differences (means \pm standard deviations) in PA, growth status, and motor skill development from one to six months....	93
Table 3.3	Type and frequency of infant positioning device (IPD) use in minutes (means \pm standard deviations) from one to six months of age.....	94
Table 3.4	Estimated fixed effects (standard errors in parentheses) in linear models including time spent in an infant positioning device (IPD) as a predictor.....	95

List of Appendices

Appendix	1.1	Supplement to chapter one literature review	106
	a)	Epidemiology of infant obesity.....	106
	b)	Methodology in pediatrics research.....	110
	c)	Environmental and innate contributors to infant obesity.....	112
Appendix	2	Overlay line graphs of all variables BY age	114
	2.1	Overlay line graphs of all variables BY age for ID 101.....	114
	a)	Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	114
	b)	Ponderal index.....	115
	c)	Infant positioning device use.....	115
	2.2	Overlay line graphs of all variables BY age for ID 102.....	116
	a)	Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	116
	b)	Ponderal index.....	117
	c)	Infant positioning device use.....	117
	2.3	Overlay line graphs of all variables BY age for ID 103.....	118
	a)	Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	118
	b)	Ponderal index.....	119
	c)	Infant positioning device use.....	119

2.4	Overlay line graphs of all variables BY age for ID 104.....	120
	a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	120
	b) Ponderal index.....	121
	c) Infant positioning device use.....	121
2.5	Overlay line graphs of all variables BY age for ID 105.....	122
	a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	122
	b) Ponderal index.....	123
	c) Infant positioning device use.....	123
2.6	Overlay line graphs of all variables BY age for ID 106.....	124
	a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	124
	b) Ponderal index.....	125
	c) Infant positioning device use.....	125
2.7	Overlay line graphs of all variables BY age for ID 107.....	126
	a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	126
	b) Ponderal index.....	127
	c) Infant positioning device use.....	127
2.8	Overlay line graphs of all variables BY age for ID 108.....	128
	a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	128
	b) Ponderal index.....	129

	c)	Infant positioning device use.....	129
2.9		Overlay line graphs of all variables BY age for ID 109.....	130
	a)	Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	130
	b)	Ponderal index.....	131
	c)	Infant positioning device use.....	131
2.10		Overlay line graphs of all variables BY age for ID 110.....	132
	a)	Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	132
	b)	Ponderal index.....	133
	c)	Infant positioning device use.....	133
2.11		Overlay line graphs of all variables BY age for ID 111.....	134
	a)	Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	134
	b)	Ponderal index.....	135
	c)	Infant positioning device use.....	135
2.12		Overlay line graphs of all variables BY age for ID 113.....	136
	a)	Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	136
	b)	Ponderal index.....	137
	c)	Infant positioning device use.....	137

2.13	Overlay line graphs of all variables BY age for ID 114.....	138
	a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	138
	b) Ponderal index.....	139
	c) Infant positioning device use.....	139
2.14	Overlay line graphs of all variables BY age for ID 115.....	140
	a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	140
	b) Ponderal index.....	141
	c) Infant positioning device use.....	141
2.15	Overlay line graphs of all variables BY age for ID 116.....	142
	a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	142
	b) Ponderal index.....	143
	c) Infant positioning device use.....	143
2.16	Overlay line graphs of all variables BY age for ID 117.....	144
	a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	144
	b) Ponderal index.....	145
	c) Infant positioning device use.....	145
2.17	Overlay line graphs of all variables BY age for ID 118.....	146
	a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	146
	b) Ponderal index.....	147

	c)	Infant positioning device use.....	147
2.18		Overlay line graphs of all variables BY age for ID 119.....	148
	a)	Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	148
	b)	Ponderal index.....	149
	c)	Infant positioning device use.....	149
2.19		Overlay line graphs of all variables BY age for ID 120.....	150
	a)	Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	150
	b)	Ponderal index.....	151
	c)	Infant positioning device use.....	151
2.20		Overlay line graphs of all variables BY age for ID 121.....	152
	a)	Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	152
	b)	Ponderal index.....	153
	c)	Infant positioning device use.....	153
2.21		Overlay line graphs of all variables BY age for ID 122.....	154
	a)	Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	154
	b)	Ponderal index.....	155
	c)	Infant positioning device use.....	155
2.22		Overlay line graphs of all variables BY age for ID 123.....	156

	a)	Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	156
	b)	Ponderal index.....	157
	c)	Infant positioning device use.....	157
2.23		Overlay line graphs of all variables BY age for ID 124.....	158
	a)	Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	158
	b)	Ponderal index.....	159
	c)	Infant positioning device use.....	159
2.24		Overlay line graphs of all variables BY age for ID 125.....	160
	a)	Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	160
	b)	Ponderal index.....	161
	c)	Infant positioning device use.....	161
2.25		Overlay line graphs of all variables BY age for ID 126.....	162
	a)	Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	162
	b)	Ponderal index.....	163
	c)	Infant positioning device use.....	163
2.26		Overlay line graphs of all variables BY age for ID 127.....	164
	a)	Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	164
	b)	Ponderal index.....	165

	c)	Infant positioning device use.....	165
2.27		Overlay line graphs of all variables BY age for ID 128.....	166
	a)	Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	166
	b)	Ponderal index.....	167
	c)	Infant positioning device use.....	167
2.28		Overlay line graphs of MEAN values of all variables BY age.....	168
	a)	Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development.....	168
	b)	Ponderal index.....	169
	c)	Infant positioning device use.....	169

ABSTRACT

Developmental trajectory of physical activity and its relationship to rate of gain in weight, subcutaneous fat, and motor skill development during the first six months of life

by

Janet Lynn Hauck

Chair: Dale A. Ulrich

The purpose of this dissertation is to first establish the developmental trajectory of physical activity (PA) and use of infant positioning devices (IPD) during infancy and determine if there is a relationship between amount of PA and IPD use to rate of gain in weight, subcutaneous fat, and motor skill development in the first six months of life.

Literature highlighting the significance of infant obesity and potential causal links is substantial. There is controversy surrounding many of the proposed contributing factors to infant obesity including the nature of their association as well as their general sensitivity to impacting obesity.

Twenty-eight infants participated in this longitudinal study from one to six months of age. During that time, we monitored infant weight, length, ponderal index, subcutaneous fat, motor skill development, objective PA, and use of IPDs.

The developmental trajectory of PA in infancy follows a positive linear trend of increased PA as the infant ages with the most dramatic rise in PA occurring during the first three months of life. The trajectory of use of IPD does vary from month to month with use of more types of devices as the infant ages and decreased frequency of use of those devices from one to six

months of age. We found an emerging trend of increased motor skill development among more physically active infants, including earlier onset of age for supine reach, extended arms in prone position, whole hand grasp, supine to prone roll, and independent sitting. This trend was also observable in infants with greater use of IPDs. We did not find a significant trend of ponderal index and subcutaneous fat relating to amount of PA or time spent in an IPD; however an observable trend emerged with less physically active infants gaining weight more rapidly in the first few months.

A comprehensive developmental study of this kind is the first to examine PA during the first six months in life. This knowledge represents the first step in developing effective preventative interventions that can be implemented during infancy in order to prevent lifelong battles with obesity and associated co-morbidities.

Chapter 1

The developmental relationship between physical activity and changes in weight status and subcutaneous fat in young infants

The prevalence of childhood obesity has rapidly increased and onset of this condition is occurring much earlier in life. Today's infants are approximately one kilogram (kg) heavier at one year of age than infants born during the preceding 40 years (Mook-Kanamori et al., 2011). Using the Fels Longitudinal Study, Johnson et al. (2012) reported notable changes in body mass index (BMI) throughout childhood for those born from 1973-1999 than those born in the previous 50 years. Adiposity rebound followed by greater maximum BMI velocity occurred earlier in life (van Rossem et al., 2011). Adiposity rebound most often occurs in middle childhood at the point when body fatness begins to rise after reaching its minimum (Eriksson, Forsen, Osmond, & Barker, 2003).

During the same time period, obesity prevalence among infants aged two years or less has increased by more than 60% (Vickers, 2011). Between 2009-2010, the National Health and Nutrition Examination Survey (NHANES) identified 9.7% of infants and toddlers surveyed or examined as obese using the 2000 Centers for Disease Control (CDC) growth charts (Ogden, 2012). When these data are applied to the currently recommended 2006 World Health Organization (WHO) growth standards, the prevalence of infant and toddler obesity is slightly less, but still apparent. During this same time, 12.1% of children aged two-five years were identified as obese (Ogden, 2012). Furthermore, when extracting Hispanic infants from the population of infants born in 2009, it was predicted that 14.8% would be classified as obese by

24 months of age (Ogden, Carroll, Kit, & Flegal, 2012). Obesity trends among children are expected to level off this decade, despite reports of a projected increase by over 30% by 2030 (Ogden, 2012). Even so, the rate of obesity among infants and children remains too high.

Past perceptions of infant weight reflected a time and a place of lower socioeconomic status, less access to food, and different cultural perspectives where a “chubby baby” was considered a “healthy baby” (Paul et al., 2009). Even today, a study examining parental perceptions of infant growth identified a sample of urban parents who prefer their child’s weight for length percentile to be high (Wijlaars, Johnson, van Jaarsveld, & Wardle, 2011). This view of increased weight indicating greater fitness, sometimes referred to as the “grand mothering effect” remains prevalent and is presumed to have contributed to the current pediatric obesity epidemic (Heinzer, 2005).

There is much urgency to break the cycle of obese children becoming obese adults who later produce obese offspring (Paul, et al., 2009). Studies are now showing that infants and toddlers having excess weight have an increased risk for remaining overweight as they age (Paul, et al., 2009). Infants who experience rapid increases in weight-for-length during the first six months of infancy are at extreme risk of being obese at three years of age (Monteiro & Victora, 2005). Forty percent of those in the highest quartile in weight-for-length in that infancy period are predicted to be obese at age three (Taveras et al., 2009). This sharp rise has led public health researchers to examine factors associated with excess weight gain.

Given the chronic continuous nature of infant obesity and the risk of obesity complications occurring later in life, it is very relevant to understand the underlying processes contributing to infant weight gain. Many researchers have examined behavioral and innate risk factors for early onset obesity including those related to maternal characteristics and behavior,

infant feeding practices, infant sleeping habits, and genetics; few have examined modifiable factors contributing to infant weight gain such as physical activity (PA) (Ayerza et al., 2011).

Early motor activity has been indicated as an important contributor to overall health and motor development during childhood (McKay & Angulo-Barroso, 2006; Thelen, 1994; Ulrich & Ulrich, 1995). However, there is limited knowledge of PA during infancy and its relationship to motor milestone acquisition is unclear (Angulo-Barroso, Burghardt, Lloyd, & Ulrich, 2008; Angulo-Kinzler, Peirano, Lin, Garrido, & Lozoff, 2002; McKay & Angulo-Barroso, 2006).

A clear pattern of increased sedentary activity among children who are overweight or obese has been established (Monasta et al., 2010). In a large study employing objectively measured PA over eight years during childhood, Moore and colleagues (2003) found that the accumulation of PA from four to eleven years of age resulted in smaller gains in subcutaneous fat and BMI. Physical activity at four years of age in isolation did not yield the same result (Moore et al., 2003). This suggests that a potential protective benefit of early life PA may not translate to later childhood health benefits unless PA is maintained. We know that PA and excess weight are inversely related from childhood through adulthood. What we do not know is when this relationship is initiated and if this relationship exists during infancy.

In a study measuring energy expenditure and PA in nine and 14 month old infants, Tennefors et al. (2003) reported an inverse relationship between PA and total body fat. A preliminary interpretation of this relationship suggests that infants having higher percent total body fat participated in less PA than infants having lower percent total body fat.

These results suggest that intervention efforts to increase PA need to occur earlier in life if the outcome is to reduce obesity incidence and risk. However given the limited evidence

available, it is difficult to interpret the relationship between early infancy motor activity on overall health and development.

There are currently no physical activity recommendations for children zero to five years of age which are evidence based (Paul, et al., 2009). At the present, there is insufficient evidence to support exercise recommendations for infants and toddlers as a means to promote PA or prevent obesity (Botton, Heude, Maccario, Ducimetiere, & Charles, 2008). Moreover, very little intervention research to modify excess growth or increase PA during infancy exists.

In a systematic review of the literature identifying obesity prevention interventions within the first five years of life, Hesketh and Campbell (2010) highlight childhood obesity prevention as a growing research area but note the relative lack of interventions targeting the child. Instead, researchers have focused their intention on the behaviors of parents. Until such evidence exists, the Council on Sports Medicine and Fitness and the Council on School Health (2006) have recommended that infants and toddlers have no screen time prior to age two, have experience in a safe and minimally structured play environment, and enjoy outdoor physical activity through unstructured movement exploration.

Despite the extreme urging of researchers for early intervention during infancy, no targeted approach to increase PA has occurred. Much of our study of childhood obesity has focused on maternal behavior during the prenatal period, dietary behavior of the mother and child from the prenatal to toddler periods, and other environmental influences. Possible periods of particular vulnerability for developing obesity are the prenatal period, infancy, and early childhood. These are unique periods of cellular differentiation and development making them exceptional to possible adiposity control through intervention (Paul, et al., 2009). Given findings that support the risk for obesity is physiologically programmed or influenced early in

life, it is critical that we understand the role of PA and its relationship to weight and adiposity during infancy (Chomtho, 2008; Paul, et al., 2009).

With the vast increase in obesity epidemic among children in recent years, it is unlikely that medical intervention alone can resolve the issue (Council on Sports Medicine and Fitness & Council on School Health, 2006). A logical step in the prevention of childhood obesity is to prevent it in the first place (Angulo-Barroso, et al., 2008). Physical activity intervention is one option which may offer success in preventing rapid weight gain during infancy. Therefore, future research should focus on interventions during early infancy to reduce rapid weight gain and subsequent obesity (Monasta, et al., 2010; Taveras et al., 2010).

Specific Aims

The primary aim of this study was to describe the developmental trajectory of physical activity (PA) of infants from birth until six months of age. The second aim was to determine whether a relationship exists between PA and changes in ponderal index and subcutaneous fat during the first six months of life. A comprehensive developmental study of this kind is the first to examine PA during the first six months in life. This knowledge can be used to begin to establish baseline measures of PA during early life. With this new knowledge, we can develop effective interventions for infants that may be at risk for childhood obesity and develop healthy PA recommendations for infants. This knowledge is useful in describing patterns of PA occurring during infancy and quantifying the relationship between PA and rate of change in ponderal index and subcutaneous fat during infancy. Two hypotheses were tested. First, the developmental trajectory of physical activity in infants will increase in amount in a semi-linear fashion, with more dramatic increases between three and six months of age which coincides with increased kicking and improvements in independent sitting. Second, when the overall trend of

PA from one to six months of age is compared to monthly changes in ponderal index and subcutaneous fat, an inverse relationship will emerge. It is anticipated that infants who display higher levels of PA will display smaller gains in their ponderal index and smaller increases in subcutaneous fat. Infants displaying lower levels of PA will display higher increases in their ponderal index and subcutaneous fat.

Method

Participants

All methods and procedures were approved by the Health Sciences and Behavioral Sciences Institutional Review Board at the University of Michigan. All mother/neonate dyads were consented by the mother prior to participation in this study.

Twenty-eight mother/neonate dyads were recruited from Southeast Michigan to participate in this longitudinal study which consisted of six data collections each, yielding 168 total time points. Participants included mothers aged 18 years and older with a healthy infant less than six weeks of age. Infants were excluded who received a medical diagnosis that was suspected to impair or delay growth, muscle development, motor development, cognition, or nutritional status. Such diagnoses include but are not limited to cystic fibrosis, Down syndrome, neuromuscular disease, spina bifida, hypotonia, fetal alcohol syndrome, pre-mature birth (< 37 weeks gestation), etc. One mother/neonate dyad was dropped from the study after receiving a neuromuscular diagnosis which impairs growth and development. None of the remaining 27 dyads had a physical disability or medical condition which would limit or impair physical activity (PA) or growth. Participant characteristics and family demographic information including gender, race, gestational size, feeding modality, maternal marital status, maternal

highest level of education, and maternal BMI were computed as percentages of the total sample and can be found in Table 1.1.

Procedures

During the study period, we collected data from each participant once monthly for six consecutive months. All data collection took place in the home of the infant, with the exception of initial recruitment information including gender, age, contact information, and address collected prior to the start of the study. The mother was present at all times. Collecting data at the home of each participant provided convenience and ease for the mother, as well as comfort for the infant. The first home visit occurred when the infant was aged approximately one month (+/- one week), with each subsequent home visit occurring when the infant was two, three, four, five, and six months of age (+/- one week). Participants received between \$15-\$25 cash incentive for participation during each home visit, totaling \$100 for full participation.

The research team included the principal investigator (PI) and five trained research assistants. The PI and one to two research assistants attended each one hour home visit. Research assistants' responsibilities consisted of field work and lab work. Field tasks included assisting with equipment, data recording, stabilizing each infant's head and legs during anthropometric measurement, and interaction with siblings. Lab tasks included data entry and data reduction.

Measurement

During the study period, we monitored the PA and growth of each infant participant on a monthly basis. At the first home visit, measurements of demographic information, maternal height, weight, and some information relating to the preconception, prenatal and postpartum

periods were collected. In addition, we administered a short survey of infant feeding modality each month.

During the first home visit, each mother completed a number of surveys including a maternal demographic survey, an infant demographic survey, and an intake survey which were used as a series of covariates that have been associated with infant and childhood obesity. The maternal supplemental information survey included maternal age, race, marital status, highest level of education, method of delivery, birth complications, and hospital discharge information. The infant demographic survey included date of birth, due date, race, medical conditions, birth weight, birth length, neonatal complications, and number of siblings including birth order. The intake survey consisted of questions regarding the preconception, prenatal, and postpartum periods including pregravid weight, diabetes status, hypertension status, prenatal care, gravid weight gain, and feeding modality (measured monthly). In addition to surveys, we measured maternal weight in kilograms (kg) using a Health O Meter H-349KL digital scale and height in centimeters (cm) using a SECA S-214 portable stadiometer one month postpartum. To calculate BMI, we converted height from cm to meters (m) and used the following formula: $\text{Weight (kg)} / \text{Height (m)}^2$.

Anthropometric Measurement

During each home visit, we measured infant weight, length, ponderal index, and subcutaneous fat at three sites. These measures were repeated once monthly from one through six months of age.

We measured infant weight (kg) using a Tanita digital baby scale and infant recumbent crown-heel length (cm) using an infant length board. The length board had a static headboard and moveable footboard. The infant's ankle was dorsiflexed while the body was aligned.

Infants were measured in supine position wearing only a clean diaper. We tracked weight-for-length percentile monthly using the 2006 WHO growth standards (Neelon, Oken, Taveras, Rifas-Shiman, & Gillman, 2011). We used weight and length to determine ponderal index using the following formula: $100 \times \frac{\sqrt[3]{\text{Mass (kg)}}}{\text{Length (cm)}}$. Ponderal index is a common pediatric measure of leanness and is the preferred index because unlike BMI, it is not highly correlated with length (Ekelund et al., 2006). Ponderal index and growth percentiles were used as a measure of weight status.

We measured subcutaneous fat in millimeters (mm) at the abdomen, mid-thigh, and mid-calf using Lange-skinfold-calipers (Tanner & Whitehouse, 1975). While the infant is in a supine position, mid-thigh and mid-calf on the right leg were measured using a flexible measuring tape. Mid-thigh was determined by marking the greater trochanter and lateral condyle of the femur and measuring the midpoint in between. Mid-calf was determined by marking the condyle of the femur and lateral malleolus and measuring the midpoint in between. Horizontal abdominal skinfold was taken at approximately one cm lateral to the umbilicus on the right side (Ulrich, Lloyd, Tiernan, Looper, & Angulo-Barroso, 2008). We were quick in measuring skinfolds and waited between subsequent trials to prevent compression of the tissue, which can lead to underestimates of fat (Dauncey, Gandy, & Gairdner, 1977).

Physical Activity

Physical activity (PA) was measured once monthly during a 24-hour period using an Actical accelerometer (MiniMitter/Respironics Inc., Bend, OR). The monitor provides information on frequency, intensity, and duration of activity in a small, robust device. Actical's are the smallest motion sensor available, making them ideal for use with infants. This monitor has been used in research with infants before and has been found unobtrusive to the infant

(Ulrich, et al., 2008). Accelerometers are reliable with children ($r = 0.89$) (Pfeiffer, McIver, Dowda, Almeida, & Pate, 2006) and the preferred measure of PA.

Actical's have an omnidirectional sensor with a 0.5-3Hz range allowing them to measure movement in all directions. The Actical utilizes a sensor or accelerometer to quantify the occurrence and intensity of motion. This sensor incorporates the amplitude and frequency (32Hz) of motion and produces an electrical current that varies in magnitude. An increased intensity of movement produces an increase in voltage (Respironics, 2003). Actical stores this information as activity counts. These unitless activity counts are aggregated over a user-specified length of time known as an epoch. A detector within each device identifies the highest count per second and sums the total of peak values for each epoch. Fifteen second epochs are used in this study because they are sensitive to capturing the sudden, jerky movements produced by small children (Pfeiffer, et al., 2006).

Participants wore the monitor for 24 hours once monthly from one to six months of age. Infants wore the monitor on their right ankle and right wrist attached with an elastic band covered by a cloth sleeve. These monitors were easily removed for clothing change and bathing. During the monitoring period, each mother completed a monitoring log in order to corroborate the data received from the monitor. The log required the mother to classify the type of activity her infant engaged in as either sleeping, feeding, quiet play, active play, or being mechanically or adult handled in 30 minute intervals. This information is helpful in interpreting the intensity of infant PA as well providing a template to accurately remove data that reflects mechanical or adult handling rather than infant produced movement. This technique has been used previously and found to successfully correlate to infant activity (Tulve, Jones, McCurdy, & Croghan, 2007).

Data Reduction

An activity count (represented as a unitless whole number) is provided for each 15 second epoch, totaling 5760 numbers in a 24 hour monitoring period. These numbers can be accumulated and time stamped. We were able to attribute each number (representing an activity count that ranged from 0 to 200+) to a specific activity category by comparing time stamps to the monitoring log completed by the mother. These activity counts were then assigned to categories based on the mother's classification of her infant's activity. Categories included sleeping, feeding, quiet play, and active play. All activity counts that were classified by the mother as adult or mechanical handling were excluded. Once each activity count was classified into a category, each category was summed and a one-minute average was determined. The one-minute average of total activity was also calculated by combining all four categories. This yielded five total PA variables including one-minute average of total PA, one-minute average of sleeping PA, one-minute average of feeding PA, one-minute average of quiet play PA, and one-minute average of active play PA.

Statistical Approach

Relationships between variables and (possible non-linear) trends from one to six months of age on the key dependent variables were initially examined using scatterplots, and summarized with Pearson correlation coefficients (given linear relationships) and R^2 statistics. Mean differences between groups of infants based on infant PA at the ankle were examined using two-sample t-tests and supplemented with effect sizes and power estimates. We used Cohen's d effect sizes to provide a more comprehensive interpretation of results which will include a 0.50 to 0.80 effect size to represent a moderate meaningful difference (Cohen, 1977). Any value above 0.80 was considered a large meaningful difference.

We examined relationships between objective PA at the ankle and wrist with ponderal index and subcutaneous fat from one to six months of age using linear models with auto-correlated errors, given the longitudinal nature of these data. We analyzed dependent variables measuring ponderal index and subcutaneous fat as absolute values as well as month to month differences when examining relationships of these variables with PA. This modeling approach was used to estimate the relationship of PA with ponderal index and subcutaneous fat, while controlling for the relationship of age with the absolute value and change in value for each outcome. This approach, implemented using the MIXED procedure in SPSS Version 20, makes use of all available data for the repeatedly measured participants to examine trends in longitudinal data where missing data are sometimes present. This approach also offers an advantage over standard ordinary least squares (OLS) regression in that the correlations of errors can be modeled; longitudinal data sets often have correlated errors within individuals, and OLS regression assumes that these correlations are zero. If this assumption is incorrect, standard errors of estimated regression coefficients and subsequent statistical tests will also be incorrect.

Physical activity measured at the ankle, PA measured at the wrist, age, and age² (allowing for possible non-linear trends in the outcomes of interest over six months) were entered into the models as fixed effects. Based on initial scatter plots, fixed effects of squared versions of PA were added to the models as well if there was evidence of non-linear associations of PA with a particular dependent variable. Allowing errors in the model associated with the same infant to have a first-order auto-regressive correlation structure implied that observations closer to each other in age (e.g., month one and month two) had a stronger correlation than observations farther apart in age, which was found to be reasonable for these data. Estimates of

the correlations of adjacent errors in the models (represented by the parameter rho) were computed to indicate levels of dependency in these longitudinal data.

Results

To investigate differences in ponderal index and subcutaneous fat as they related to physical activity (PA) level, we grouped infants into either a high or low PA group (using the median value) given their average PA at the ankle from one to six months of age. We calculated group differences including effect size and power estimates for various growth variables including peak weight velocity (PWV), ponderal index, subcutaneous fat, and weight-for-length percentile as well as maternal body mass index (BMI). Peak weight velocity represents an infant's greatest rate of change in weight during a given month. We found that infants with high PA had a significantly lower PWV than infants with low PA. In addition, there are significant differences between PA groups for maternal BMI, with lower maternal BMI for infants in the high PA group (see Table 1.2).

We examined relationships between PA at the ankle and wrist with all other variables using linear models. For the dependent variable measuring PA at the ankle, a significant linear trend with age was found ($r = 0.420$, $p < 0.001$; $R^2 = 0.181$) (see Figure 1.1). As age increased by one month, the expected PA at the ankle increased by 21.37 counts per minute (see Table 1.3). For PA at the wrist, a significant quadratic trend from one to six months of age was found, where PA initially accelerated across the first five months then decelerated thereafter ($R^2 = 0.058$) (see Figure 1.2). As age increased by one month, the expected PA at the wrist increased by 39.90 counts per minute. After five months, as age increased by one month, the expected PA at the wrist decreased by 4.33 counts per minute (see Table 1.4). However, observations within participants were independent of each other (estimated $\rho = 0.21$, $SE = 0.16$).

For the dependent variable measuring change in subcutaneous fat from one month to the next, a strongly significant quadratic trend from one to six months of age was found, where the subcutaneous fat changes initially decelerated across the first four months and then slightly accelerated after five months ($R^2 = 0.441$) (see Figure 1.3 and Tables 1.3, 1.4). However, observations within participants were independent of each other for change in subcutaneous fat when examined with PA at the ankle (estimated $\rho = 0.02$, $SE = 0.12$) and wrist (estimated $\rho = -0.0033$, $SE = 0.14$). In addition, when controlling for this relationship of age with skinfold change, a significant linear relationship of PA at the ankle was found with skinfold change. Holding age fixed (e.g., for all infants with data at two age's), as PA at the ankle at a given month increased by one count per minute, the expected subcutaneous fat change relative to the previous month increased by 0.01 millimeters (mm) (see Table 1.3). That is, higher values for PA at the ankle in a given month were associated with larger changes in subcutaneous fat relative to the previous month. For subcutaneous fat (sum of skinfold thickness at three sites), a strongly significant quadratic trend from one to six months of age was found, where subcutaneous fat initially accelerated across the first four months and then decelerated through six months ($R^2 = 0.211$) (see Figure 1.4 and Tables 1.3, 1.4).

For the dependent variable measuring change in ponderal index from one month to the next, a significant quadratic trend from one to six months of age was found, where ponderal index changes initially decelerated slightly across the first three months and then accelerated slightly after five months ($R^2 = 0.041$) (see Figure 1.5 and Tables 1.3, 1.4).

Discussion

This is the first study to objectively quantify infant physical activity (PA) during the first six months of life. In addition, this is the first study to compare PA to how an infant grows on a

monthly basis. We present these results as a preliminary yet comprehensive effort to address the question of describing the trajectory of infant PA and its effects on growth during the first six months of life.

Infant growth is largely influenced by environmental factors with specific links to variable growth in the fetal and postnatal periods as a result of maternal influence. Peak weight velocity (PWV) and rapid growth in infants have both been attributed to gravid weight gain, maternal smoking, and infant nutritional practices (Botton, et al., 2008; Ekelund, et al., 2006; Mahrshahi, Battistutta, Magarey, & Daniels, 2011; Secker-Walker & Vacek, 2003). Moreover, rapid growth and greater peak weight velocity during infancy relate to later life obesity (Ekelund, et al., 2006; Taveras, et al., 2009). These factors have led researchers to consider early life as an important period for programming of later life obesity and health risk (Taveras, et al., 2009; Wells, Hallal, Wright, Singhal, & Victora, 0000).

Group difference results indicate that maternal BMI is significantly related to an infant's physical activity levels, with more physically active infants having mothers with lower BMIs. It is possible that maternal BMI is lower among more active mothers and increased PA among their infants is simply an artifact of maternal movement. Our results also indicate that peak weight velocity (PWV) significantly varies between infants with high or low PA levels. Infants who are more active experienced a lower PWV, indicating a reduction in rapid weight gain during a period of particular vulnerability. Upon further investigation, there was no evidence of a relationship between maternal BMI and peak weight velocity, suggesting infant PA as the potential catalyst linking the two. We are not suggesting a causal relationship, merely an association. Regardless, knowing the association of maternal BMI to infant PA levels and that these activity levels relate to the amount of peak weight an infant gains in a month, we have an

opportunity to identify infants at risk for experiencing a rapid weight gain during the first six months. Consequently, we are justified in thinking that altering PA levels in these infants may affect the amount of weight gained during that sensitive period, however more research is needed before any claim could be made.

Ekelund et al. (2006) reported an association of rapid weight gain during infancy with adult adiposity and obesity in later life. Early intervention to prevent rapid weight gain during the first six months of life needs to be a priority. A great opportunity for affecting childhood obesity is during the infancy period when development can be interrupted and possibly redirected to healthier patterns (Ariza, Greenberg, & Unger, 2004). Given our findings of lower PWV among highly active infants and our current knowledge of the association of early rapid growth and later onset obesity, one suggestion for intervention is to promote PA during early infancy.

Infants are capable of developing in many ways. In stable conditions, it can be expected that an infant's characteristics (growth, development, activity) will adapt to that environment (Bateson et al., 2004). Developmental plasticity encompasses those processes that generate an adaptive or maladaptive response to environmental influences occurring during development (Gluckman & Hanson, 2007). These adaptive and maladaptive responses are known to manifest as a change in phenotype, metabolic function, and growth among others (Bateson, et al., 2004; Gluckman & Hanson, 2007). Given the variable nature of infant development and the influence of developmental plasticity, it is plausible that modification of the environment to promote increased PA could result in an adaptive response for increased PA during infancy. If an activity promoting environment is stabilized and continued, we hypothesize that the sustained stimulus of increased PA could benefit the infant in terms of health and developmental outcomes

beyond the infancy period. In other words, would promoting an environment rich with highly motivating physical pursuits enable us to ‘preprogram’ an infant to increase their level of PA over a sustained period of time?

We measured infant PA at the ankle and wrist during a 24 hour period once a month for the first six months of life. We found that there is a clear trajectory of increased PA at both the ankle and wrist that can be expected as an infant ages from birth to six months. With each month, you can expect an increase of 21 activity counts per minute in PA at the ankle and a 40 count per minute increase in PA at the wrist, with a slight decrease in this trajectory at the wrist beyond five months of age. More drastic increases in PA were apparent from one to three months of age, with cumulative gains there onward. It is possible that more counts per minute of PA observed at the wrist than the ankle may be due to more use of the their hands to manipulate and explore objects. In addition, infants are often swaddled at the trunk and legs during early infancy which would constrict movement of the legs.

Our results also indicate that infant PA monitored at the ankle and wrist is highly variable from one infant to the next leading us to believe that there is such a thing as a highly active infant as well as a more sedentary infant. Not only is PA variable between infants, results from the linear model indicate high variability in PA monitored at the wrist within infants from month to month ($\rho = -0.33E^{-2}$, $SE = 0.14$). Pending evidence of intra-infant reliability during a 24 hour measurement period at a given age, this finding could suggest that it is possible to influence the PA level at the wrist for the same infant at a given time. However, one could attribute these independent observations within an infant as reliant on motor skill development. Fine motor milestones such as reaching and grasping are typically attained during the six month period when our study occurred and the onset of these milestones may relate to the dramatic change observed

in PA at the wrist. However these explanations need to be studied in more detail in future research.

Our results for PA at the ankle at six months are similar to another study measuring PA in six month old infants with and without iron deficiency (Angulo-Kinzler, et al., 2002). We found that six month old infants typically display approximately 120 counts per minute of PA at the ankle. Angulo-Kinzler et al. (2002) reported waking PA at the ankle for six month old infants as approximately 125 counts per minute. Despite these similarities, the PA for each of these studies were measured using different accelerometer models, therefore caution must be used when comparing results. In order to make results of raw PA data more comparable between devices for infant PA, we must first develop a method of classifying infant PA into intensity levels. This would create standardized criteria for interpreting infant PA results regardless of the device used to collect the data. A technique that is already available for interpreting PA from early childhood through adulthood. McKay and Angulo-Barroso (2006) were the first to report infant PA data categorizing activity as either high or low intensity using Actiwatch (Mini Mitter Company, OR, USA), which has rarely been replicated (Angulo-Barroso, et al., 2008). Despite these efforts, results of this study are still not comparable to others using a different accelerometer device. Future research should focus on continuing to better understand infant PA including interpreting the intensity of infant movement.

We measured subcutaneous fat at three sites once monthly for six months. We found that overall subcutaneous fat (sum of three sites) increased steadily from one to four months of age. During this same time, there is a notable steady decline in the monthly change in overall subcutaneous fat. This tells us that infants experienced a rapid increase in subcutaneous fat during the first three or four months of life, but that rapid gain was slightly smaller with each

passing month until four months of age. After four months of age, infants seemed to lose subcutaneous fat or at the very least maintain their current levels. During this same time, there appears to be little monthly change in overall subcutaneous fat. Not surprisingly, monthly change in ponderal index seems to follow the same trajectory with slightly smaller gains in ponderal indices through four months of age.

We compared our subcutaneous fat results to another study which reported skinfold thickness in typically developing infants from three to six months of age. McKay and Angulo-Barroso (2006) reported lower skinfold thickness values per month at the thigh and umbilical sites. When comparing shank sites, our findings are remarkably similar with less than one mm difference between the two studies. We had more than three times the sample size and varying standard deviations which we feel may reflect in differences observed at the umbilicus and thigh between the two studies.

We measured the developmental trajectory of ponderal index from birth through six months of age, but did not find a significant trend over time. Despite this, ponderal index was highly correlated from month to month within the same infant. One possible explanation for not finding a significant trend over time was that genders were combined during analyses. A similar study measured BMI at age 15 years and compared those results to previously recorded ponderal indices (Howe et al., 2010). They do not report linear model results examining ponderal index with age, however they included a graphic showing the trajectory of ponderal index by gender from birth to 24 months of age. We used this graphic to compare our ponderal index results from zero to six months. Like Howe and colleagues, we found that ponderal index increased from zero to three months of age, then decreased over the next three months with ponderal indices at six months nearing those at birth. Furthermore, we graphed ponderal indices by

gender and found that ponderal index trajectories did not closely mimic those presented by Howe and colleagues; however a similar trend was observed within genders. Males tended to experience more dramatic increases in ponderal index during the first three months when compared to girls. Given a larger sample size, perhaps our data would match other reported trends.

We've shown that infant PA measured at the ankle increased steadily from one to six months of age. Subcutaneous fat also increased steadily from one to four months of age. It is not surprising that a relationship between the two was detected with subcutaneous fat increasing by 0.01 millimeters (mm) with every one count per minute increase in PA at the ankle. Although this result is significant, we measured subcutaneous fat to the nearest 0.5 mm, therefore finding a difference in subcutaneous fat as a fraction of a mm is not particularly meaningful. Furthermore, in a study of nine and 14 month old Swedish infants, Tennefors et al. (2003) reported a significant negative relationship of PA to total body fat percentage. They reported that infants with increased PA have smaller total percent body fat. Results from Tennefors and colleagues report the opposite association of what our findings suggest, leading us to further question the meaningfulness of this finding. Continued study of these measures beyond six months of age may allow similar trends over time to emerge.

The developmental trajectories of subcutaneous fat and ponderal index seem to correspond with what is known about how infants gain weight in early infancy depending on their feeding modality. In 2001, Dewey et al. reported that infants who are primarily breastfed tend to gain weight rapidly in the first three months of life and then gain weight slowly for the remainder of infancy. Infants who are primarily formula fed gain weight at a slower rate for the first three months, and then experience rapid gains through 12 months of age (Dewey, Cohen,

Brown, & Rivera, 2001). These results were supported in a 2010 Centers for Disease Control (CDC) report which summarized the weight gain trends of infants in the first year of life between various growth charts (Grummer-Strawn, Reinold, & Krebs, 2010). Similarly, we found that infants gained subcutaneous fat and weight more rapidly in the first four months of life, which corresponded to increases in ponderal index during the same time. A majority of our sample was either breastfed or received formula in addition to breast milk during the study duration. Given this, we would expect the trajectories of subcutaneous fat and ponderal index over the first six months to closely mimic the weight gain trajectories of a breastfed infant.

At the end of six months, we classified the weight status of all 27 infants in our study using the 2006 WHO growth standards, which classify an infant as obese when they are above the 97.7th percentile for weight-for-length (Neelon, et al., 2011). We found that 26 of our infants had a healthy weight at age six months and only one infant was classified as obese at six months. When classified using the 2000 CDC growth charts, another six infants were identified as overweight (above the 85th percentile) and one additional infant is classified as obese (above the 95th percentile). As a result, it was more difficult for us to attribute PA differences at the ankle and wrist as a product of weight status. Given a larger sample size with greater variability in weight status at six months of age, perhaps a more stable relationship of PA level varying with healthy and obese weight groups would emerge. It is also suggested that future research include a larger distribution of large for gestational age infants.

Despite a somewhat homogenous sample, including similar maternal education level, feeding modality, and growth in the first six months, we provided a very comprehensive description of PA during the first six months of life. Our first hypothesis was accepted with contingencies. We found that infant physical activity can vary from one infant to the next and

does follow a predictable positive linear trend from one through six months of age. However, we found that the most dramatic increases in PA (both at the ankle and wrist) occurred during the first three months of infancy, rather than from three to six months of age. Our second hypothesis was rejected. We found little evidence to support an inverse trend of decreased ponderal indices and subcutaneous fat occurring within infants who have increased PA. We are not suggesting that this relationship does not exist; we were simply unable to demonstrate it. In addition, we reported emerging trends describing how maternal BMI and infant PWV are related to activity level. By using our descriptions within this cohort, we are able to identify infants at risk for lower levels of PA by looking at their mother's BMI. Theoretically, identified infants could then be recommended to a regimen of increased PA during the first six months of life. If we can substantially increase their level of PA, our research would suggest their risk of experiencing a greater PWV is reduced.

It is essential that we continue to examine, quantify, and understand PA patterns during infancy and the influence PA during this stage of development has on growth throughout childhood. We have taken an important step in describing the developmental trajectory of PA during the first six months of life. We think it would be valuable to continue to follow infants beyond the first six months to see how PA in early infancy influences later growth outcomes. Future research should focus on understanding how deviations in PA from this trajectory are associated with other areas of infant development. Furthermore, these results may be influential in designing PA interventions for infants at risk for rapid weight gain and increased risk of later life obesity.

References

- Angulo-Barroso, R., Burghardt, A., Lloyd, M., & Ulrich, D. (2008). Physical activity in infants with Down syndrome receiving a treadmill intervention. *Infant behavior & development*, *31*(2), 255.
- Angulo-Kinzler, R., Peirano, P., Lin, E., Garrido, M., & Lozoff, B. (2002). Spontaneous motor activity in human infants with iron-deficiency anemia. *Early human development*, *66*(2), 67.
- Ariza, A. J., Greenberg, R. S., & Unger, R. (2004). Childhood overweight: management approaches in young children. *Pediatr Ann*, *33*(1), 33-38.
- Ayerza, C. A., Rodriguez, M. G., Samper, V. M. P., Murillo, A. P., Alvarez, S. M. L., Moreno, A. L. A., & Olivares, L. J. L. (2011). Nutritional characteristics of newborns of overweight and obese mothers. *An Pediatr (Barc)*, *75*(3), 175-181. doi: 10.1016/j.anpedi.2011.03.001
- Bateson, P., Barker, D., Clutton-Brock, T., Deb, D., D'Udine, B., Foley, R. A., . . . Sultan, S. E. (2004). Developmental plasticity and human health. [10.1038/nature02725]. *Nature*, *430*(6998), 419-421.
- Botton, J., Heude, B., Maccario, J., Ducimetiere, P., & Charles, M. A. (2008). Postnatal weight and height growth velocities at different ages between birth and 5 y and body composition in adolescent boys and girls. *Am J Clin Nutr*, *87*(6), 1760-1768.
- The Children's Health Fund: Preventing pediatric diabetes: are racial disparities a factor? A children's health fund issue briefing. 1-6, 2004.

- Chomtho, S., Wells, J.C., Williams, J.E., Davies, P.S., Lucas, A., & Fewtrell., M. (2008). Infant growth and later body composition: evidence from the 4-component model. *The American journal of clinical nutrition*, 87(6), 1776.
- Cohen, D. (1977). *Statistical power analysis for the behavioral sciences* (Rev Ed). New York, NY: Academic Press. 1977
- Council on Sports Medicine and Fitness & Council on School Health (2006). Active Healthy Living: Prevention of Childhood Obesity Through Increased Physical Activity. *Pediatrics*, 117, 1834 -1842.
- Dauncey, M. J., Gandy, G., & Gairdner, D. (1977). Assessment of total body fat in infancy from skinfold thickness measurements. *Archives of disease in childhood*, 52(3), 223.
- Dewey, K. G., Cohen, R. J., Brown, K. H., & Rivera, L. L. (2001). Effects of exclusive breastfeeding for four versus six months on maternal nutritional status and infant motor development: results of two randomized trials in Honduras. *J Nutr*, 131(2), 262-267.
- Ekelund, U., Ong, K., Linne, Y., Neovius, M., Brage, S., Dunger, D. B., . . . Rossner, S. (2006). Upward weight percentile crossing in infancy and early childhood independently predicts fat mass in young adults: the Stockholm Weight Development Study (SWEDES). *Am J Clin Nutr*, 83(2), 324-330.
- Eriksson, J., Forsen, T., Osmond, C., & Barker, D. (2003). Obesity from cradle to grave. *Int J Obes Relat Metab Disord*, 27(6), 722-727.
- Gluckman, P. D., & Hanson, M. A. (2007). Developmental plasticity and human disease: research directions. *Journal of Internal Medicine*, 261(5), 461-471. doi: 10.1111/j.1365-2796.2007.01802.x

- Grummer-Strawn, L. M., Reinold, C., & Krebs, N. F. (2010). Use of World Health Organization and CDC growth charts for children aged 0-59 months in the United States. *MMWR Recomm Rep*, 59(RR-9), 1-15.
- Heinzer, M. (2005). Obesity in infancy: Questions, more questions, and few answers. *Newborn and infant nursing reviews*, 5(4), 194.
- Hesketh, K. D., & Campbell, K. J. (2010). Interventions to prevent obesity in 0-5 year olds: an updated systematic review of the literature. *Obesity*, 18(n1s), S27.
- Howe, L. D., Tilling, K., Benfield, L., Logue, J., Sattar, N., Ness, A. R., . . . Lawlor, D. A. (2010). Changes in ponderal index and body mass index across childhood and their associations with fat mass and cardiovascular risk factors at age 15. *PloS one*, 5(12), e15186. doi: 10.1371/journal.pone.0015186
- McCormick, D. P., Sarpong, K., Jordan, L., Ray, L. A., & Jain, S. (2010). Infant Obesity: Are We Ready to Make this Diagnosis? *The journal of pediatrics*, 157(1), 15.
- McKay, S. M., & Angulo-Barroso, R. M. (2006). Longitudinal assessment of leg motor activity and sleep patterns in infants with and without Down syndrome. *Infant Behavior and Development*, 29(2), 153-168. doi: DOI: 10.1016/j.infbeh.2005.09.004
- Mihrshahi, S., Battistutta, D., Magarey, A., & Daniels, L. A. (2011). Determinants of rapid weight gain during infancy: baseline results from the NOURISH randomised controlled trial. *BMC Pediatr*, 11, 99. doi: 10.1186/1471-2431-11-99
- Monasta, Batty, Cattaneo, Lutje, Ronfani, Van Lenthe, & Brug. (2010). Early life determinants of overweight and obesity: a review of systematic reviews. *Obesity reviews*, 11(10), 695.
- Monteiro, P. O. A., & Victora, C. G. (2005). Rapid growth in infancy and childhood and obesity in later life: a systematic review. *Obesity reviews*, 6(2), 143.

- Mook-Kanamori, D. O., Durmus, B., Sovio, U., Hofman, A., Raat, H., Steegers, E. A., . . . Jaddoe, V. W. (2011). Fetal and infant growth and the risk of obesity during early childhood: the Generation R Study. *Eur J Endocrinol*, *165*(4), 623-630. doi: 10.1530/eje-11-0067
- Moore, L. L., Gao, D., Bradlee, M. L., Cupples, L. A., Sundarajan-Ramamurti, A., Proctor, M. H., . . . Ellison, R. C. (2003). Does early physical activity predict body fat change throughout childhood? *Prev Med*, *37*(1), 10-17.
- Neelon, Oken, Taveras, Rifas-Shiman, & Gillman. (2011). Age of Achievement of Gross Motor Milestones in Infancy and Adiposity at Age 3 Years. *Matern Child Health J*. doi: 10.1007/s10995-011-0828-3
- Ogden, C. L. (2012). Prevalence of Obesity and Trends in Body Mass Index Among US Children and Adolescents, 1999-2010. *JAMA : the journal of the American Medical Association*, *307*(5), 483-490. doi: 10.1001/jama.2012.40
- Ogden, C. L., Carroll, M. E., Kit, B. K., & Flegal, K. M. (2012). Prevalence of obesity in the United States, 2009-2010. *NCHS Data Brief*(82), 1-8.
- Paul, Bartok, Downs, Stifter, Ventura, & Birch. (2009). Opportunities for the primary prevention of obesity during infancy. *Advances in pediatrics*, *56*(1), 107.
- Pfeiffer, K. A., McIver, K. L., Dowda, M., Almeida, M. J. C. A., & Pate, R. R. (2006). Validation and calibration of the Actical accelerometer in preschool children. *Medicine and science in sports and exercise*, *38*(1), 152.
- Respironics. (2003). Actical: physical activity monitoring system–instruction manual software version 2.0 Mini Mitter.

- Secker-Walker, R. H., & Vacek, P. M. (2003). Relationships between cigarette smoking during pregnancy, gestational age, maternal weight gain, and infant birthweight. *Addict Behav*, 28(1), 55-66.
- Tanner, J. M., & Whitehouse, R. H. (1975). Revised standards for triceps and subscapular skinfolds in British children. *Archives of disease in childhood*, 50(2), 142.
- Taveras, Blackburn, Gillman, Haines, McDonald, Price, & Oken. (2010). First Steps for Mommy and Me: A Pilot Intervention to Improve Nutrition and Physical Activity Behaviors of Postpartum Mothers and Their Infants. *Maternal and child health journal*.
- Taveras, Rifas-Shiman, Belfort, Kleinman, Oken, & Gillman. (2009). Weight status in the first 6 months of life and obesity at 3 years of age. *Pediatrics*, 123(4), 1177.
- Tennefors, C., Coward, W. A., Hernell, O., Wright, A., & Forsum, E. (2003). Total energy expenditure and physical activity level in healthy young Swedish children 9 or 14 months of age. *European journal of clinical nutrition*, 57(5), 647.
- Thelen, E., & Smith, L. (1994). Chapter 1, Lessons from learning to walk, in a *A dynamic systems approach to the development of cognition and action*. (pp. 3-20). Cambridge: MIT press.
- Tulve, N., Jones, P., McCurdy, T., & Croghan, C. (2007). A pilot study using an accelerometer to evaluate a caregiver's interpretation of an infant or toddler's activity level as recorded in a time activity diary. *Research Quarterly for Exercise and Sport*, 78(4), 375.
- Ulrich, Lloyd, Tiernan, Looper, & Angulo-Barroso. (2008). Effects of intensity of treadmill training on developmental outcomes and stepping in infants with Down syndrome: a randomized trial. *Physical Therapy*, 88(1), 114.

- Ulrich, & Ulrich. (1995). Spontaneous leg movements of infants with Down syndrome and nondisabled infants. *Child development*, 66(6), 1844.
- van Rossem, L., Taveras, E. M., Gillman, M. W., Kleinman, K. P., Rifas-Shiman, S. L., Raat, H., & Oken, E. (2011). Is the association of breastfeeding with child obesity explained by infant weight change? *Int J Pediatr Obes*, 6(2-2), e415-422. doi: 10.3109/17477166.2010.524700
- Vickers, M. H. (2011). Developmental programming of the metabolic syndrome - critical windows for intervention. *World J Diabetes*, 2(9), 137-148. doi: 10.4239/wjd.v2.i9.137
- Wells, J. C. K., Hallal, P. C., Wright, A., Singhal, A., & Victora, C. G. (0000). Fetal, infant and childhood growth: relationships with body composition in Brazilian boys aged 9 years. *Int J Obes Relat Metab Disord*, 29(10), 1192-1198.
- Wijlaars, L. P., Johnson, L., van Jaarsveld, C. H., & Wardle, J. (2011). Socioeconomic status and weight gain in early infancy. *Int J Obes (Lond)*, 35(7), 963-970. doi: 10.1038/ijo.2011.88

Table 1.1. Characteristics of participants and their families as percentage of the total sample.

	n = 27 (17 F, 10 M)
Infant Characteristics	
Race	
White (%)	81.5
Black (%)	7.4
Asian (%)	11.1
Gestational Size	
SGA (%)	33.3
AGA (%)	63.0
LGA (%)	3.7
Feeding Modality	
Exclusive Breastfeeding (%)	48.2
Mixed feeding (%)	40.7
Exclusive Formula feeding (%)	11.1
Maternal Characteristics (one month post gravid)	
Maternal Age (years)(mean \pm SD)	32.36 \pm 3.99
Marital Status	
Single (%)	7.4
Married (%)	88.9
Divorced (%)	3.7
Education Level	
High School (%)	7.4
Some College (%)	14.8
Associates (%)	7.4
Bachelors (%)	25.9
Masters (%)	29.6
Doctorate (%)	14.8
BMI	
Healthy (%)	37
Overweight (%)	29.6
Obese (%)	33.3

SGA = small for gestational age; AGA = appropriate for gestational age; LGA = large for gestational age; SD = standard deviation; BMI = body mass index

Table 1.2. Physical activity (PA) group differences (means \pm standard deviations) in PA, maternal BMI, and infant growth status from one to six months of age.

Infant Characteristics	Low PA [†] N = 13	High PA [†] N = 14	Effect Size	Power
Ankle PA	77.70 \pm 34.75	114.55 \pm 45.66**	0.91	0.62
Wrist PA	86.82 \pm 53.08	139.81 \pm 74.61**	0.82	0.53
PWV (kg)	1.35 \pm 0.27	1.14 \pm 0.24**	0.82	0.67
Ponderal Index	3.00 \pm 0.09	2.99 \pm 0.08	0.12	0.06
Skinfolds Sum (mm)	41.13 \pm 6.04	40.52 \pm 8.07	0.09	0.06
Wt_for_Length percentile	52.08 \pm 28.83	49.21 \pm 28.67	0.10	0.06
Maternal BMI	30.24 \pm 12.12	27.52 \pm 5.38*	0.29	0.11

*P<.05, ** P<.001; PA = physical activity; [†] = PA measured at the ankle; kg = kilograms; mm = millimeters; BMI = body mass index

Table 1.3. Estimated fixed effects (standard errors in parenthesis) in linear models incorporating physical activity (PA) at the ankle as a predictor.

DV	Intercept	PA Ankle	Age	Age ²	rho
PA @ Ankle	45.55 (14.60)*	X	21.37 (9.27)*	-1.44 (1.27)	0.40 (0.11)*
Δ Skinfolds Sum	19.66 (3.06)**	0.01 (0.79E ⁻²)	-8.05 (1.60)**	0.72 (0.20)**	0.02 (0.12)
Skinfolds Sum	25.33 (1.79)**	0.01 (0.85E ⁻²)	8.56 (0.97)**	-1.03 (0.13)**	0.81 (0.04)**
Δ Ponderal Index	0.09 (0.03)*	-0.20E ⁻³ (0.14E ⁻³)	-0.04 (0.02)*	0.52E ⁻² (0.26E ⁻²)*	-0.47 (0.10)**
Ponderal Index	3.02 (0.03)**	5.44E ⁻⁵ (0.13E ⁻³)	-0.94E ⁻² (0.01)	0.84E ⁻³ (0.19E ⁻²)	0.73 (0.06)**

*p<.05, **p<.001; PA = physical activity; Δ = change-in

Table 1.4. Estimated fixed effects (standard errors in parenthesis) in linear models incorporating physical activity (PA) at the wrist as a predictor.

DV	Intercept	PA Wrist	Age	Age ²	rho
PA @ Wrist	38.86 (29.38)	X	39.90 (18.76)***	-4.33 (2.57)*	0.21 (0.16)
Δ Skinfolds Sum	19.16 (3.72)***	0.34E ⁻² (0.56E ⁻²)	-7.37 (1.96)***	0.65 (0.24)**	-0.33E ⁻² (0.14)
Skinfolds Sum	28.39 (1.91)***	0.40E ⁻² (0.49E ⁻²)	7.31 (1.04)***	-0.87 (0.14)***	0.84 (0.04)***
Δ Ponderal Index	0.09 (0.03)**	-5.22E ⁻⁵ (0.10E ⁻²)	-0.04 (0.02)**	0.54E ⁻² (0.30E ⁻²)*	-0.39 (0.12)**
Ponderal Index	3.01 (0.03)***	1.26E ⁻⁵ (6.98E ⁻⁵)	0.50E ⁻² (0.02)	-0.13E ⁻² (0.19E ⁻²)	0.78 (0.05)***

*p<.10, **p<.05, ***p<.01; PA = physical activity; Δ = change-in

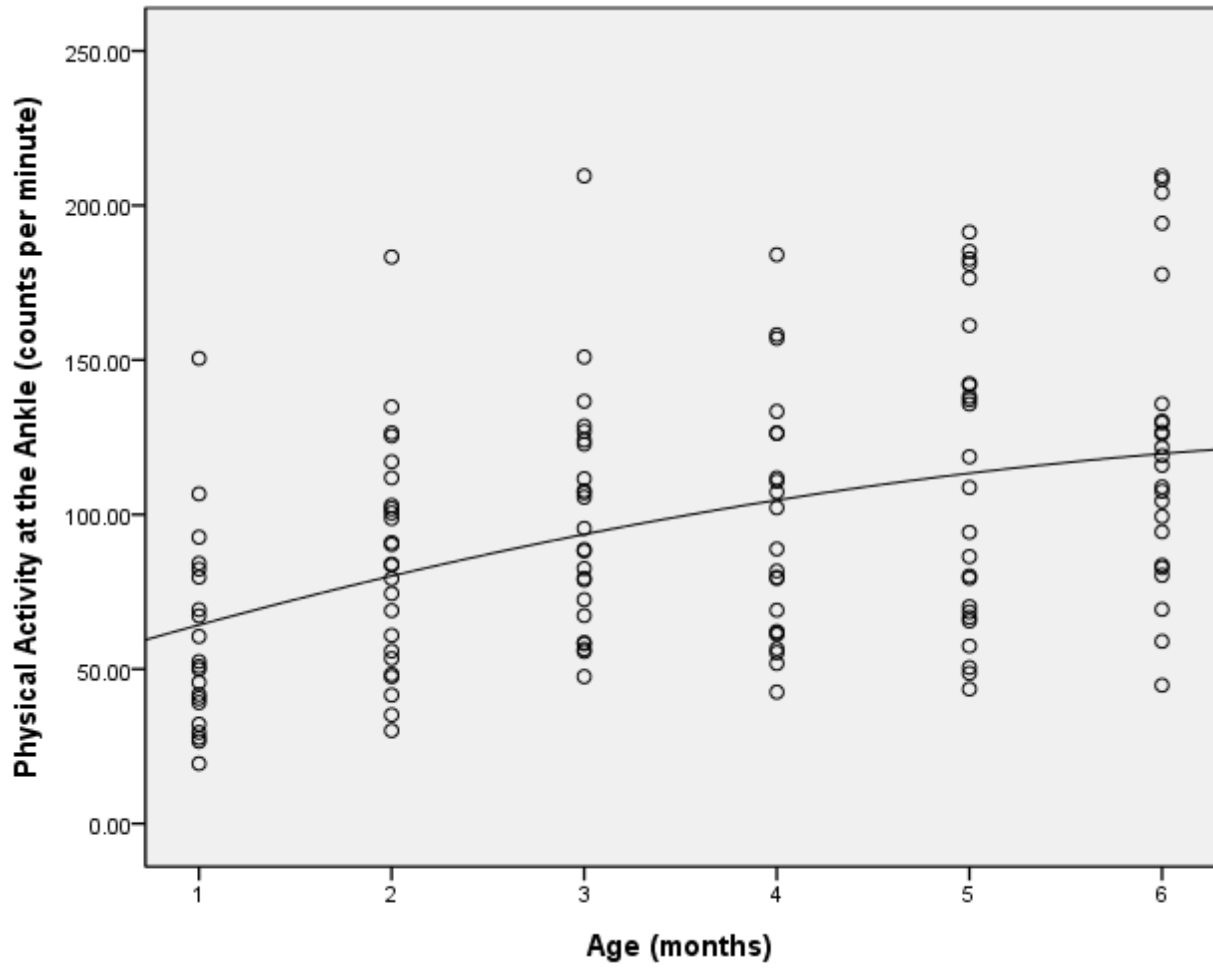


Figure 1.1. Physical activity (PA) at the ankle from one to six months of age.

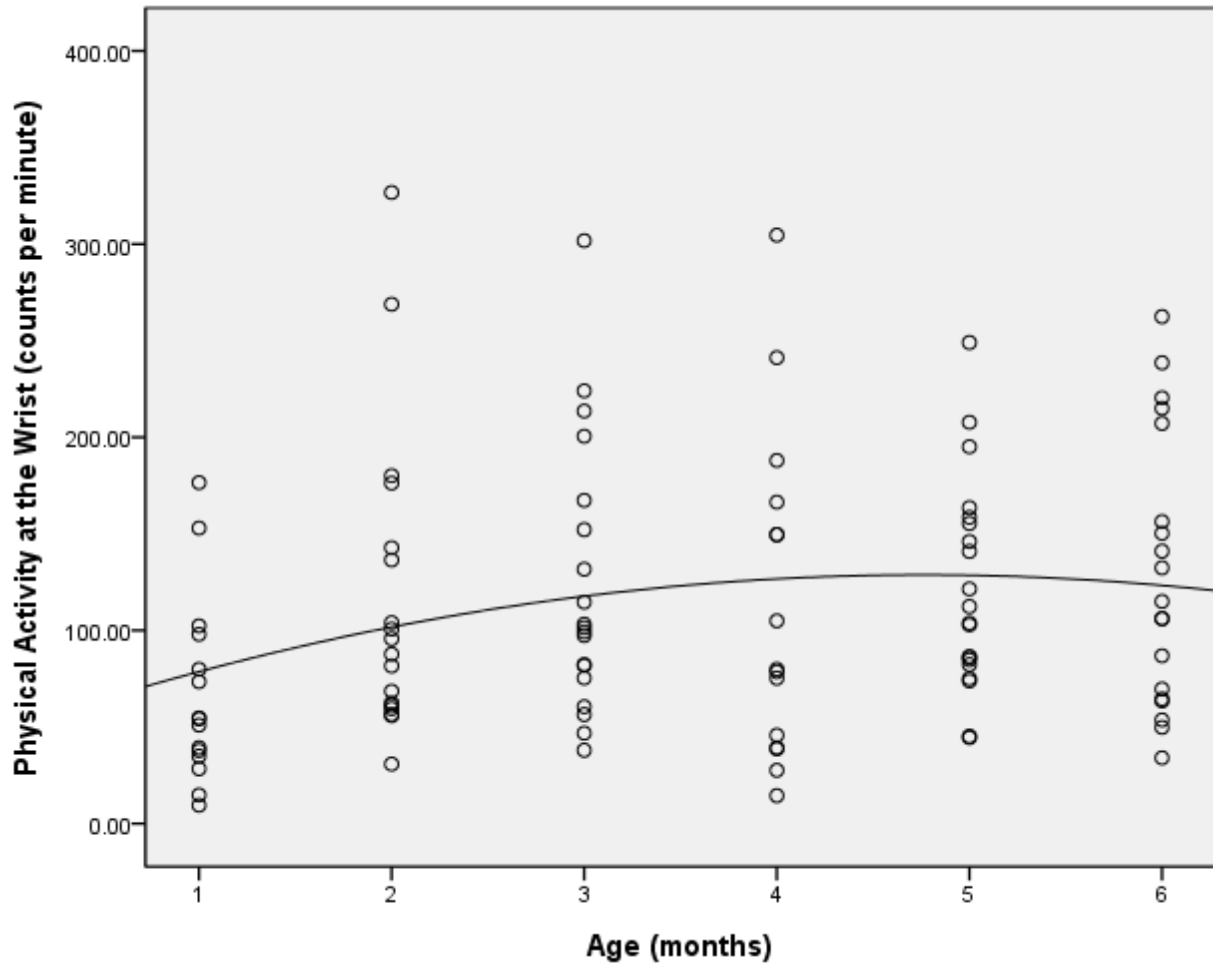


Figure 1.2. Physical activity (PA) at the wrist from one to six months of age.

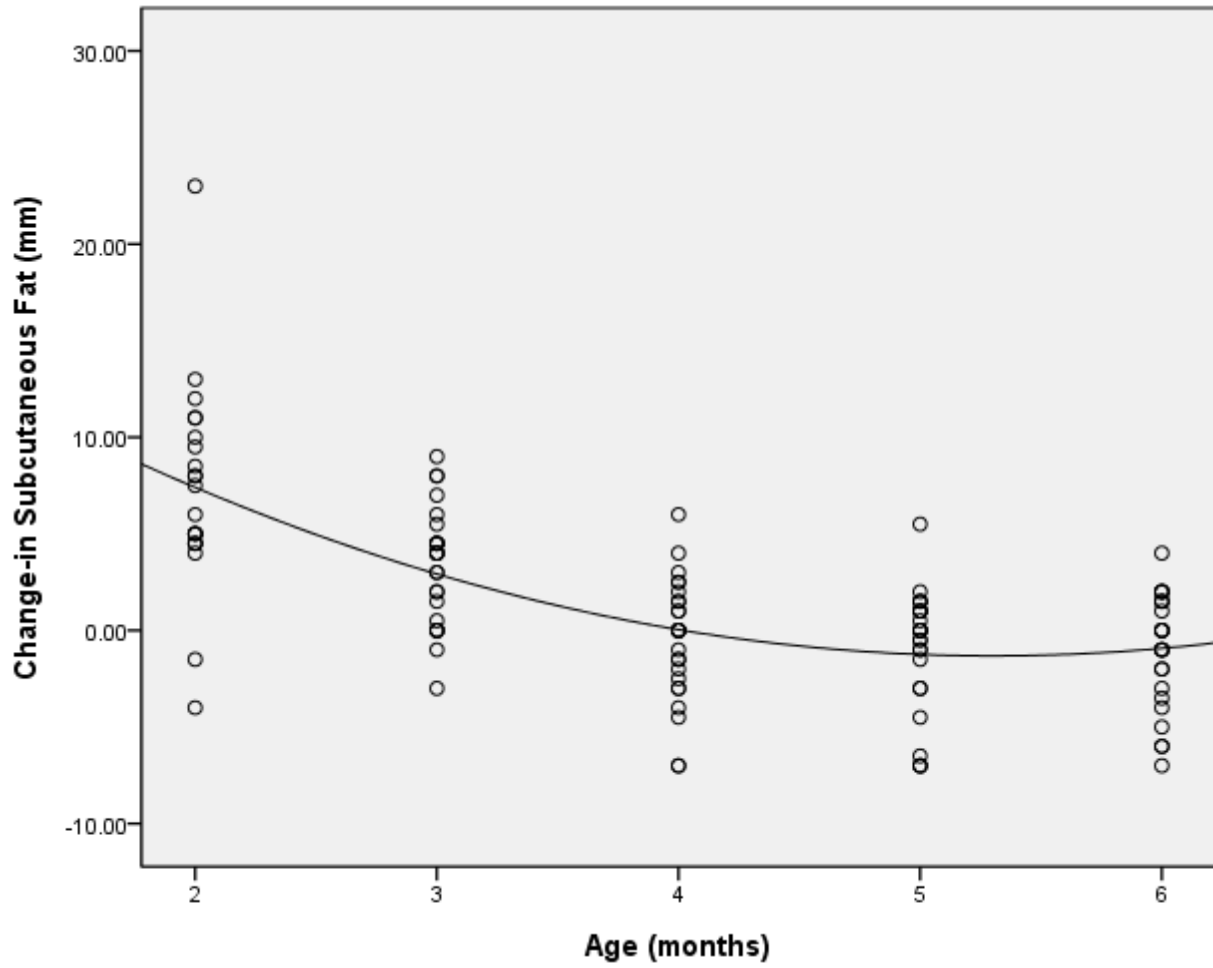


Figure 1.3. Change-in subcutaneous fat from two to six months of age.

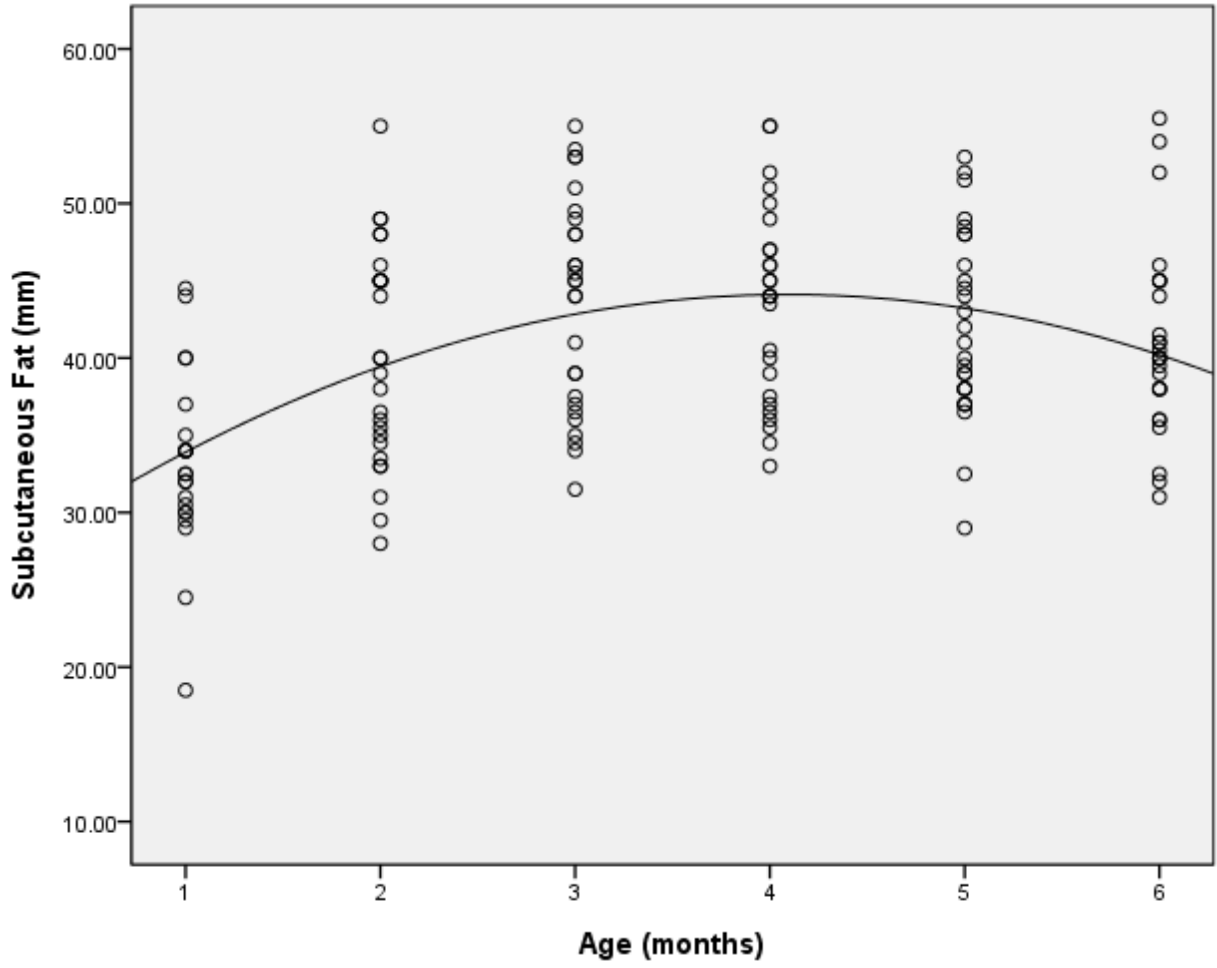


Figure 1.4. Subcutaneous fat from one to six months of age.

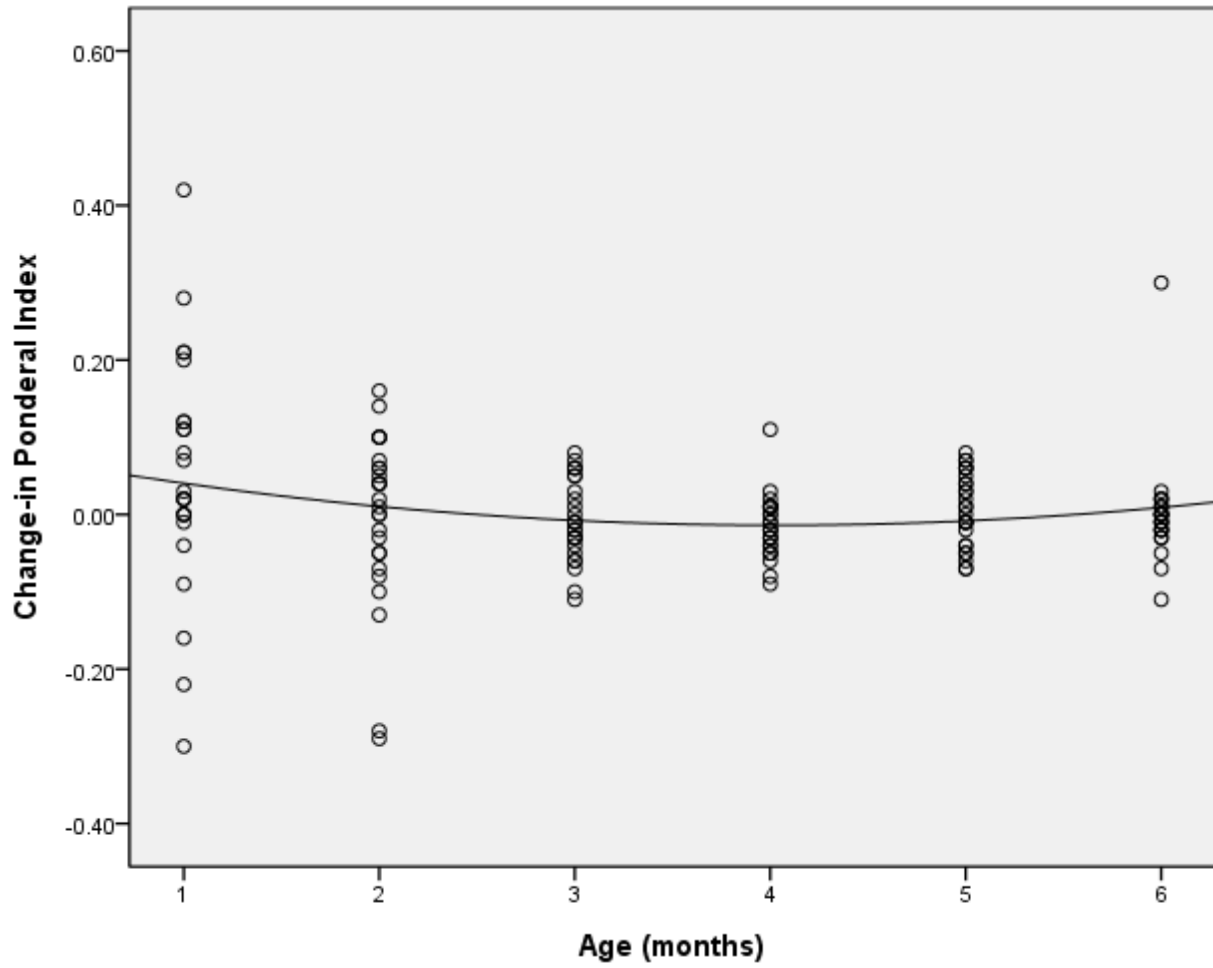


Figure 1.5. Change-in ponderal index from one to six months of age.

Chapter 2

The developmental relationship between physical activity and change in motor skill development during the first six months of life

Early motor activity has been indicated as an important contributor to overall development during childhood (McKay & Angulo-Barroso, 2006; Thelen, 1994; Ulrich & Ulrich, 1995). However, there is limited study of physical activity (PA) during infancy much less its contribution to motor milestone achievement (Angulo-Barroso, Burghardt, Lloyd, & Ulrich, 2008; Angulo-Kinzler, Peirano, Lin, Garrido, & Lozoff, 2002; McKay & Angulo-Barroso, 2006).

In a longitudinal study measuring leg motor activity for infants with and without Down syndrome, McKay and Angulo-Barroso (2006) indicate that infants with DS move as frequently as their typically developing peers, but with a reduction in intensity. Moreover, infants generating more minutes of low intensity PA tend to have more delayed onset of walking. This speculates a possible link between PA intensity and attainment of motor milestones beginning at three months of age. Similarly, Ulrich and Ulrich (1995) reported that infants with DS moved their legs just as frequently as chronological age and motor age matched peers but used different patterns of movement. Specifically, infants with DS demonstrated fewer kicking patterns. The frequency of this kicking behavior alone, was significantly related to onset of crawling and walking. These descriptive relationships suggest a trend of increased supine motor activity and motor skill achievement in later infancy. To explore these trends, recent research has incorporated PA training to determine if modifying PA can influence onset of motor milestones.

During a PA intervention involving treadmill training for infants with DS, Lloyd et al. (2007) demonstrated that infants with higher levels of PA captured at the waist via an accelerometer attained their sitting, pull-to-stand, and cruising motor milestones sooner. This provides preliminary evidence of a relationship between early trunk movement and motor skill development (Lloyd, Burghardt, Ulrich, & Angulo-Barroso, 2007).

In a longitudinal study investigating the effects of training intensity on PA during a treadmill training intervention for infants with Down syndrome (DS), Angulo-Barroso et al. (2008) were the first to present evidence suggesting sustained PA promotion via intervention efforts during infancy. Authors reported a positive relationship of training intensity to longitudinal PA intensity with infants participating in high intensity training demonstrating continued high intensity PA after training ended. Furthermore, Lloyd and colleagues (2007) demonstrated that those infants participating in higher levels of PA captured at the waist via an accelerometer attained their sitting, pull-to-stand, and cruising motor milestones sooner. This provides preliminary evidence of a relationship between early trunk movement and motor skill development.

To further explore the effect of PA intensity on motor skill attainment, Lloyd et al. (2010) investigated the relationship of training intensity to onset of walking for infants with DS receiving the same PA training. They found that infants who participated in high intensity treadmill training achieved the milestone of independent walking earlier than infants who received low intensity training (Lloyd, Burghardt, Ulrich, & Angulo-Barroso, 2010). Based on these results, authors suggest that higher intensity PA earlier in life may place an infant in a better developmental pathway to be more active as they age. Moreover, these results present

evidence suggesting intensity of PA in infancy does impact motor skills and that promoting leg activity is recommended to facilitate earlier walking onset in infants with DS.

Currently, there are no PA recommendations for children under five years of age which are evidence based (Paul et al., 2009). This is mostly due to lack of evidence in support of exercise recommendations for infants and toddlers for the purposes of promoting PA, motor skill development, or obesity prevention (Botton, Heude, Maccario, Ducimetiere, & Charles, 2008). Moreover, very little intervention research to modify excess weight gain or increase PA during infancy exists. With the few interventions that have attempted to modify excess weight gain, researchers have largely focused on nutritional habits (Ayerza et al., 2011; Taveras et al., 2010; Taylor et al., 2011). In a systematic review of the literature identifying obesity prevention interventions within the first five years of life, Hesketh and Campbell (2010) highlight childhood obesity prevention as a growing research area but note the relative lack of interventions targeting the child. Instead, researchers have focused their attention on the behaviors of parents.

Child PA is described as highly variable from one hour to the next and greatly influenced by a variety of factors including physiological, psychological, environmental, and cultural aspects (Goran, Reynolds, & Lindquist, 1999). Moreover, expanding a child's repertoire of motor skills through intervention can provide them with the resources to become more physically active (MacDonald et al., 2012), which is considered a primary means for combating obesity (Goran, et al., 1999). Many PA interventions for children do exist and have been systematically reviewed to reveal strong evidence for increasing PA (Dobbins, De Corby, Robeson, Husson, & Tirilis, 2009; van Sluijs, McMinn, & Griffin, 2007). However, researchers are continually faced with the issue of maintaining increased habitual PA after the intervention ends.

Recently, the development of an ‘Activitystat’ hypothesis has gained attention (Rowland, 1998). The Activitystat hypothesis suggests that there is a biological control center which maintains regulatory control over PA based on the body’s energy homeostasis. This hypothesis postulates that increases in habitual PA via interventions or otherwise will be counterbalanced by periods of compensatory sedentary behavior (Reilly, 2011). This regulatory control of energy output suggests that interventions to increase PA in childhood are unlikely to affect habitual PA in the long term (Wilkin, 2011). What is unknown is when this regulatory process is programmed and whether environmental factors early in life can influence the Activitystat set point within the individual. If this Activitystat process is enacted during infancy or early childhood, we could hypothetically perturb the set point by promoting increased PA and motor skill development during infancy.

Given evidence linking motor activity to motor skill development as well as the suggestion of the Activitystat hypothesis, it is critical that we understand the role of PA and its relationship to growth and development during infancy (Chomtho, 2008; Paul, et al., 2009).

Specific Aims

The primary aim of this study was to investigate the association of physical activity (PA) in early infancy to rate of gain in motor skill development during the first six months of life. This longitudinal study takes a novel approach to understanding PA and motor behavior at the earliest stage of life. This knowledge can be used to develop effective interventions for infants that may be at risk for motor delay and develop healthy PA recommendations for infants.

The following hypothesis was tested. The overall trend of PA from zero to six months of age will be related to monthly gains in motor skill development during the same period. A

positive relationship is anticipated with infants having the most PA displaying more rapid acquisition of motor skills than infants with the least PA.

Method

Participants

All methods and procedures were approved by the Health Sciences and Behavioral Sciences Institutional Review Board at the University of Michigan. All mother/neonate dyads were consented by the mother prior to participation in this study.

Twenty-eight mother/neonate dyads were recruited from Southeast Michigan to participate in this longitudinal study which consisted of six data collections each, yielding 168 total time points. Participants included mothers aged 18 years and older with a healthy infant less than six weeks of age. Infants were excluded who received a medical diagnosis that was suspected to impair or delay growth, muscle development, motor development, cognition, or nutritional status. Such diagnoses include but are not limited to cystic fibrosis, Down syndrome, neuromuscular disease, spina bifida, hypotonia, fetal alcohol syndrome, pre-mature birth (< 37 weeks gestation), etc. One mother/neonate dyad was dropped from the study after receiving a neuromuscular diagnosis which impairs growth and development. None of the remaining 27 dyads had a physical disability or medical condition which would limit or impair physical activity (PA) or growth. Participant characteristics and family demographic information including gender, race, gestational size, feeding modality, maternal marital status, maternal highest level of education, and maternal BMI were computed as percentages of the total sample and can be found in Table 2.1.

Procedures

During the study period, we collected data from each participant once monthly for six consecutive months. All data collections took place in the home of the infant, with the exception of initial recruitment information including gender, age, contact information, and address which was collected prior to the start of the study. The mother was present at all times. Collecting data at the home of each participant provided convenience and ease for the mother, as well as comfort for the infant. The first home visit occurred when the infant was aged approximately one month (+/- one week), with each subsequent home visit occurring when the infant was two, three, four, five, and six months of age (+/- one week). Participants received between \$15-\$25 cash incentive for participation during each home visit, totaling \$100 for full participation.

The research team included the principal investigator (PI) and five trained research assistants. The PI and one to two research assistants attended each one-hour home visit. Research assistants' responsibilities consisted of field work and lab work. Field tasks included assisting with equipment, data recording, stabilizing each infant's head and legs during anthropometric measurement, and interaction with siblings. Lab tasks included data entry and data reduction.

Measurement

During the study period, we monitored the PA and growth of each infant participant on a monthly basis. At the first home visit, measurements of demographic information, maternal height, weight, and some information relating to the preconception, prenatal and postpartum periods were collected. In addition, we administered a short survey of infant feeding modality each month.

During the first home visit, each mother completed a number of surveys including a maternal demographic survey, an infant demographic survey, and an intake survey which were used as a series of covariates that have been associated with infant and childhood obesity. The maternal supplemental information survey included maternal age, race, marital status, highest level of education, method of delivery, birth complications, and hospital discharge information. The infant demographic survey included date of birth, due date, race, medical conditions, birth weight, birth length, neonatal complications, and number of siblings including birth order. The intake survey consisted of questions regarding the preconception, prenatal, and postpartum periods including pregravid weight, diabetes status, hypertension status, prenatal care, gravid weight gain, and feeding modality (measured monthly). In addition to surveys, we measured maternal weight in kilograms (kg) using a Health O Meter H-349KL digital scale and height in centimeters (cm) using a SECA S-214 portable stadiometer one month postpartum. To calculate BMI, we converted height from cm to meters (m) and used the following formula: $\text{Weight (kg)} / \text{Height (m)}^2$.

Anthropometric Measurement

During each home visit, we measured infant weight, length, motor development, and 24 hour PA. These measures were repeated once monthly from one through six months of age. Infant weight (kg) was measured using a Tanita digital baby scale and infant recumbent crown-heel length (cm) was measured using an infant length board. The length board had a static headboard and moveable footboard. The infant's ankle was dorsiflexed while the body was aligned. Infants were measured in supine position wearing only a clean diaper.

Motor Development

During each home visit, we measured motor skill development emphasizing the achievement of new motor skill items using the Bayley Scales of Infant Development, 3rd edition (BSID-3) (Bayley, 2006). For data analysis, we summed gross and fine motor raw scores to create an overall motor development variable. In addition, change in motor skill development from month to month was calculated. The BSID-3 assessment is standardized and determines whether the infant is ahead, behind, or on time for acquisition of motor milestones. The same person administered this measure each month for all infants.

Physical Activity

Physical activity (PA) at the ankle and wrist were measured once monthly during a 24-hour period using an Actical accelerometer (MiniMitter/Respironics Inc., Bend, OR). The monitor provides information on frequency, intensity, and duration of activity in a small, robust device. Actical's are the smallest motion sensor available, making them ideal for use with infants. This monitor has been used in research with infants before and has been found unobtrusive to the infant (Ulrich, Lloyd, Tiernan, Looper, & Angulo-Barroso, 2008). Accelerometers are reliable with children ($r = 0.89$) (Pfeiffer, McIver, Dowda, Almeida, & Pate, 2006) and the preferred measure of PA.

Actical's have an omnidirectional sensor with a 0.5-3Hz range allowing them to measure movement in all directions. The Actical utilizes a sensor or accelerometer to quantify the occurrence and intensity of motion. This sensor incorporates the amplitude and frequency (32Hz) of motion and produces an electrical current that varies in magnitude. An increased intensity of movement produces an increase in voltage (Respironics, 2003). Actical stores this information as activity counts. These unitless activity counts are aggregated over a user-

specified length of time known as an epoch. A detector within each device identifies the highest count per second and sums the total of peak values for each epoch. Fifteen second epochs are used in this study because they are sensitive to capturing the sudden, jerky movements produced by small children (Pfeiffer, et al., 2006).

Participants wore the monitor for 24 hours once monthly from one to six months of age. Infants wore the monitor on their right ankle and right wrist attached with an elastic band covered by a cloth sleeve. These monitors were easily removed for clothing change and bathing. During the monitoring period, each mother completed a monitoring log in order to corroborate the data received from the monitor. The log required the mother to classify the type of activity her infant engaged in as either sleeping, feeding, quiet play, active play, or being mechanically or adult handled in 30 minute intervals. This information is helpful in interpreting the intensity of infant PA as well providing a template to accurately remove data that reflects mechanical or adult handling rather than infant produced movement. This technique has been used previously and found to successfully correlate to infant activity (Tulve, Jones, McCurdy, & Croghan, 2007).

Data Reduction

An activity count (represented as a unitless whole number) is provided for each 15 second epoch, totaling 5760 numbers in a 24 hour monitoring period. These numbers can be accumulated and time stamped. We were able to attribute each number (representing an activity count that ranged from 0 to 200+) to a specific activity category by comparing time stamps to the monitoring log completed by the mother. These activity counts were then assigned to categories based on the mother's classification of her infant's activity. Categories included sleeping, feeding, quiet play, and active play. All activity counts that were classified by the mother as

adult or mechanical handling were excluded. Once each activity count was classified into a category, each category was summed and a one-minute average was determined. The one-minute average of total activity was also calculated by combining all four categories. This yielded five total PA variables including one-minute average of total PA, one-minute average of sleeping PA, one-minute average of feeding PA, one-minute average of quiet play PA, and one-minute average of active play PA.

Statistical Approach

Relationships between variables and (possible non-linear) trends from one to six months of age on the key dependent variables were initially examined using scatterplots, and summarized with Pearson correlation coefficients (given linear relationships) and R^2 statistics. Mean differences between groups of infants based on infant PA at the ankle and wrist were examined using two-sample t-tests and supplemented with effect sizes and power estimates. We used Cohen's d effect sizes to provide a more comprehensive interpretation of results which will include a 0.50 to 0.80 effect size to represent a moderate meaningful difference (Cohen, 1977). Any value above 0.80 was considered a large meaningful difference.

We examined the concurrent serial data on objective PA measured at the ankle and wrist and monthly change in motor skill development incorporating a mixed-effects modeling approach. This modeling approach was used to estimate the relationship of PA with change in motor skill development, while controlling for the relationship of age with the change in each outcome. This approach, implemented using the MIXED procedure in SPSS Version 20, makes use of all available data for the repeatedly measured subjects to examine trends in longitudinal data where missing data are often present. This approach also offers an advantage over standard ordinary least squares (OLS) regression in that the correlations of errors can be modeled;

longitudinal data sets often have correlated errors within individuals, and OLS regression assumes that these correlations are zero. If this assumption is incorrect, standard errors of estimated regression coefficients and subsequent statistical tests will also be incorrect.

Physical activity measured at the ankle, PA measured at the wrist, age, and age² (allowing for possible non-linear trends in the outcomes of interest over six months) were entered into the models as fixed effects. Based on initial scatter plots, fixed effects of squared versions of PA were added to the models as well if there was evidence of non-linear associations of PA with a particular dependent variable. Allowing errors in the model associated with the same infant to have a first-order auto-regressive correlation structure implied that observations closer to each other in age (e.g., month one and month two) had a stronger correlation than observations farther apart in age, which was found to be reasonable for these data. Estimates of the correlations of adjacent errors in the models (represented by the parameter rho) were computed to indicate levels of dependency in these longitudinal data.

Results

To establish possible gender differences from one to six months for PA and motor skill development, we examined the trajectories of each measure using scatterplots. We found an observable difference in the trajectory of PA at the ankle and wrist with females displaying elevated amounts of PA. The discrepancy in PA from males to females is not consistent from month to month with the greatest difference appearing at one month of age for both PA at the ankle and wrist. For motor skill development, we found no discernible difference in the trajectory of cumulative motor development between genders.

To investigate differences in motor skill development as it related to physical activity (PA) level, we grouped infants into either a high or low PA group (using the median value) given

their average PA at the ankle and wrist from one to six months of age. We calculated group differences including effect size and power estimates for various motor skill development variables including cumulative motor skill development and age at onset of six specific motor skills. We found that infants with high PA at the ankle had significantly greater overall motor development as well as fine motor and gross motor development (see Table 2.2). We found that infants with high PA at the wrist had significantly earlier onset of age for six motor milestones including supine reach, extended arms in prone position, whole hand grasp, supine to prone roll, and independent sitting for 30 and 60 seconds (see Table 2.3).

We examined relationships between PA at the ankle and wrist with both cumulative and monthly change in motor skill development using linear models. For the dependent variable measuring change in motor skill development from one month to the next, a significant quadratic trend with age was found, where change in motor development initially accelerated across the first four months then gradually decelerated thereafter ($R^2 = 0.063$) (see Figure 2.1 and Tables 2.4, 2.4). However, observations within participants were independent of each other for change in motor skill development when examined with PA at the wrist (estimated $\rho = -0.15$, $SE = 0.13$). For motor skill development (cumulative value), a significant linear trend from one to six months of age was found, where motor skill development increased at a constant rate from one through six months ($r = 0.957$, $p < 0.001$; $R^2 = 0.915$) (see Figure 2.2 and Tables 2.4, 2.5). When motor skill development is modeled with PA at the ankle, every one month increase in age will result in an expected increase in motor skill development by 8.05 skills. When modeled with PA at the wrist, every one month increase in age will result in an expected increase in motor skill development by 6.50 skills.

Discussion

This is the first study to objectively quantify infant physical activity (PA) beginning at one month of age. In addition, we are the first to compare PA to rate of motor skill development on a monthly basis this early in life. We present these results as a preliminary yet comprehensive effort to address the question of describing the relationship of infant PA to motor skill development during the first six months of life. We assume that increases in motor skill development result in a larger repertoire of motor behaviors that can be used within a physical activity context.

There appears to be a trend of increased motor development among infants who are more physically active. Group difference results for PA at the ankle indicate that overall motor development including fine and gross motor skill development are significantly related to an infant's PA level, with infants having more physically active legs demonstrating improved motor skill development. Group difference results for PA at the wrist indicate that acquisition of six specific motor skills is significantly related to an infant's PA level, with infants having more physically active arms acquiring specific motor skills at a significantly younger age. Motor skills included supine reach, extended arms in prone position, whole hand grasp, supine to prone roll, and independent sitting for 30 and 60 seconds.

We are pleased to see these trends develop but feel it is important to interpret why PA at the ankle and wrist vary in strength with their relationship to different components of motor development. The Bayley Scales of Infant Development-3 (Bayley, 2006) assessed in early infancy is more sensitive to attainment of new motor milestones involving the upper body. For this reason, wrist placement PA data was stronger at observing subtle changes in motor milestones relating to PA. With careful consideration of the six specific skills analyzed, four of

the six skills directly relate to upper body development (including using the arms for stabilization for the task of independent sitting for 30 seconds). On the other hand, ankle placement PA data was stronger at identifying changes in overall total motor development relating to PA, oddly enough, this included fine motor development. These findings suggest that PA measured at the ankle may be more robust in determining relationships of PA to early motor skill development.

Lloyd et al. (2010) conducted a similar study measuring the association of motor skill acquisition to leg PA levels in 12 and 14 month old infants with Down syndrome. Their results were similar in that infants producing higher intensity PA (increased intensity, not amount) acquired independent walking at an earlier age. Given a clear relationship linking increased PA to earlier onset of motor milestones, we would encourage further investigation of this relationship to determine whether advanced motor skill development is causing an increase in PA or if high PA levels are influencing motor skill acquisition.

We measured motor skill development once monthly for the first six months of life. We found that there is a clear trajectory of increased motor skill development that can be expected as an infant ages from one to six months. With each month, you can expect an increase in 7 to 8 motor skills during the first six months of life, regardless of gender. During this same time, there is a notable increase in the monthly change in overall motor skill development until four months of age at which point infants experienced less drastic monthly increases in motor skill development. This tells us that the greatest acceleration of motor skill development is occurring at approximately four months of age. When this analysis was run accessing the relationship of motor skill development to PA at the wrist, we found variability from month to month in overall motor skill development within infants, indicating that observations within an infant were not highly correlated with each other. This was not the case when evaluating the relationship of PA

at the ankle to motor skill development which is what we would suspect given the highly significant positive linear relationship of motor skill development from one to six months of age.

We compared our motor skill development results to another study which reported motor development in typically developing infants from three to six months of age. McKay and Angulo-Barroso (2006) used an earlier edition of the Bayley Scales assessment (Bayley, 1993) to measure and determine cumulative motor scores and reported considerably lower scores per month. Our sample displayed consistently higher motor scores each month. We do not believe this difference is the result of measurement error or bias. The administration manuals for both editions are very similar and we followed the manual meticulously when assessing motor development. We had more than three times the sample size and considerably larger standard deviations in monthly motor scores however, suggesting that our sample included a few infants that were quite precocious in their motor development.

There is great variability in PA at the ankle and wrist which is evidenced by high standard deviations observed in the comparisons. This variability led to a reduction of statistical power in the comparison of means analyses. Despite low power to detect differences between groups, we still found a significant relationship between level of ankle PA and overall motor scores as well as wrist PA and age of onset of six specific motor skills. Unfortunately, we were not able to detect a relationship between level of PA and motor skill development using linear modeling. We suspect that our small sample size, combined with large standard deviations is at fault for our inability to determine a clear relationship using linear modeling when our mean PA group data demonstrates an association of motor development with PA level.

It has been hypothesized that various mammals including humans demonstrate an ‘Activitystat.’ An Activitystat suggests humans display consistent rank orders over age within a

large group based on their non-exercise physical activity. To further investigate the individual variation in PA between infants in this study as it relates to the Activitystat hypothesis, we assigned a rank order to each infant's PA level from one to six months of age. This allowed us to identify which infants were the most and least physically active during each month. We then tracked the trajectory of these rank orders for each infant from one to six months to see if there was intra-variability in rank from month to month. It does not appear that an Activitystat is observable in the first six months of life. These results are consistent for both PA at the ankle and wrist. Seventeen out of 27 infants experienced dramatic deviations in their rank order (rank change > 5 places) of PA from one to six months. Interestingly, the 10 infants whose rank order remained relatively constant (rank change < 5 places) from one to six months were those whose PA clustered towards the mean. Infants with the highest and lowest levels of PA were most likely to deviate dramatically in rank order from month to month. This may indicate that the Activitystat regulatory system is not fully programmed by six months of age. These results lend more evidence to suggest that early infancy represents a critical period in development for promoting certain behaviors such as PA and motor skill development as well as preventing others including rapid weight gain. Furthermore, lack of evidence of an Activitystat in early infancy presents a unique opportunity to perturb or manipulate the PA homeostasis set point by promoting increased PA during the first six months of life.

Despite a somewhat homogenous sample, including similar maternal education level, feeding modality, and motor skill development in the first six months, we provided a very comprehensive description of the association of PA to motor skill development during the first six months of life. Our hypothesis was confirmed. We found that infant physical activity can vary from one infant to the next and does relate to overall motor development and age of onset of

specific motor milestones. In addition, we reported new evidence to suggest the absence of an Activitystat in the first six months of life.

It is essential that we continue to examine, quantify, and understand PA patterns during infancy and the influence PA during this stage of development has on motor skill development and PA behaviors throughout childhood. We think it would be valuable to continue to follow infants beyond the first six months to see how PA in early infancy influences later motor skill development and PA levels (eg. 12 and 18 months of age). Future research should focus on understanding how changes in PA during infancy can influence other areas of infant development. Furthermore, these results should be considered when designing motor skill development interventions for infants at risk for motor delay.

References

- Angulo-Barroso, R., Burghardt, A., Lloyd, M., & Ulrich, D. (2008). Physical activity in infants with Down syndrome receiving a treadmill intervention. *Infant behavior & development, 31*(2), 255.
- Angulo-Kinzler, R., Peirano, P., Lin, E., Garrido, M., & Lozoff, B. (2002). Spontaneous motor activity in human infants with iron-deficiency anemia. *Early human development, 66*(2), 67.
- Ayerza, C. A., Rodriguez, M. G., Samper, V. M. P., Murillo, A. P., Alvarez, S. M. L., Moreno, A. L. A., & Olivares, L. J. L. (2011). Nutritional characteristics of newborns of overweight and obese mothers. *An Pediatr (Barc), 75*(3), 175-181. doi: 10.1016/j.anpedi.2011.03.001
- Bayley, N. (1993). *Bayley Scales of Infant Development* (2nd ed.). San Antonio, TX: The Psychological Corporation.
- Bayley, N. (2006). *Bayley Scales of Infant and Toddler Development*. San Antonio, TX: The Psychological Corporation.
- Botton, J., Heude, B., Maccario, J., Ducimetiere, P., & Charles, M. A. (2008). Postnatal weight and height growth velocities at different ages between birth and 5 y and body composition in adolescent boys and girls. *Am J Clin Nutr, 87*(6), 1760-1768.
- Chomtho, S., Wells, J.C., Williams, J.E., Davies, P.S., Lucas, A., & Fewtrell., M. (2008). Infant growth and later body composition: evidence from the 4-component model. *The American journal of clinical nutrition, 87*(6), 1776.
- Cohen, D. (1977). *Statistical power analysis for the behavioral sciences* (Rev Ed). New York, NY: Academic Press. 1977

- Dobbins, M., De Corby, K., Robeson, P., Husson, H., & Tirilis, D. (2009). School-based physical activity programs for promoting physical activity and fitness in children and adolescents aged 6-18. *Cochrane Database Syst Rev*(1), CD007651. doi: 10.1002/14651858.cd007651
- Goran, M. I., Reynolds, K. D., & Lindquist, C. H. (1999). Role of physical activity in the prevention of obesity in children. *Int J Obes Relat Metab Disord*, 23 Suppl 3, S18-33.
- Hesketh, K. D., & Campbell, K. J. (2010). Interventions to prevent obesity in 0-5 year olds: an updated systematic review of the literature. *Obesity*, 18(n1s), S27.
- Lloyd, M., Burghardt, A., Ulrich, D., & Angulo-Barroso, R. (2010). Physical activity and walking onset in infants with Down syndrome. *Adapted physical activity quarterly*, 27(1), 1-16.
- Lloyd, M., Burghardt, A., Ulrich, D. A., & Angulo-Barroso, R. M. (2007). Relationship between early physical activity and motor milestone achievement in infants with Down syndrome. *Journal of Sport and Exercise Psychology*, 29(July 2007 Supplement).
- MacDonald, M., Esposito, P., Hauck, J., Jeong, I., Hornyak, J., Argento, A., & Ulrich, D. A. (2012). Bicycle Training for Youth With Down Syndrome and Autism Spectrum Disorders. *Focus on Autism and Other Developmental Disabilities*, 27(1), 12-21. doi: 10.1177/1088357611428333
- McKay, S. M., & Angulo-Barroso, R. M. (2006). Longitudinal assessment of leg motor activity and sleep patterns in infants with and without Down syndrome. *Infant Behavior and Development*, 29(2), 153-168. doi: DOI: 10.1016/j.infbeh.2005.09.004
- Paul, Bartok, Downs, Stifter, Ventura, & Birch. (2009). Opportunities for the primary prevention of obesity during infancy. *Advances in pediatrics*, 56(1), 107.

- Pfeiffer, K. A., McIver, K. L., Dowda, M., Almeida, M. J. C. A., & Pate, R. R. (2006). Validation and calibration of the Actical accelerometer in preschool children. *Medicine and science in sports and exercise*, 38(1), 152.
- Reilly, J. J. (2011). Can we modulate physical activity in children? *Int J Obes (Lond)*, 35(10), 1266-1269. doi: 10.1038/ijo.2011.62
- Respironics. (2003). Actical: physical activity monitoring system—instruction manual software version 2.0 Mini Mitter.
- Rowland, T. W. (1998). The biological basis of physical activity. *Med Sci Sports Exerc*, 30(3), 392-399.
- Taveras, Blackburn, Gillman, Haines, McDonald, Price, & Oken. (2010). First Steps for Mommy and Me: A Pilot Intervention to Improve Nutrition and Physical Activity Behaviors of Postpartum Mothers and Their Infants. *Maternal and child health journal*.
- Taylor, B. J., Heath, A. L., Galland, B. C., Gray, A. R., Lawrence, J. A., Sayers, R. M., . . . Taylor, R. W. (2011). Prevention of Overweight in Infancy (POI.nz) study: a randomised controlled trial of sleep, food and activity interventions for preventing overweight from birth. *BMC Public Health*, 11, 942. doi: 10.1186/1471-2458-11-942
- Thelen, E., & Smith, L. (1994). Chapter 1, Lessons from learning to walk, in a *A dynamic systems approach to the development of cognition and action*. (pp. 3-20). Cambridge: MIT press.
- Tulve, N., Jones, P., McCurdy, T., & Croghan, C. (2007). A pilot study using an accelerometer to evaluate a caregiver's interpretation of an infant or toddler's activity level as recorded in a time activity diary. *Research Quarterly for Exercise and Sport*, 78(4), 375.

- Ulrich, Lloyd, Tiernan, Looper, & Angulo-Barroso. (2008). Effects of intensity of treadmill training on developmental outcomes and stepping in infants with Down syndrome: a randomized trial. *Physical Therapy*, 88(1), 114.
- Ulrich, & Ulrich. (1995). Spontaneous leg movements of infants with Down syndrome and nondisabled infants. *Child development*, 66(6), 1844.
- van Sluijs, E. M., McMinn, A. M., & Griffin, S. J. (2007). Effectiveness of interventions to promote physical activity in children and adolescents: systematic review of controlled trials. *BMJ*, 335(7622), 703. doi: 10.1136/bmj.39320.843947.BE
- Wilkin, T. J. (2011). Can we modulate physical activity in children? No. *Int J Obes (Lond)*, 35(10), 1270-1276. doi: 10.1038/ijo.2011.163

Table 2.1. Characteristics of participants and their families as percentage of the total sample.

	n = 27 (17 F, 10 M)
Infant Characteristics	
Race	
White (%)	81.5
Black (%)	7.4
Asian (%)	11.1
Gestational Size	
SGA (%)	33.3
AGA (%)	63.0
LGA (%)	3.7
Feeding Modality	
Exclusive Breastfeeding (%)	48.2
Mixed feeding (%)	40.7
Exclusive Formula feeding (%)	11.1
Maternal Characteristics (one month post gravid)	
Maternal Age (years)(mean \pm SD)	32.36 \pm 3.99
Marital Status	
Single (%)	7.4
Married (%)	88.9
Divorced (%)	3.7
Education Level	
High School (%)	7.4
Some College (%)	14.8
Associates (%)	7.4
Bachelors (%)	25.9
Masters (%)	29.6
Doctorate (%)	14.8
BMI	
Healthy (%)	37
Overweight (%)	29.6
Obese (%)	33.3

SGA = small for gestational age; AGA = appropriate for gestational age; LGA = large for gestational age; SD = standard deviation; BMI = body mass index

Table 2.2. Physical activity (PA) group differences (means \pm standard deviations) in PA at the ankle and motor skill development from one to six months of age.

Infant Characteristics	Low PA [†] N = 13	High PA [†] N = 14	Effect Size	Power
Ankle PA (counts)	73.02 \pm 24.61	151.91 \pm 29.25**	2.92	0.99
Wrist PA (counts)	103.34 \pm 70.96	139.17 \pm 61.18*	0.54	0.27
Motor Development (raw score)	26.52 \pm 14.02	37.26 \pm 11.33**	0.84	0.56
Fine Motor (raw score)	10.32 \pm 6.35	15.51 \pm 5.42**	0.88	0.59
Gross Motor (raw score)	16.14 \pm 7.90	21.74 \pm 6.11**	0.79	0.51
Supine reach (months)	4.10 \pm 0.69	3.91 \pm 0.61	0.29	0.11
Prone extended arms (months)	4.82 \pm 0.81	4.88 \pm 0.79	0.07	0.05
Whole hand grasp (months)	4.78 \pm 0.65	4.88 \pm 0.73	0.14	0.07
Supine to prone roll (months)	5.37 \pm 1.19	5.49 \pm 1.10	0.10	0.06
Independent sit 30s (months)	5.50 \pm 1.02	5.49 \pm 0.94	0.01	0.05
Independent sit 60s (months)	6.30 \pm 0.67	6.35 \pm 0.75	0.07	0.05

*P<.05, **p<.001; PA = physical activity; † = PA measured at the ankle; s = seconds

Table 2.3. Physical activity (PA) group differences (means \pm standard deviations) in PA at the wrist and motor skill development from one to six months of age.

Infant Characteristics	Low PA [†] N = 13	High PA [†] N = 13	Effect Size	Power
Ankle PA (counts)	92.80 \pm 48.49	100.99 \pm 41.12	0.18	0.07
Wrist PA (counts)	77.20 \pm 43.87	149.08 \pm 72.43**	1.20	0.85
Motor Development (raw score)	29.38 \pm 13.52	30.88 \pm 14.15	0.12	0.06
Fine Motor (raw score)	11.74 \pm 6.37	12.37 \pm 6.42	0.10	0.06
Gross Motor (raw score)	17.52 \pm 7.34	18.40 \pm 8.00	0.11	0.06
Supine reach (months)	4.31 \pm 0.73	3.77 \pm 0.42**	0.91	0.62
Prone extended arms (months)	5.00 \pm 0.79	4.70 \pm 0.72*	0.40	0.17
Whole hand grasp (months)	4.92 \pm 0.62	4.70 \pm 0.72*	0.33	0.13
Supine to prone roll (months)	5.62 \pm 1.01	5.22 \pm 1.23*	0.36	0.14
Independent sit 30s (months)	5.85 \pm 0.96	5.18 \pm 0.89**	0.72	0.44
Independent sit 60s (months)	6.54 \pm 0.50	6.16 \pm 0.78**	0.58	0.30

*P<.05, **p<.001; PA = physical activity; † = PA measured at the wrist; s = seconds

Table 2.4. Estimated fixed effects (standard errors in parenthesis) in linear models incorporating physical activity (PA) at the ankle as a predictor.

DV	Intercept	PA Ankle	Age	Age ²	rho
Δ Motor Dev.	2.53 (2.80)	-0.52E ⁻² (0.66E ⁻²)	3.34 (1.47)**	-0.43 (0.18)**	-0.21 (0.11)*
Motor Dev.	2.02 (1.36)	-0.61E ⁻² (0.70E ⁻²)	8.05 (0.80)***	-0.02 (0.12)	0.69 (0.06)***

*P<.10, **p<.05, ***p<.01; PA = physical activity; Δ = change-in

Table 2.5. Estimated fixed effects (standard errors in parenthesis) in linear models incorporating physical activity (PA) at the wrist as a predictor.

DV	Intercept	PA Wrist	Age	Age ²	rho
Δ Motor Dev.	1.62 (3.20)	-0.30E ⁻² (0.47E ⁻²)	3.79 (1.67)*	-0.47 (0.21)*	-0.15 (0.13)
Motor Dev.	3.60 (1.51)	0.30E ⁻² (0.45E ⁻²)	6.50 (0.92)**	0.16 (0.12)	0.66 (0.07)

*p<.05, **p<.01; PA = physical activity; Δ = change-in

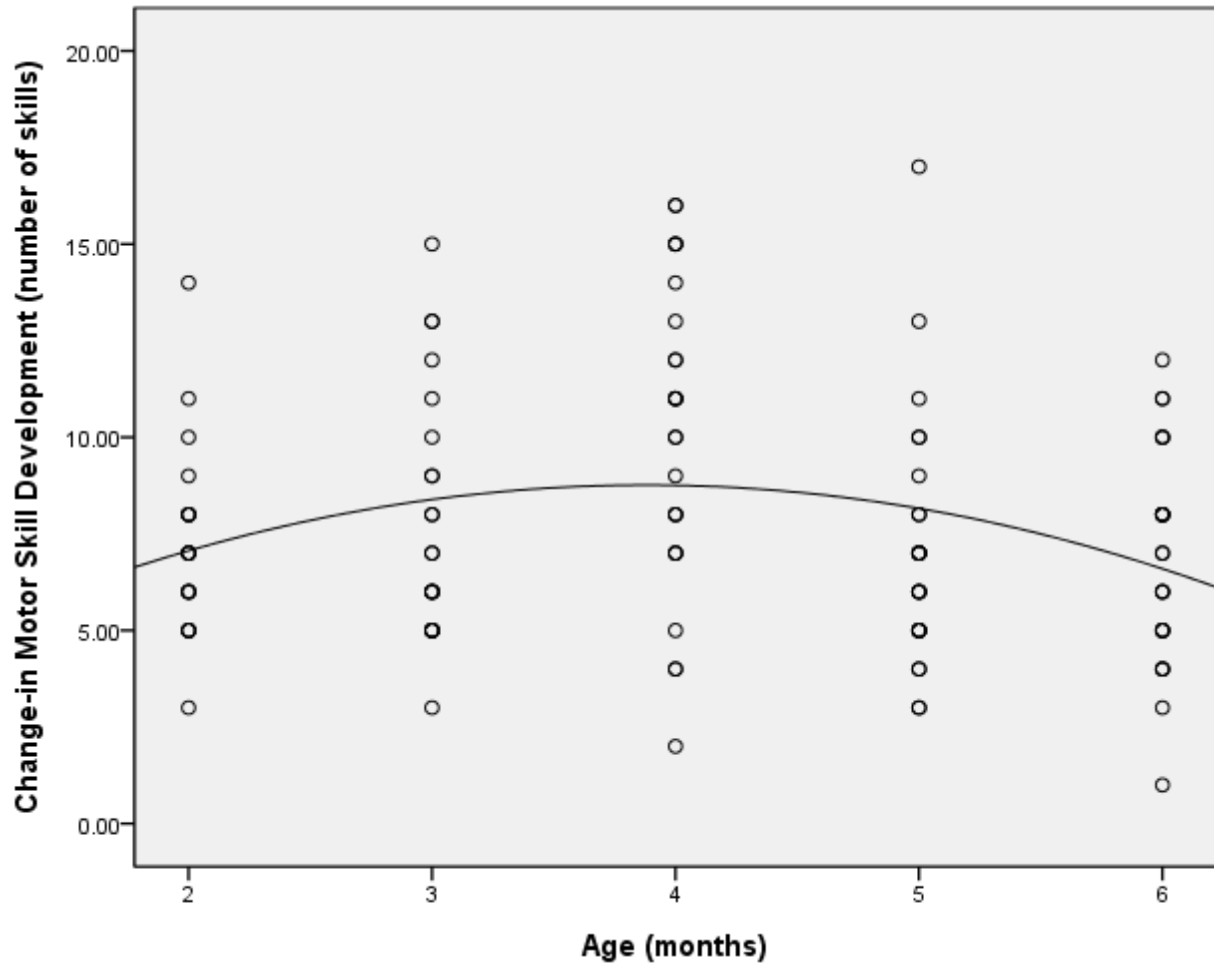


Figure 2.1. Change-in motor skill development from two to six months of age.

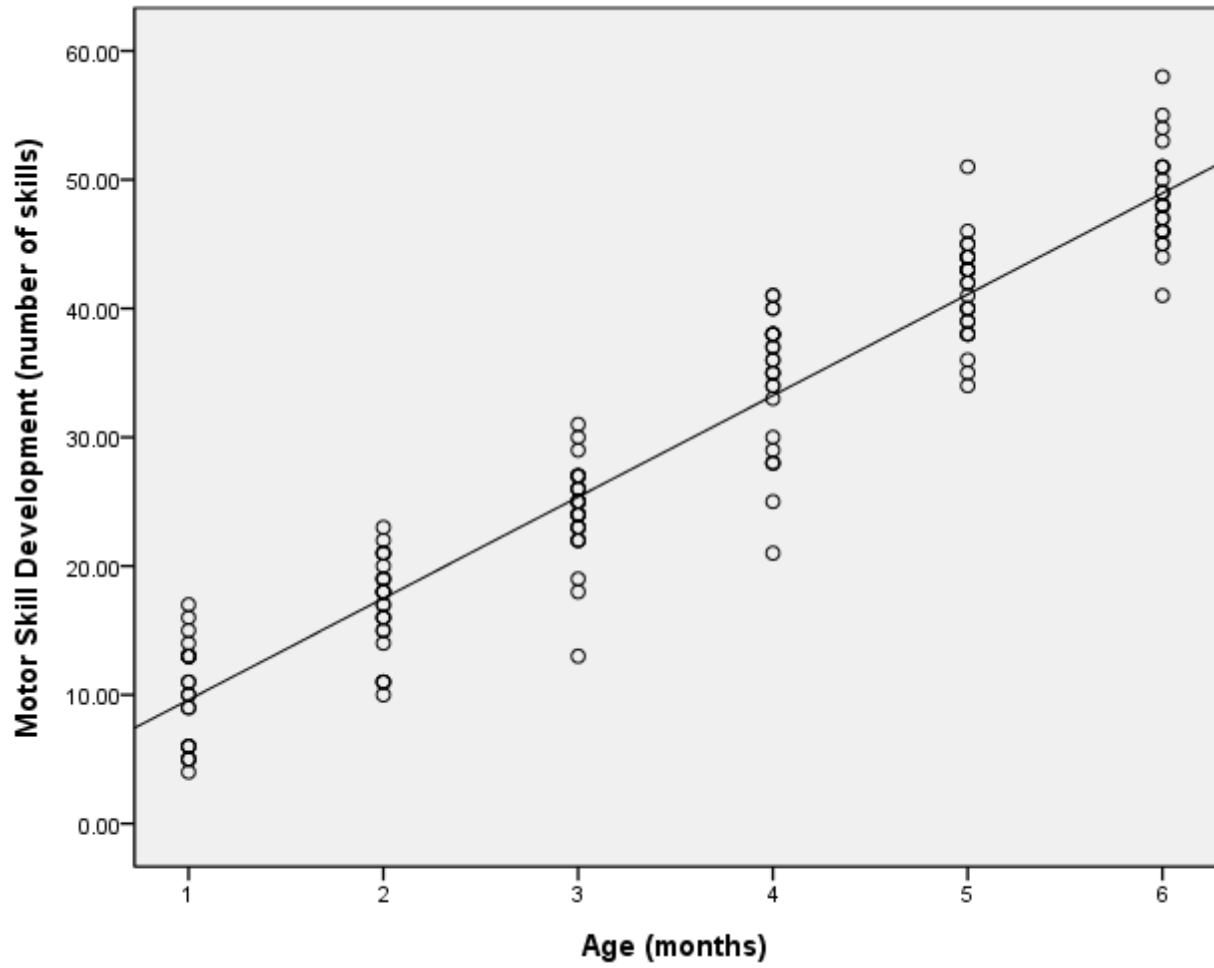


Figure 2.2. Motor skill development from one to six months of age.

Chapter 3

Does the amount of time an infant spends in an infant positioning device influence changes observed in weight status, subcutaneous fat, physical activity and motor skill development?

Despite a recent report detailing the stabilization of childhood obesity rate (Ogden, Carroll, Kit, & Flegal, 2012), the prevalence of childhood obesity remains too high and onset of this condition is occurring much earlier in life. Today's infants are approximately one kilogram (kg) heavier at one year of age than infants born during the past four decades (Mook-Kanamori et al., 2011). Using the Fels Longitudinal Study, Johnson et al. (2012) reported differences in body mass index (BMI) throughout childhood for those born from 1973-1999 than those born in the previous 50 years. Researchers also reported a trend of earlier onset adiposity rebound followed by greater maximum BMI velocity (Johnson et al., 2012; van Rossem et al., 2011). Adiposity rebound is the point in middle childhood when body fatness begins to rise after reaching its minimum (Eriksson, Forsen, Osmond, & Barker, 2003). During this same period of time, infant obesity prevalence has increased by more than 60% (Vickers, 2011).

Infant obesity is classified using the 2006 World Health Organization (WHO) growth standards. Obesity from birth to 24 months of age is defined as weight-for-length above the 97.7th percentile (>3 standard deviations) (Neelon, Oken, Taveras, Rifas-Shiman, & Gillman, 2011). Using the previously recommended 2000 Centers for Disease Control (CDC) growth charts, the National Health and Nutrition Examination Survey (NHANES) identified 9.7% of infants and toddlers surveyed from 2009-2010 as obese. When these data are applied to the 2006 WHO growth standards, the prevalence of infant and toddler obesity is slightly less, but

remains high. During this same time, 12.1% of children aged two-five years were identified as obese (Ogden, 2012). Infants who experience rapid weight gain within the first few years of life are more likely to become obese as they age (Baird, 2005; Monteiro & Victora, 2005). Moreover, a complete understanding of each of the causal contributions to rapid growth and how they interrelate in the infancy period are not known. Knowing that infancy is of particular vulnerability, the best opportunity to understand childhood obesity is to study factors contributing to excess fat growth during the infancy period (Heinzer, 2005).

An existing question in the literature is whether specific childrearing practices including the use of infant positioning devices (IPD) can alter the course of motor skill development (Adolph, Karasik, & Tamis-LeMonda, 2007). For the purposes of this study, IPDs are described as infant equipment which positions a child while restricting mobility in one or more joints. Examples include swaddling, infant slings, sitting devices, and safety equipment such as carseats. Research regarding the effect of infant positioning on motor skill development is rarely studied with a primary focus on prone positioning and the use of walker devices. Moreover, research measuring the effects of these devices on excess weight gain, body composition, and physical activity (PA) are lacking.

Within the United States and other Western cultures, childrearing practices have deviated significantly from those in Eastern cultures. Eastern culture childrearing typically includes more handling of the infant on the mother's hip or back, lap sitting, formal exercises, and floor time than what is seen in Western culture (Adolph, et al., 2007; Bril, 1986). Early research has indicated an accelerated pattern of motor skill acquisition for African infants (Geber & Dean, 1957; Iloeje, Obiekwe, & Kaine, 1991; Kilbride, Robbins, & Kilbride, 1970). However, further research indicated that acquisition of specific motor skills was only accelerated for as long as the

stimulation for such skills continued (Geber & Dean, 1957). These accounts present the issue of a causal relationship between physical enrichment and timing of motor milestones (Adolph, et al., 2007). With childrearing practices in Africa and other Eastern cultures consisting largely of adult handling, we question what effects increased time spent in IPDs has on motor skill development in Western culture where they are heavily marketed.

The use of IPDs during the first year of life is very popular in western culture. In most cases, these devices place the infant in a seated or supine position and do not promote prone positioning. In addition to these devices reducing time spent in prone positioning, an initiative to prevent sudden infant death syndrome (SIDS) developed by the American Academy of Pediatrics (AAP) in 1994 called the “Back to Sleep” campaign has affected the public perception of prone position safety. “Back to Sleep” promotes supine sleep positioning in an effort to prevent accidental death prone sleep positioning. This initiative has significantly altered the way an infant is positioned for sleep and in doing so, infants are consequently spending less time in prone postures even while awake, despite the AAP advising “Front to Play” (Dudek-Shriber & Zelazny, 2007; Majnemer, 2005). In a large longitudinal study of 351 infants, Davis et al. (1998) found that infants who slept in a prone position attained more motor milestones at an earlier age than infants who slept in a supine position. Since the introduction of “Back to Sleep,” the increased time spent in supine postures has been linked to slower onset of gross motor skills including delayed arm support in prone positioning, reaching, supine to prone roll, and sitting milestones (Dudek-Shriber & Zelazny, 2007; Miller, 2009; Monson, Deitz, & Kartin, 2003; Pin, Eldridge, & Galea, 2007). In contrast, wakeful prone positioning has been linked to improved overall motor development among infants aged six and 18 months (Jennings,

Sarbaugh, & Payne, 2005). These findings show that infant posture can impact both rate and acquisition of motor skills in early life.

As a method of convenience or entertainment, parents are now using popular IPDs more frequently such as swaddling techniques, slings, bouncer seats, and infant carriers outside of transportation purposes (Callahan & Sisler, 1997; Pin, et al., 2007). During an observational study measuring the frequency of use of IPDs in 187 infants who could not sit unsupported, Callahan & Sisler (1997) found that 94% were placed in an IPD for more than 30 minutes each day, with a mean duration of 5.7 hours per day. Similarly, Zachry and Kitzmann (2011) found that of 205 caregivers sampled, approximately 53% report their infant spends less than 30 minutes a day in a wakeful prone position. In another observational study measuring the frequency of use of positioning devices compared to floor time experience for 38 young infants in childcare centers, results indicate infants are spending significantly more time in positioning devices (51.9%) than on the floor (16.2%) or being held (19.0%) (Myers, 2006). Positioning devices can limit opportunities for an infant to spontaneously move and adjust their posture, a restriction that could lead to motor delay (Adolph, et al., 2007).

One method to decrease the likelihood of motor delay is to assure wakeful prone positioning, otherwise known as “tummy time” (Miller, 2009). Most IPDs promote supine or seated positions, postures that do not encourage development of strength, control, and function needed to locomote and support the body off the floor. Infants spending significant amounts of time in supine or seated positions are provided with plenty of sensory stimulation without effort and are therefore less motivated to seek out stimulation on their own (Chizawsky, 2005). As a result, fewer opportunities to develop head control, neck strength, and core strength exist. In

addition, PA may be reduced. However the effects of IPDs and resulting motor skill development are not widely researched with the exception of infant walkers (Pin, et al., 2007).

In a study on the use of IPDs on motor development in 43 healthy eight month old infants, a significant relationship was reported between high use of devices and lower motor performance scores on the Alberta Infant Motor Scales (AIMS) , although it is difficult to determine causality (Abbott & Bartlett, 2001). In another longitudinal study with a control group measuring the effects of walkers, exersaucers, and jumpers on attainment of motor milestones in 0-12 month old infants, results indicate no significant difference in attainment of motor milestones between the device-using group (n=15) and the non-using group (n=10). However, a trend of decreased slope among the high using group for all motor assessments was reported (Fay, Hall, Murray, Saatdjian, & Vohwinkel, 2006). Given the wide variability of motor development results reported, it is important to recognize the potential for increased movement and/or increased restriction of movement between devices.

Few have studied the influence of other common IPDs on motor development, with little to no study of the relationship of frequency of use to growth and PA. With significant marketing promotion of IPDs, it is strongly suggested that research on their effects continues, especially given the potential contribution of motor development and PA during infancy to increasing prevalence of childhood obesity.

Specific Aims

The primary aim of this study was to longitudinally describe the amount of time infants spend in infant positioning devices (IPD) in a given day. A secondary aim was to determine whether a relationship exists between amount of time spent in an IPD and changes observed in ponderal index, subcutaneous fat, motor skill development, and PA at the ankle and wrist. This

knowledge can be used to inform pediatric practice and to identify modifiable factors contributing to childhood obesity at its earliest stage. The following hypotheses were tested. First, the type and frequency of IPDs used during infancy will vary from one to six months of age with more use of fewer devices during the first few months, greater use of multiple devices from three to four months, and less use of fewer devices from five to six months. Second, when overall use of IPDs is compared to monthly changes in ponderal index, subcutaneous fat, motor skill development, and PA at the ankle and wrist during the same period, an inverse relationship will emerge. For motor skill development and PA (both ankle and wrist), infants having the most time spent in an IPD will display lesser gains or delay in motor skill development and a reduction in amount and intensity of PA. For ponderal index and subcutaneous fat, a positive relationship will emerge with infants having the most time spent in an IPD displaying greater gains in ponderal index and subcutaneous fat.

Method

Participants

All methods and procedures were approved by the Health Sciences and Behavioral Sciences Institutional Review Board at the University of Michigan. All mother/neonate dyads were consented by the mother prior to participation in this study.

Twenty-eight mother/neonate dyads were recruited from Southeast Michigan to participate in this longitudinal study which consisted of six data collections per participant, yielding 168 total time points. Participants included mothers aged 18 years and older with a healthy infant less than six weeks of age. Infants were excluded who received a medical diagnosis that was suspected to impair or delay growth, muscle development, motor development, cognition, or nutritional status. Such diagnoses include but are not limited to

cystic fibrosis, Down syndrome, neuromuscular disease, spina bifida, hypotonia, fetal alcohol syndrome, pre-mature birth (< 37 weeks gestation), etc. One mother/neonate dyad was dropped from the study after receiving a neuromuscular diagnosis which impairs growth and development. None of the remaining 27 dyads had a physical disability or medical condition which would limit or impair physical activity (PA) or growth. Participant characteristics and family demographic information including gender, race, gestational size, feeding modality, maternal marital status, maternal highest level of education, and maternal BMI were computed as percentages of the total sample and can be found in Table 3.1. Average use of infant positioning devices (IPD) between demographic groups can also be found in Table 3.1.

Procedures

During the study period, we collected data from each participant once monthly for six consecutive months. All data collections took place in the home of the infant, with the exception of initial recruitment information including gender, age, contact information, and address which was collected prior to the start of the study. The mother was present at all times. Collecting data at the home of each participant provided convenience and ease for the mother, as well as comfort for the infant. The first home visit occurred when the infant was aged approximately one month (+/- one week), with each subsequent home visit occurring when the infant was two, three, four, five, and six months of age (+/- one week). Participants received between \$15-\$25 cash incentive for participation during each home visit, totaling \$100 for full participation.

The research team included the principal investigator (PI) and five trained research assistants. The PI and one to two research assistants attended each one-hour home visit. Research assistants' responsibilities consisted of field work and lab work. Field tasks included

assisting with equipment, data recording, stabilizing each infant's head and legs during anthropometric measurement, and interaction with siblings. Lab tasks included data entry and data reduction.

Measurement

During the study period, we monitored the PA and growth of each infant participant on a monthly basis. At the first home visit, measurements of demographic information, maternal height, weight, and some information relating to the preconception, prenatal and postpartum periods were collected. In addition, we administered a short survey of infant feeding modality each month.

During the first home visit, each mother completed a number of surveys including a maternal demographic survey, an infant demographic survey, and an intake survey which were used as a series of covariates that have been associated with infant and childhood obesity. The maternal supplemental information survey included maternal age, race, marital status, highest level of education, method of delivery, birth complications, and hospital discharge information. The infant demographic survey included date of birth, due date, race, medical conditions, birth weight, birth length, neonatal complications, and number of siblings including birth order. The intake survey consisted of questions regarding the preconception, prenatal, and postpartum periods including pregravid weight, diabetes status, hypertension status, prenatal care, gravid weight gain, and feeding modality (measured monthly). In addition to surveys, we measured maternal weight in kilograms (kg) using a Health O Meter H-349KL digital scale and height in centimeters (cm) using a SECA S-214 portable stadiometer one month postpartum. To calculate BMI, we converted height from cm to meters (m) and used the following formula: $\text{Weight (kg)} / \text{Height (m)}^2$.

Anthropometric Measurement

During each home visit, we measured infant weight, length, ponderal index, subcutaneous fat at three sites, motor development, and 24 hour PA at the ankle and wrist. These measures were repeated once monthly from one through six months of age.

We measured infant weight (kg) using a Tanita digital baby scale and infant recumbent crown-heel length (cm) using an infant length board. The length board had a static headboard and moveable footboard. The infant's ankle was dorsiflexed while the body was aligned. Infants were measured in supine position wearing only a clean diaper. We tracked weight-for-length percentile monthly using the 2006 WHO growth standards (Neelon, et al., 2011). We used weight and length to determine ponderal index using the following formula: $100 \times \frac{\sqrt[3]{Mass (kg)}}{Length (cm)}$. Ponderal index is a common pediatric measure of leanness and is the preferred index because unlike BMI, it is not highly correlated with length (Ekelund et al., 2006). Ponderal index is used as a measure of weight status.

We measured subcutaneous fat in millimeters (mm) at the abdomen, mid-thigh, and mid-calf using Lange-skinfold-calipers (Tanner & Whitehouse, 1975). While the infant is in a supine position, mid-thigh and mid-calf on the right leg were measured using a flexible measuring tape. Mid-thigh was determined by marking the greater trochanter and lateral condyle of the femur and measuring the midpoint in between. Mid-calf was determined by marking the condyle of the femur and lateral malleolus and measuring the midpoint in between. Horizontal abdominal skinfold was taken at approximately one cm lateral to the umbilicus on the right side (Ulrich, Lloyd, Tiernan, Looper, & Angulo-Barroso, 2008). We were quick in measuring skinfolds and waited between subsequent trials to prevent compression of the tissue, which can lead to underestimates of fat (Dauncey, Gandy, & Gairdner, 1977).

Motor Development

We measured motor skill development using the Bayley Scales of Infant Development, 3rd edition (BSID-3) (Bayley, 2006). For data analysis, we summed gross and fine motor raw scores to create an overall motor development variable. In addition, change in motor skill development from month to month was calculated. The BISD-3 assessment is standardized and determines whether the infant is ahead, behind, or on time for acquisition of motor milestones. The same person administered this measure each month for all infants.

Physical Activity

Physical activity (PA) at the ankle and wrist were measured once monthly during a 24-hour period using an Actical accelerometer (Mini Mitter/Respironics Inc., Bend, OR). The monitor provides information on frequency, intensity, and duration of activity in a small, robust device. Actical's are the smallest motion sensor available, making them ideal for use with infants. This monitor has been used in research with infants before and has been found unobtrusive to the infant (Ulrich, et al., 2008). Accelerometers are reliable with young children ($r = 0.89$) (Pfeiffer, McIver, Dowda, Almeida, & Pate, 2006) and the preferred measure of PA.

Actical's have an omnidirectional sensor with a 0.5-3Hz range allowing them to measure movement in all directions. The Actical utilizes a sensor or accelerometer to quantify the occurrence and intensity of motion. This sensor incorporates the amplitude and frequency (32Hz) of motion and produces an electrical current that varies in magnitude. An increased intensity of movement produces an increase in voltage (Respironics, 2003). Actical stores this information as activity counts. These unitless activity counts are aggregated over a user-specified length of time known as an epoch. A detector within each device identifies the highest count per second and sums the total of peak values for each epoch. Fifteen second epochs are

used in this study because they are sensitive to capturing the sudden, jerky movements produced by small children (Pfeiffer, et al., 2006).

Participants wore the monitors for 24 hours once monthly from one to six months of age. Infants wore the monitor on their right ankle and right wrist attached with an elastic band covered by a cloth sleeve. These monitors were easily removed for clothing change and bathing. During the monitoring period, each mother completed a monitoring log in order to corroborate the data received from the monitor. The log required the mother to classify the type of activity her infant engaged in as either sleeping, feeding, quiet play, active play, or being mechanically or adult handled in 30 minute intervals. This information is helpful in interpreting the intensity of infant PA as well providing a template to accurately remove data that reflects mechanical or adult handling rather than infant produced movement. This technique has been used previously and found to successfully correlate to infant activity (Tulve, Jones, McCurdy, & Croghan, 2007).

Data Reduction

An activity count (represented as a unitless whole number) is provided for each 15 second epoch, totaling 5760 numbers in a 24 hour monitoring period. These numbers can be accumulated and time stamped. We were able to attribute each number (representing an activity count that ranged from 0 to 200+) to a specific activity category by comparing time stamps to the monitoring log completed by the mother. These activity counts were then assigned to categories based on the mother's classification of her infant's activity. Categories included sleeping, feeding, quiet play, and active play. All activity counts that were classified by the mother as adult or mechanical handling were excluded. Once each activity count was classified into a category, each category was summed and a one-minute average was determined. The one-

minute average of total activity was also calculated by combining all four categories. This yielded five total PA variables including one-minute average of total PA, one-minute average of sleeping PA, one-minute average of feeding PA, one-minute average of quiet play PA, and one-minute average of active play PA.

Infant Positioning Device

Use of infant positioning devices (IPD) was measured once monthly during a 24-hour period. Type of device used and frequency of use was collected. During the 24 hour PA monitoring period, each mother completed a monitoring log to coincide with the PA devices. The log required the mother to observe and record the type of positioning device the infant used in a 30-minute interval using a brief KEY provided. In addition, the mother also indicated how much time in minutes that the infant spent in that device. This log provided a detailed account of the amount of time an infant spends in various infant positioning devices during a 24-period.

Statistical Approach

Relationships between variables and (possible non-linear) trends from one to six months of age on the key dependent variables were initially examined using scatterplots, and summarized with Pearson correlation coefficients (given linear relationships) and R^2 statistics. Mean differences between groups of infants based on infant positioning device (IPD) use were examined using two-sample t-tests and supplemented with effect sizes and power estimates. We used Cohen's d effect sizes to provide a more comprehensive interpretation of results which will include a 0.50 to 0.80 effect size to represent a moderate meaningful difference (Cohen, 1977). Any value above 0.80 was considered a large meaningful difference. We examined type and frequency of use of 10 common IPDs by calculating mean use in minutes from one to six months of age. Additionally, we examined amount of use of two specific IPDs (sitter and jumping

devices) from one to six months of age between groups of infants based on PA levels using scatterplots.

We examined relationships between the amount of time an infant spends in an IPD in a given day with changes observed in ponderal index, subcutaneous fat, PA at the ankle and wrist, and motor skill development from one to six months of age using linear models with auto-correlated errors, given the longitudinal nature of these data. We analyzed dependent variables measuring ponderal index, subcutaneous fat, PA, and motor skill development as absolute or cumulative values as well as month to month differences when examining relationships of these variables with time spent in an IPD. This modeling approach was used to estimate the relationship of IPD use with ponderal index, subcutaneous fat, PA, and motor skill development while controlling for the relationship of age with the absolute or cumulative value and change in each outcome from month to month. This approach, implemented using the MIXED procedure in SPSS Version 20, makes use of all available data for the repeatedly measured participants to examine trends in longitudinal data where missing data are often present. This approach also offers an advantage over standard ordinary least squares (OLS) regression in that the correlations of errors can be modeled; longitudinal data sets often have correlated errors within individuals, and OLS regression assumes that these correlations are zero. If this assumption is incorrect, standard errors of estimated regression coefficients and subsequent statistical tests will also be incorrect.

Infant positioning device minutes (total minutes spent in an IPD during a 24 hour period), age, and age² (allowing for possible non-linear trends in the outcomes of interest over six months) were entered into the models as fixed effects. Based on initial scatter plots, fixed effects of squared versions of IPD were added to the models as well if there was evidence of

non-linear associations of IPD with a particular dependent variable. Allowing errors in the model associated with the same infant to have a first-order auto-regressive correlation structure implied that observations closer to each other in age (e.g., month one and month two) had a stronger correlation than observations farther apart in age, which was found to be reasonable for these data. Estimates of the correlations of adjacent errors in the models (represented by the parameter ρ) were computed to indicate levels of dependency in these longitudinal data.

Results

To establish possible gender differences from one to six months for ponderal index, subcutaneous fat, PA at the ankle and wrist, motor skill development and time spent in infant positioning devices (IPD), we examined the trajectories of each measure using scatterplots. We found an observable difference in the trajectory of PA at the ankle and wrist with females displaying elevated amounts of PA. The discrepancy in PA from males to female is not consistent from month to month with the greatest difference appearing at one month of age for both PA at the ankle and wrist. For all other measures, we found no discernible difference in their trajectories between genders.

To investigate differences in ponderal index, subcutaneous fat, physical activity (PA) at the ankle and wrist, and motor skill development as they related to IPD use (in minutes), we grouped infants into either a high or low IPD use group (using the median value) given their average IPD use from one to six months of age. We calculated group differences including effect size and power estimates for various growth variables including ponderal index, subcutaneous fat, and peak weight velocity (PWV) as well as various motor development variables including cumulative motor skill development and age at onset of six specific motor skills. We found that infants with high IPD use had significantly increased PA at the wrist as

well as significantly lower PWV. There was a meaningful difference in amount of subcutaneous fat as well with infants with more IPD use having less subcutaneous fat as indicated by a moderate effect size. In addition, infants with high IPD use had significantly earlier onset of age for all six motor milestones including supine reach, extended arms in prone position, whole hand grasp, supine to prone roll, and independent sitting for 30 and 60 seconds (see Table 3.2).

To examine the overall use of IPDs including type and frequency from one to six months of age, we calculated mean amount of use in minutes for 10 common IPDs each month for six months. We also included total IPD use for each month (see Table 3.3). We found that total cumulative use of all devices is greater from one to three months of age at which point total use of IPDs gradually decreases through six months. At one month of age, parents reported use of fewer types of devices, having only indicated using seven devices on average. As infants aged however, the types of devices used increases in number, with eight devices used at two and three months of age, nine devices used at four months of age, and 10 devices used at five and six months of age. There also appears to be differences in frequency of use of certain devices. Swaddles are the most frequently used device in early infancy, with swings and bouncers having more frequent use at these ages as well. Carseats and strollers are used relatively consistently over all six months, averaging slightly more than one hour in a carseat and 15 minutes in a stroller per day. Devices used more frequently at five and six months of age include jumpers, walkers, and highchairs.

We examined relationships between IPD use in a given day with all other variables using linear models. For the dependent variable measuring IPD use, a non significant mostly negative linear trend with age was found ($r = -0.296$, $p < 0.001$). As age increased by one month, the expected IPD use decreased by 13.63 minutes (see Table 3.4). There was an observable

quadratic trend with greater deceleration of IPD use after four months ($R^2 = 0.09$) (see Figure 3.1).

For all other dependent variables including ponderal index, subcutaneous fat, PA, motor skill development and their respective monthly change counterparts, only significant trends with age were detected. There are no observable relationships between these variables and IPD use in a given day (see Table 3.4). Graphical displays of significant trends of age with change in ponderal index ($R^2 = 0.041$), change in subcutaneous fat ($R^2 = 0.441$), overall subcutaneous fat ($R^2 = 0.211$), PA at the ankle ($r = 0.208$, $p = 0.033$; $R^2 = 0.181$) and wrist ($R^2 = 0.058$), change in motor skill development ($R^2 = 0.063$), and cumulative motor skill development ($r = 0.957$, $p < 0.001$; $R^2 = 0.915$) can be found in Figures 3.1 - 3.8.

To better understand how PA at the wrist is affected by two common IPDs, upright sitting and jumping devices, we grouped infants into either a high or low PA group (using the median value) given their PA at the wrist at age six months. Infants with increased PA at the wrist spent more time in an upright sitting device in a given 24 hour period from two to five months of age at which point infants with decreased PA displayed more use of upright sitting devices (see Figure 3.9). There is minimal difference in time spent in a jumping device from one to four months between PA groups. From five months onward, infants with increased PA at the wrist spent more time in jumping devices (see Figure 3.10).

Discussion

This is the first study to quantify use of infant positioning devices (IPD) beginning at one month of age. In addition, this is the first study to compare the magnitude of IPD use to rate of change in ponderal index, subcutaneous fat, physical activity (PA) at the ankle and wrist, and motor skill development on a monthly basis this early in life. We present these results as a

preliminary yet comprehensive effort to address the question of describing the relationship of IPD use to growth and motor behavior during the first six months of life.

Group difference results indicate that IPD use is significantly related to an infant's PA level. Infants who spent more time in IPDs had significantly higher PA at the wrist. In addition, these same infants also experienced a significantly smaller peak weight gain and had less subcutaneous fat, as indicated by a moderate effect size. When comparing differences between the two highest and lowest IPD users in the sample, the highest IPD users had significantly increased ponderal indices and weight-for-length percentiles. Furthermore, infants who spent more time in IPDs had significantly later onset of six specific motor milestones. This would indicate that although certain devices may be related to increased PA, they are still unfavorable for promoting increased motor skill development. A similar study reported an emerging trend of a relationship between higher use of walkers, exersaucers, and jumpers to slower motor development (Fay, et al., 2006). Unfortunately, authors did not discriminate between devices; therefore their unique contribution to this possible slower onset of motor skills is unknown. Given these findings, it would be advantageous to investigate which IPDs are capable of promoting increased PA and motor skill development. Once known, these devices can be used to promote PA and motor skills in infants experiencing motor delay.

We measured type and frequency of use of 10 specific IPDs during a typical 24 hour period once monthly from one to six months of age. We found a clear trajectory of increased types of IPDs used from one to six months of age. An obvious pattern of less use of more devices from one to six months of age exists. The frequency of use of these devices varies over time with swaddles, swings and bouncers having more frequent use in early infancy, carseats and strollers having consistent use each month, and increased use of jumpers, walkers, and highchairs

at five and six months of age. It appears that the most frequently used device in early infancy is the swaddle and the most frequently used device in middle infancy is a sitter device. In a typical 24 hour period, device use accumulated to approximately 8.5 hours for one month olds, 7.8 hours for two months olds, 8.7 hours for three month olds, 5.6 hours for four month olds, 4.9 hours for five month olds, and 4.2 hours for six month olds. This decelerating trend of decreased IPD use over time is similar to the trend indicated in our linear modeling results, although the trend was not significant. As an infant ages one month, their expected IPD use decreases by 13.63 minutes per day, with a greater rate of decline after four months of age. We must be clear that in describing the trajectory of use of IPDs, means and standard deviations account for all infants in our sample, not just the infants who used certain devices. As a result, some standard deviations are remarkably high.

We compared our results for frequency of use of IPDs from one to four months with a similar study measuring the mean duration of IPD use for 187 infants who could not sit unsupported. Callahan and Sisler (1997) found that on average, infants who could not sit unsupported spent 5.7 hours per day in an IPD. Our results are elevated with infants under four months of age spending approximately 7.7 hours per day in an IPD. We have a considerably lower sample size which could explain the greater use of IPDs in our study.

In addition, we compared average IPD use between various demographic groups. We found that higher use of IPDs is reported among infants who were born large for gestational age, are black, are exclusively formula fed and whose mother's are single, high school educated only, and are obese. Future research is needed to substantiate these relationships beyond this cohort.

To understand how PA is influenced by two frequently used IPDs, we graphically displayed mean use of sitting and jumping devices from one to six months by PA group. We

observed that infants with high PA at the wrist used sitting devices more frequently than infants with low PA levels. The gap in use widens dramatically at four and five months of age, but then narrows again at six months of age. We observed that a portion of the infants with high PA learned to sit independently between five and six months of age and therefore had little need to use the device. This would explain the opposite trend for infants with low PA and attribute the increase in sitting device use at six months to not having learned to sit independently by that time.

For jumping devices, we observed that infants with high PA generally used jumping devices more frequently than infants with low PA levels with a greater gap in use at six months. Please note that all jumping device activity was eliminated from PA wrist data so that PA was not artificially increased due to the accelerating nature of these devices. Therefore increased time in a jumping device did not directly translate to an equal increase in PA at the wrist. So within our sample, it appears that infants who spend more time in jumping devices at five and six months of age are engaging in increased PA at the wrist when outside of the jumping device.

Linear modeling results indicated that all variables measured including ponderal index, subcutaneous fat, PA, motor skill development, or their respective monthly change counterparts did not significantly relate to time spent in an IPD. This is possibly due to a limited sample size where use of IPDs ranged greatly between infants. Despite this, we did report some very interesting emerging trends when growth, PA, and motor skill development are compared to infants with high IPD use and those with low IPD use. Additionally, we generated graphics which highlight how use of sitting and jumping devices varies between infants with high and low PA levels (see Figures 3.9, 3.10).

Despite a small sample size, we provided a very comprehensive description of IPD use including type and frequency during the first six months of life. Our first hypothesis was accepted with contingencies. We found that IPD use does vary from month to month with use of more types of devices as the infant ages and decreased frequency of use of those devices from one to six months of age. We did not expect the number of devices to continue to increase throughout the study period. It would be interesting to track when certain devices are no longer used by parents including swaddles and swings as well as parental perception of purpose of use. Our second hypothesis was accepted with contingencies. We reported evidence to suggest that infants with more use of IPDs have later age of onset for six specific motor milestones. However, we found little evidence to support a positive trend of increased ponderal indices and subcutaneous fat occurring within infants who have increased use of IPDs. Either no relationship exists or we were simply unable to demonstrate it given our sample of 27 infants. The present study was underpowered to test the variance between ponderal indices and subcutaneous fat as they relate to IPD use within and between infants. Future study should take advantage of multilevel models in larger samples to better study the effects of IPDs on these measures.

It is essential that we continue to examine, quantify, and understand the effect that common IPDs have on growth, PA, and motor skill development during infancy and throughout childhood. We have taken an important step in describing the type and frequency of IPD use during the first six months of life. We think it would be valuable to continue to follow infants beyond the first six months to see how IPD use in early infancy influences later growth outcomes. Future research should focus on understanding how deviations in IPD use from this trajectory influence other areas of infant development.

Furthermore, we did not differentiate between devices suspected to positively or negatively influence PA and motor skill development. Future research should discriminate the benefits and consequences of these devices on various growth and motor behaviors to better understand their influence on infant development. Anecdotal evidence from this study supports the notion of increased PA and motor skill development among infants with high use of jumping devices. For this reason, future research may not consider jumping devices as those that constrain movement which could impede PA and/or motor skill development. Not all IPDs have equal influence on development. In addition, greater understanding of the effects of wakeful prone positioning and its influence on PA is of great interest. Our results may be influential in either promoting or discouraging use of specific devices to infants at risk for motor delay, but further investigation is recommended before doing so.

References

- Abbott, A. L., & Bartlett, D. J. (2001). Infant motor development and equipment use in the home. *Child care health and development*, 27(3), 295.
- Adolph, K., Karasik, L., & Tamis-LeMonda, C. (2007). Moving between cultures: cross-cultural research on motor development. In M. Bornstein (Eds.), *Handbook of cross-cultural developmental science, Vol. 1, Domains of development across cultures*, Erlbaum.
- Baird, J. (2005). Being big or growing fast: systematic review of size and growth in infancy and later obesity. *BMJ. British medical journal*, 331(7522), 929.
- Bayley, N. (2006). Bayley Scales of Infant and Toddler Development. San Antonio, TX: The Psychological Corporation.
- Bril, B. (1986). Motor development and cultural attitudes. 297-313.
- Callahan, C., & Sisler, C. (1997). Use of seating devices in infants too young to sit. *Archives of pediatrics & adolescent medicine*, 151(3), 233.
- Chizawsky, L. L. K. (2005). Tummy Time! *AWHONN lifelines*, 9(5), 382.
- Cohen, D. (1977). *Statistical power analysis for the behavioral sciences* (Rev Ed). New York, NY: Academic Press. 1977
- Dauncey, M. J., Gandy, G., & Gairdner, D. (1977). Assessment of total body fat in infancy from skinfold thickness measurements. *Archives of disease in childhood*, 52(3), 223.
- Davis, B. E., Moon, R. Y., Sachs, H. C., & Ottolini, M. C. (1998). Effects of sleep position on infant motor development. *Pediatrics*, 102(5), 1135.
- Dudek-Shriber, L., & Zelazny, S. (2007). The effects of prone positioning on the quality and acquisition of developmental milestones in four-month-old infants. *Pediatric physical therapy*, 19(1), 48.

- Ekelund, U., Ong, K., Linne, Y., Neovius, M., Brage, S., Dunger, D. B., . . . Rossner, S. (2006). Upward weight percentile crossing in infancy and early childhood independently predicts fat mass in young adults: the Stockholm Weight Development Study (SWEDES). *Am J Clin Nutr*, 83(2), 324-330.
- Eriksson, J., Forsen, T., Osmond, C., & Barker, D. (2003). Obesity from cradle to grave. *Int J Obes Relat Metab Disord*, 27(6), 722-727.
- Fay, D., Hall, M., Murray, M., Saatdjian, A., & Vohwinkel, E. (2006). The Effect of Infant Exercise Equipment on Motor Milestone Achievement. *Pediatric physical therapy*, 18(1), 90.
- Geber, M., & Dean, R. F. (1957). Gesell tests on African children. *Pediatrics*, 20(6), 1055-1065.
- Heinzer, M. (2005). Obesity in infancy: Questions, more questions, and few answers. *Newborn and infant nursing reviews*, 5(4), 194.
- Iloeje, S. O., Obiekwe, V. U., & Kaine, W. N. (1991). Gross motor development of Nigerian children. *Ann Trop Paediatr*, 11(1), 33-39.
- Jennings, J., Sarbaugh, B., & Payne, N. (2005). Conveying the message about optimal infant positions. *Physical & occupational therapy in pediatrics*, 25(3), 3.
- Johnson, W., Soloway, L. E., Erickson, D., Choh, A. C., Lee, M., Chumlea, W. C., . . . Demerath, E. W. (2012). A changing pattern of childhood BMI growth during the 20th century: 70 y of data from the Fels Longitudinal Study. *Am J Clin Nutr*, 95(5), 1136-1143. doi: 10.3945/ajcn.111.022269
- Kilbride, Robbins, & Kilbride. (1970). The comparative motor development of baganda, american white, and american black infants. *American Anthropologist*, 72, 1422-1428.

- Majnemer, A., and Varr, R.G. . (2005). Influence of supine sleep positioning on early motor milestone acquisition. *Developmental medicine and child neurology*, 47, 370-376.
- Miller, L., Johnson, A., Duggan, L., Behm, M. (2009). Consequences of the "Back to Sleep" Program in Infants. *Journal of Pediatric Nursing, In Press, Corrected Proof*. doi: DOI: 10.1016/j.pedn.2009.10.004
- Monson, R. M., Deitz, J., & Kartin, D. (2003). The relationship between awake positioning and motor performance among infants who slept supine. *Pediatric physical therapy*, 15(4), 196.
- Monteiro, P. O. A., & Victora, C. G. (2005). Rapid growth in infancy and childhood and obesity in later life: a systematic review. *Obesity reviews*, 6(2), 143.
- Mook-Kanamori, D. O., Durmus, B., Sovio, U., Hofman, A., Raat, H., Steegers, E. A., . . . Jaddoe, V. W. (2011). Fetal and infant growth and the risk of obesity during early childhood: the Generation R Study. *Eur J Endocrinol*, 165(4), 623-630. doi: 10.1530/eje-11-0067
- Myers, C. T. (2006). The use of infant seating devices in child care centers. *The American Journal of Occupational Therapy*, 60(5), 489.
- Neelon, Oken, Taveras, Rifas-Shiman, & Gillman. (2011). Age of Achievement of Gross Motor Milestones in Infancy and Adiposity at Age 3 Years. *Matern Child Health J*. doi: 10.1007/s10995-011-0828-3
- Ogden, C. L. (2012). Prevalence of Obesity and Trends in Body Mass Index Among US Children and Adolescents, 1999-2010. *JAMA : the journal of the American Medical Association*, 307(5), 483-490. doi: 10.1001/jama.2012.40

- Ogden, C. L., Carroll, M. E., Kit, B. K., & Flegal, K. M. (2012). Prevalence of obesity in the United States, 2009-2010. *NCHS Data Brief*(82), 1-8.
- Pfeiffer, K. A., McIver, K. L., Dowda, M., Almeida, M. J. C. A., & Pate, R. R. (2006). Validation and calibration of the Actical accelerometer in preschool children. *Medicine and science in sports and exercise*, 38(1), 152.
- Pin, T., Eldridge, B., & Galea, M. P. (2007). A review of the effects of sleep position, play position, and equipment use on motor development in infants. *Developmental medicine and child neurology*, 49(11), 858.
- Respiroics. (2003). Actical: physical activity monitoring system—instruction manual software version 2.0 Mini Mitter.
- Tanner, J. M., & Whitehouse, R. H. (1975). Revised standards for triceps and subscapular skinfolds in British children. *Archives of disease in childhood*, 50(2), 142.
- Tulve, N., Jones, P., McCurdy, T., & Croghan, C. (2007). A pilot study using an accelerometer to evaluate a caregiver's interpretation of an infant or toddler's activity level as recorded in a time activity diary. *Research Quarterly for Exercise and Sport*, 78(4), 375.
- Ulrich, Lloyd, Tiernan, Looper, & Angulo-Barroso. (2008). Effects of intensity of treadmill training on developmental outcomes and stepping in infants with Down syndrome: a randomized trial. *Physical Therapy*, 88(1), 114.
- van Rossem, L., Taveras, E. M., Gillman, M. W., Kleinman, K. P., Rifas-Shiman, S. L., Raat, H., & Oken, E. (2011). Is the association of breastfeeding with child obesity explained by infant weight change? *Int J Pediatr Obes*, 6(2-2), e415-422. doi: 10.3109/17477166.2010.524700

- Vickers, M. H. (2011). Developmental programming of the metabolic syndrome - critical windows for intervention. *World J Diabetes*, 2(9), 137-148. doi: 10.4239/wjd.v2.i9.137
- Zachry, A. H., & Kitzmann, K. M. (2011). Caregiver Awareness of Prone Play Recommendations. *The American Journal of Occupational Therapy*, 65(1), 101.

Table 3.1. Characteristics of participants and their families with average IPD use in minutes.

Infant Characteristics	n = 27 (17 F, 10 M)	Mean IPD Use (Mean ± SD)
Race		
White	81.5%	373.93 ± 191.78
Black	7.4%	631.83 ± 304.23
Asian	11.1%	268.00 ± 184.97
Gestational Size		
SGA	33.3%	290.99 ± 130.14
AGA	63.0%	425.50 ± 240.93
LGA	3.7%	441.67 ± 0.00
Feeding Modality		
Exclusive Breastfeeding	48.2%	333.94 ± 174.21
Mixed feeding	40.7%	335.66 ± 161.38
Exclusive Formula feeding	11.1%	753.56 ± 270.55
Maternal Characteristics (one month post gravid)		
Maternal Age (years)(mean ± SD)	32.36 ± 3.99	
Marital Status		
Single	7.4%	909.50 ± 16.09
Married	88.9%	342.66 ± 162.19
Divorced	3.7%	251.33 ± 0.00
Education Level		
High School	7.4%	909.50 ± 16.09
Some College	14.8%	396.38 ± 150.56
Associates	7.4%	351.58 ± 101.27
Bachelors	25.9%	351.47 ± 211.93
Masters	29.6%	261.06 ± 94.71
Doctorate	14.8%	409.41 ± 132.44
BMI		
Healthy	37%	346.61 ± 163.66
Overweight	29.6%	324.25 ± 145.27
Obese	33.3%	470.44 ± 281.00

SGA = small for gestational age; AGA = appropriate for gestational age; LGA = large for gestational age; SD = standard deviation; BMI = body mass index

Table 3.2. Infant positioning device (IPD) use group differences (means \pm standard deviations) in PA, growth status, and motor skill development from one to six months.

Infant Characteristics	Low IPD N = 13	High IPD N = 14	Effect Size	Power
Ankle PA (counts per minute)	90.44 \pm 39.62	102.52 \pm 48.48	0.27	0.10
Wrist PA (counts per minute)	110.80 \pm 71.92	117.32 \pm 68.05**	0.09	0.06
Ponderal Index	3.00 \pm 0.09	2.99 \pm 0.09	0.11	0.06
Skinfolds Sum (mm)	43.01 \pm 7.03	38.76 \pm 6.66	0.62	0.34
Peak Weight Velocity (kg)	1.32 \pm 0.24	1.16 \pm 0.28*	0.61	0.33
Motor Development (raw score)	30.55 \pm 13.63	29.37 \pm 14.06	0.09	0.06
Fine Motor (raw score)	12.07 \pm 6.13	11.89 \pm 6.62	0.03	0.05
Gross Motor (raw score)	18.36 \pm 7.74	17.39 \pm 7.65	0.13	0.06
Supine reach (months)	4.08 \pm 0.62	4.07 \pm 0.71**	0.02	0.05
Prone extended arms (months)	4.70 \pm 0.72	5.00 \pm 0.79*	0.40	0.17
Whole hand grasp (months)	4.77 \pm 0.66	4.85 \pm 0.68*	0.12	0.06
Supine to prone roll (months)	5.29 \pm 1.27	5.43 \pm 1.06*	0.14	0.07
Independent sit 30s (months)	5.33 \pm 0.93	5.69 \pm 1.00**	0.37	0.15
Independent sit 60s (months)	6.16 \pm 0.78	6.54 \pm 0.50**	0.58	0.30

*P<.05, **p<.001; IPD = infant positioning device; PA = physical activity; mm = millimeters; kg = kilograms; s = seconds;

Table 3.3. Type and frequency of infant positioning device (IPD) use in minutes (means \pm standard deviations) from one to six months of age.

IPD Type	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
Swaddle	229.50 \pm 300.14	209.15 \pm 309.18	218.20 \pm 341.99	96.96 \pm 239.24	26.88 \pm 87.35	40.38 \pm 131.16
Carseat	74.40 \pm 92.39	56.73 \pm 77.60	84.72 \pm 78.54	50.09 \pm 75.95	77.71 \pm 149.48	40.00 \pm 51.52
Sling	11.00 \pm 23.60	11.69 \pm 38.06	10.80 \pm 37.63	6.42 \pm 18.07	4.92 \pm 18.72	2.11 \pm 7.77
Stroller	15.75 \pm 28.57	14.62 \pm 41.69	21.68 \pm 50.25	12.83 \pm 41.03	17.92 \pm 62.05	17.69 \pm 37.45
Swing	74.65 \pm 125.43	56.85 \pm 108.54	91.80 \pm 141.10	49.78 \pm 95.17	46.04 \pm 84.63	16.15 \pm 30.64
Bouncer	73.50 \pm 96.03	79.00 \pm 138.75	47.48 \pm 131.62	26.83 \pm 44.00	14.38 \pm 26.39	9.19 \pm 17.49
Sitter	11.25 \pm 28.74	37.88 \pm 83.62	44.4 \pm 167.31	77.42 \pm 243.59	74.54 \pm 230.76	44.69 \pm 122.14
Jumper	0.00 \pm 0.00	0.00 \pm 0.00	2.80 \pm 9.80	10.65 \pm 28.18	24.01 \pm 35.14	53.00 \pm 93.62
Walker	0.00 \pm 0.00	0.00 \pm 0.00	0.00 \pm 0.00	0.00 \pm 0.00	2.08 \pm 10.21	3.46 \pm 17.65
Highchair	0.00 \pm 0.00	2.31 \pm 11.77	0.00 \pm 0.00	1.30 \pm 6.26	6.04 \pm 16.81	24.65 \pm 31.09
Total IPD use	508.05 \pm 288.12	468.23 \pm 292.26	521.88 \pm 395.40	335.91 \pm 354.07	294.33 \pm 341.24	251.35 \pm 207.89

IPD = infant positioning device

Table 3.4. Estimated fixed effects (standard errors in parentheses) in linear models including time spent in an infant positioning device (IPD) as a predictor.

DV	Intercept	IPD	Age	Age ²	rho
IPD	533.52 (113.25)***	X	-13.63 (69.39)	-5.85 (9.39)	0.53 (0.07)***
Δ Ponderal Index	0.08 (0.03)***	-1.42E ⁻⁵ (1.67E ⁻⁵)	-0.43 (0.02)**	0.53E ⁻² (0.25E ⁻²)**	-0.48 (0.10)***
Ponderal Index	3.01 (0.03)***	1.94E ⁻⁶ (1.60E ⁻⁵)	-0.72E ⁻² (0.01)	0.59E ⁻³ (0.18E ⁻²)	0.63E ⁻² (0.26)
Δ Skinfolds Sum	20.13 (3.03)***	0.71 E ⁻³ (0.10E ⁻²)	-8.03 (1.60)***	0.75 (0.20)***	0.02 (0.12)
Skinfolds Sum	29.99 (1.82)***	-0.30E ⁻³ (0.11E ⁻²)	8.14 (0.87)***	-0.96 (0.12)***	0.86 (0.03)***
Δ PA @ Ankle	44.24 (39.72)	0.12E ⁻² (0.01)	-14.54 (21.09)	1.38 (2.59)	-0.32 (0.12)**
PA @ Ankle	44.31 (15.31)**	-0.55E ⁻² (0.01)	21.79 (9.22)**	-1.54 (1.32)	0.25 (0.18)
Δ PA @ Wrist	148.03 (93.74)	-0.01 (0.03)	-56.43 (48.87)	5.42 (5.96)	-0.41 (0.13)**
PA @ Wrist	31.58 (27.34)	0.01 (0.24)	41.61 (17.61)**	-4.53 (2.59)*	-0.08 (0.19)
Δ Motor Dev.	1.14 (2.76)	-1.01E ⁻⁵ (0.88E ⁻³)	3.94 (1.45)**	-0.51 (0.18)**	-0.18 (0.10)*
Motor Dev.	2.55 (1.45)*	-0.70E ⁻³ (0.97E ⁻³)	7.72 (0.80)***	-0.33E ⁻² (0.11)	0.67 (0.58)***

*p<.10, **p<.05, ***p<.001, IPD = Infant positioning device; Δ = change-in

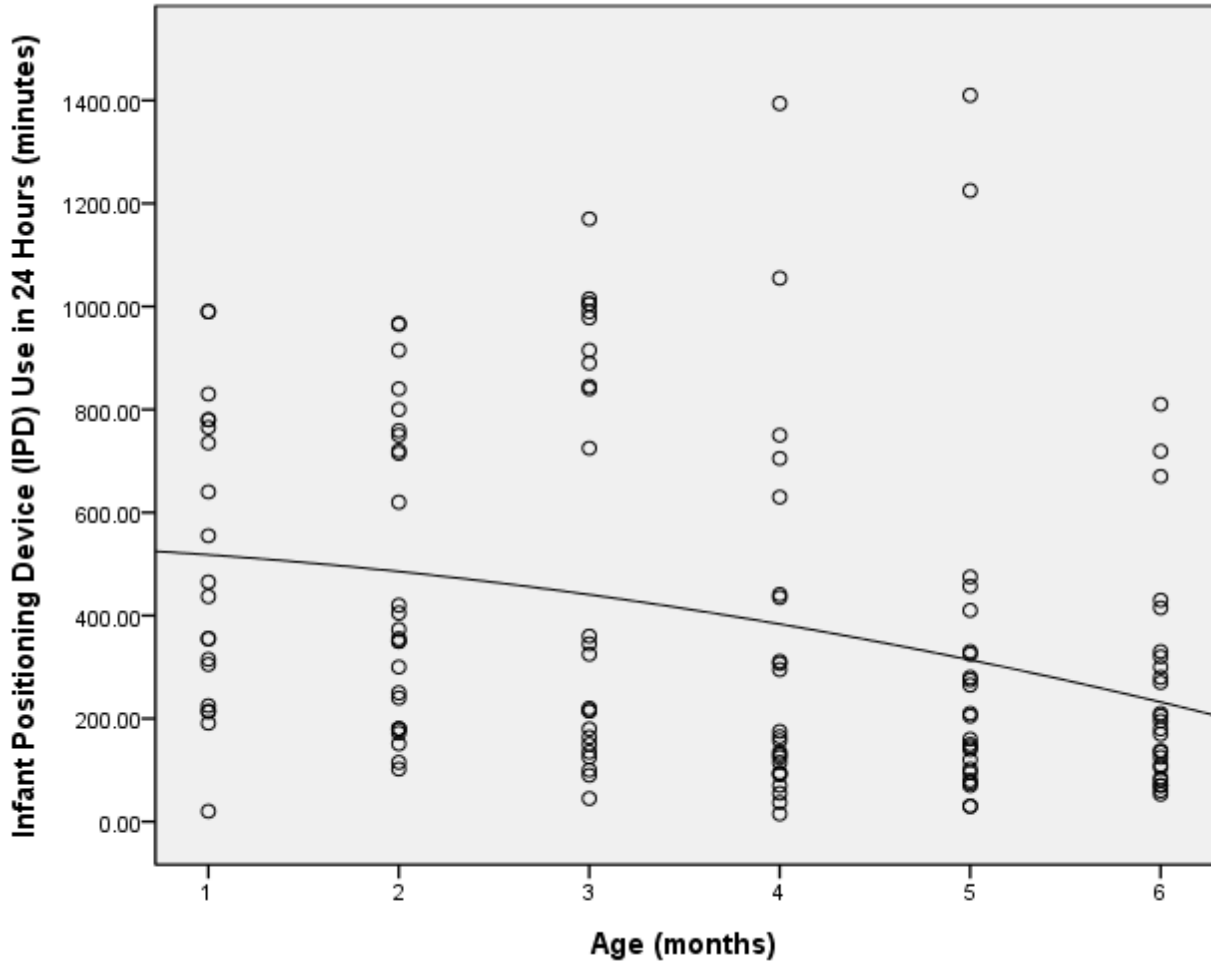


Figure 3.1. Infant positioning device (IPD) use during a 24 hour period from one to six months of age.

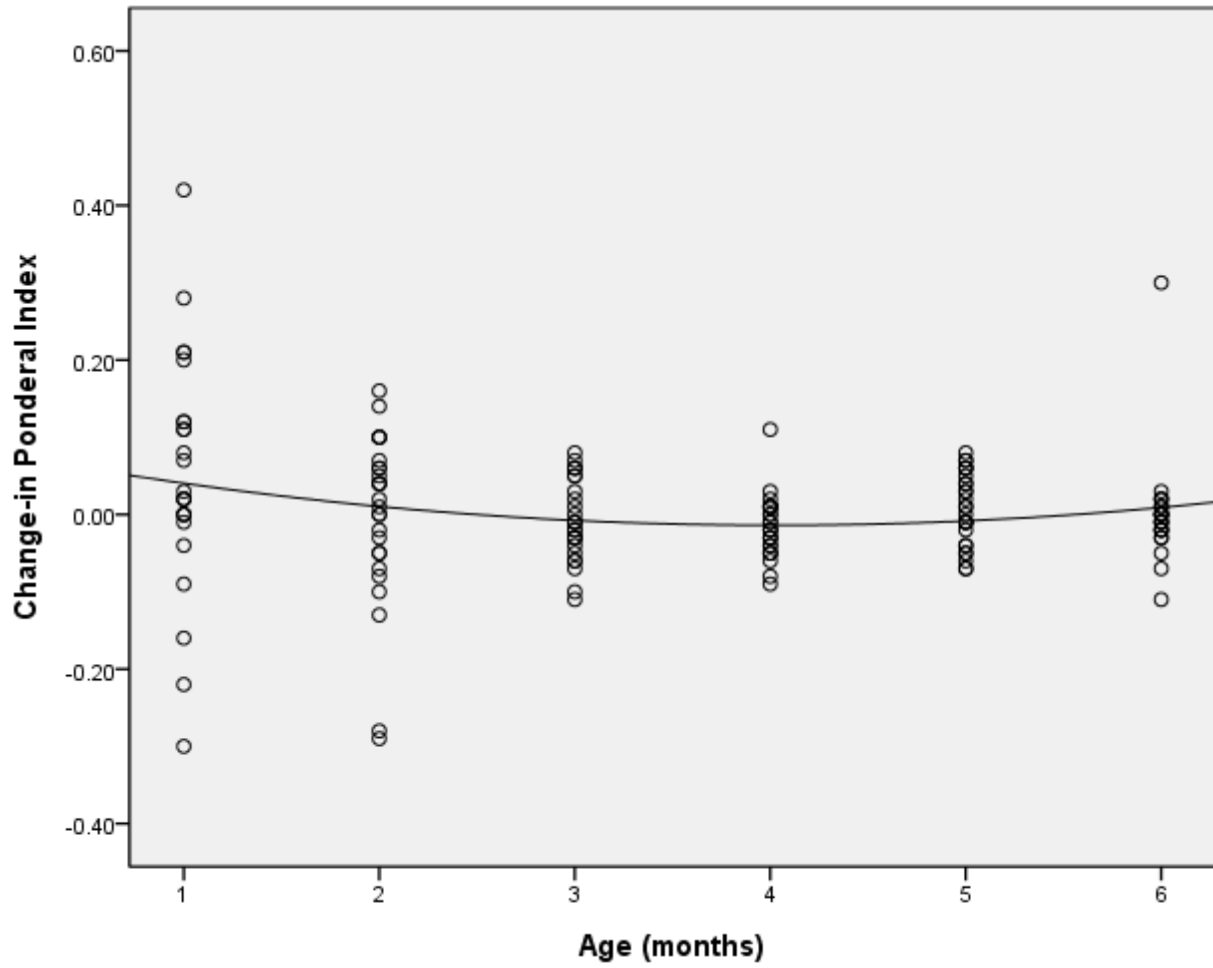


Figure 3.2. Change-in ponderal indices from one to six months of age.

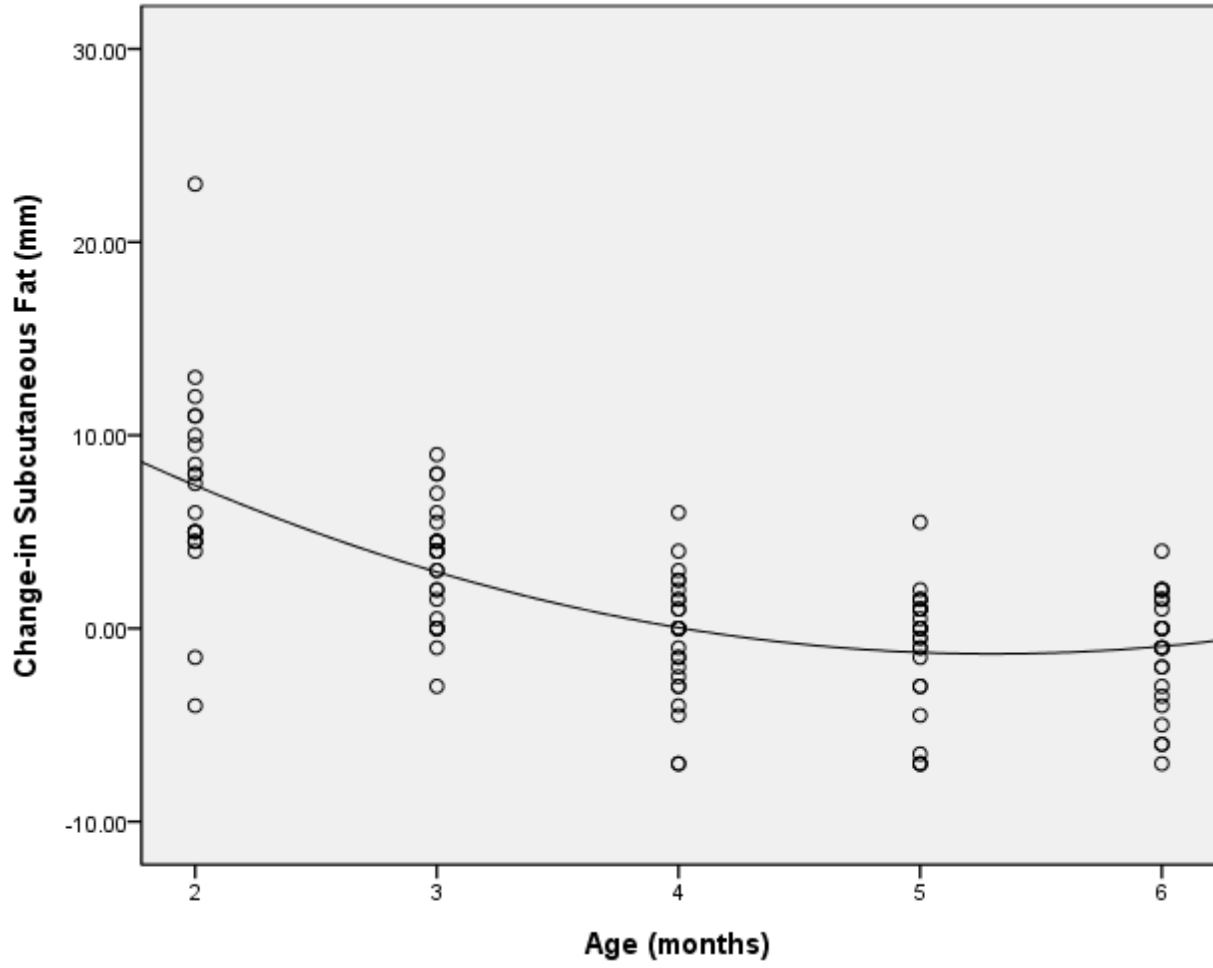


Figure 3.3. Change-in subcutaneous fat from two to six months of age.

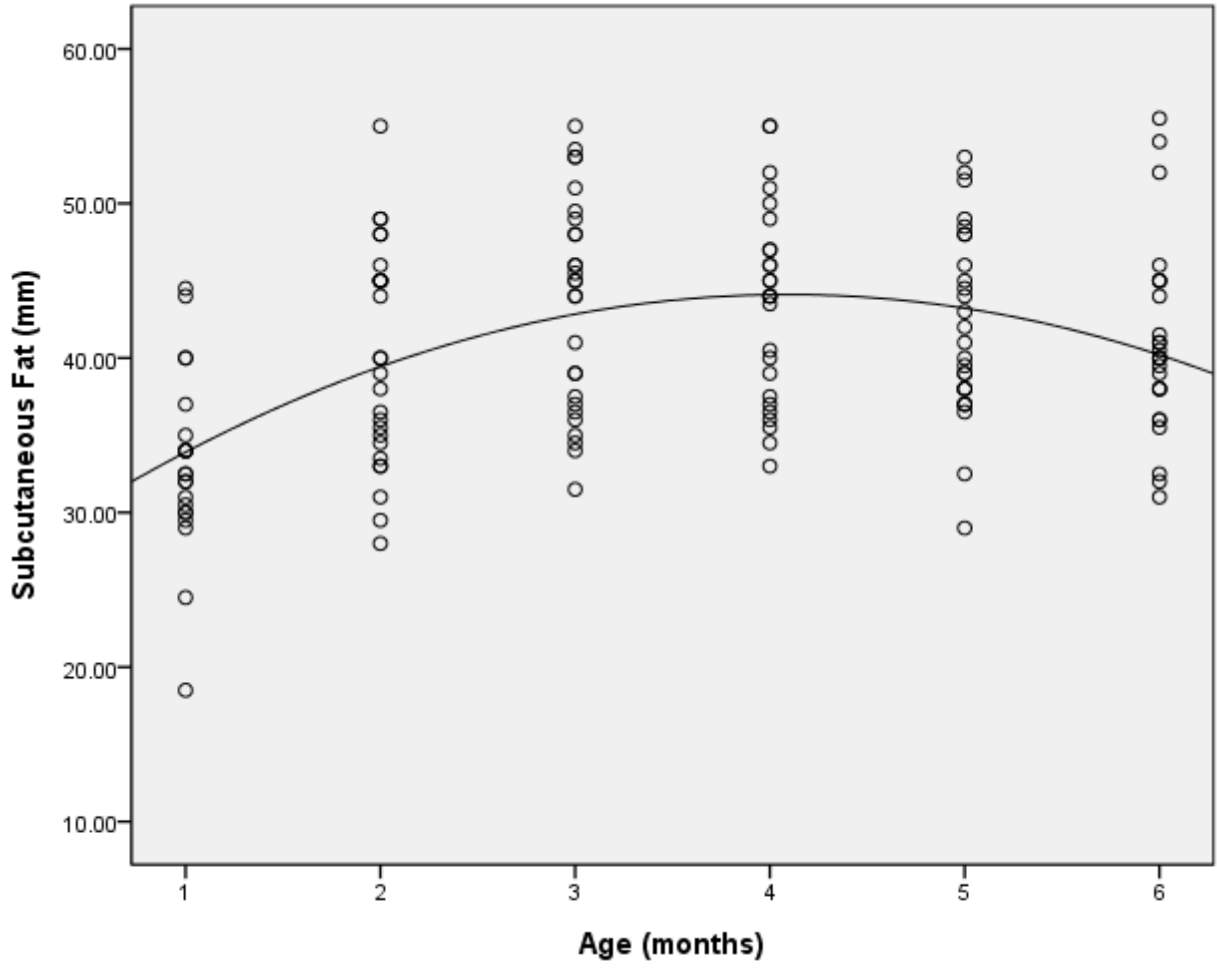


Figure 3.4. Subcutaneous fat from one to six months of age.

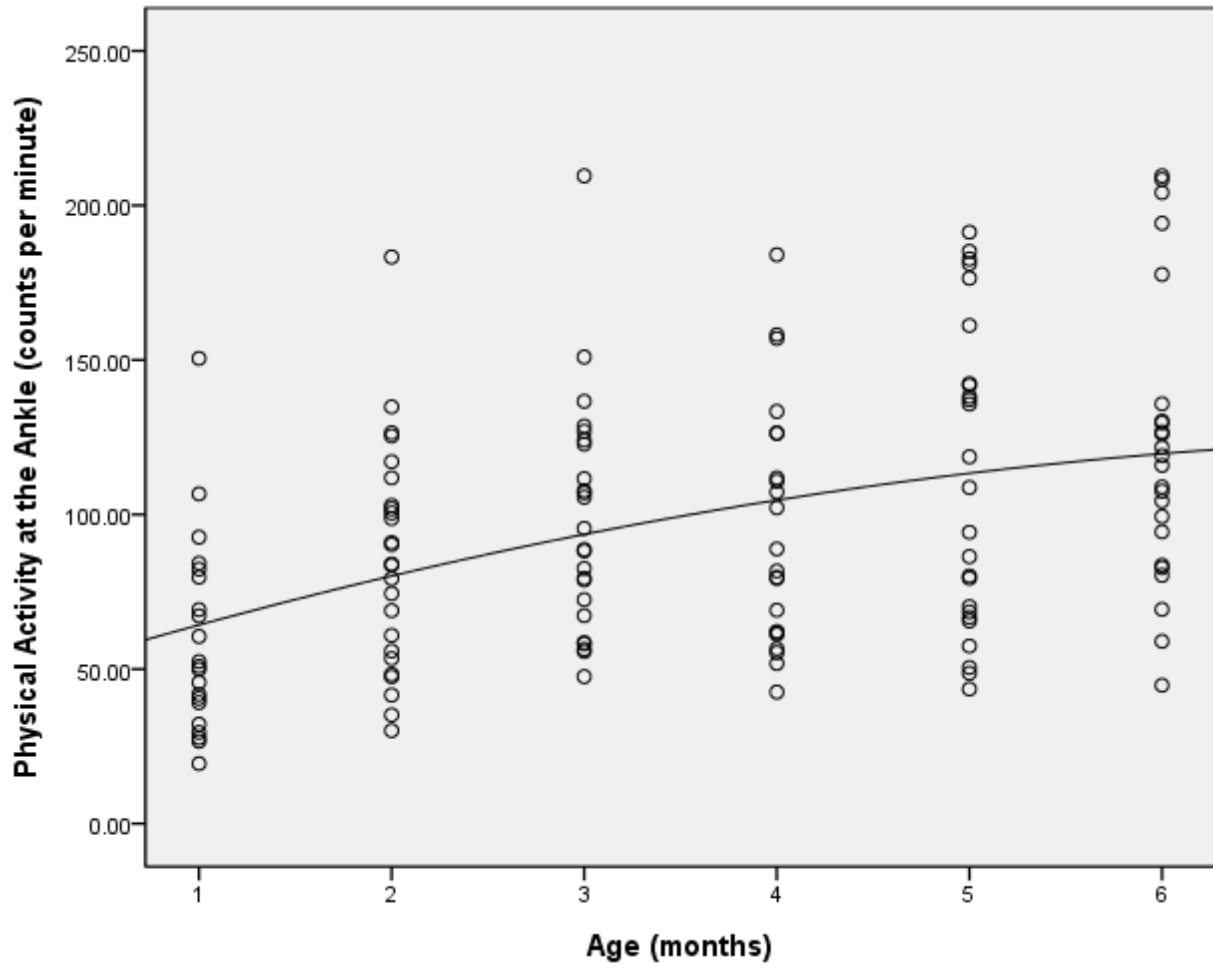


Figure 3.5. Physical activity (PA) at the ankle from one to six months of age.

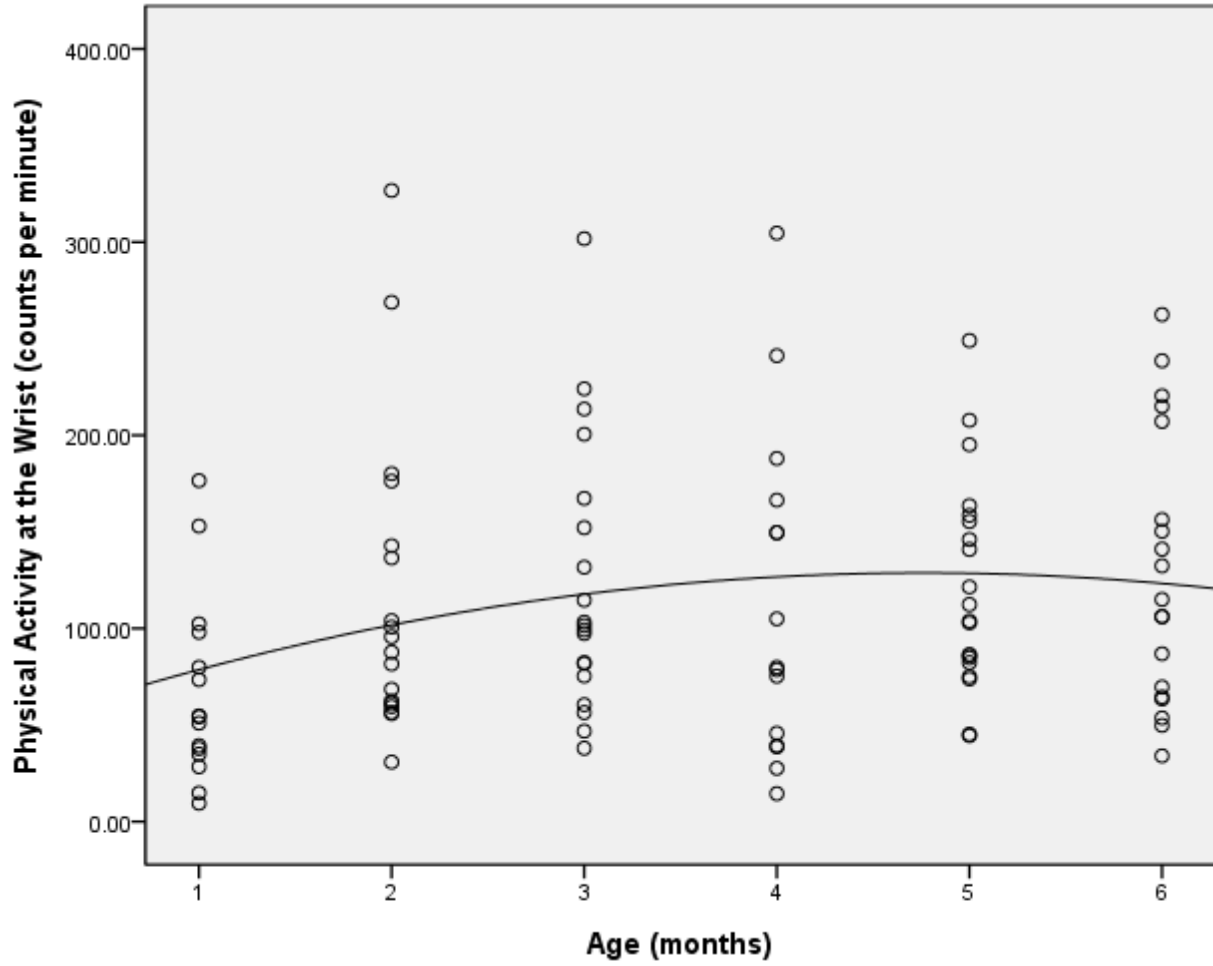


Figure 3.6. Physical activity (PA) at the wrist from one to six months of age.

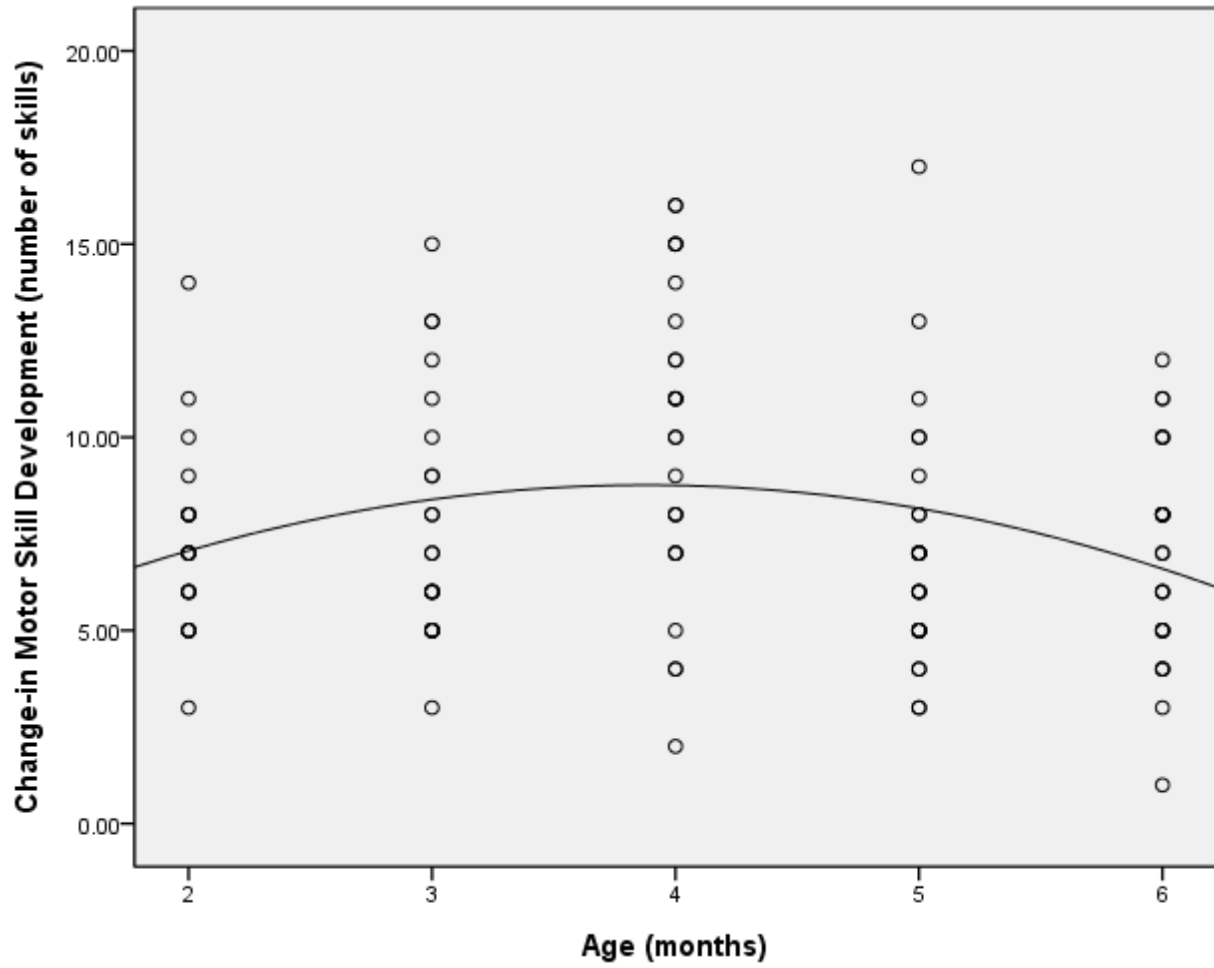


Figure 3.7. Change-in motor skill development from two to six months of age.

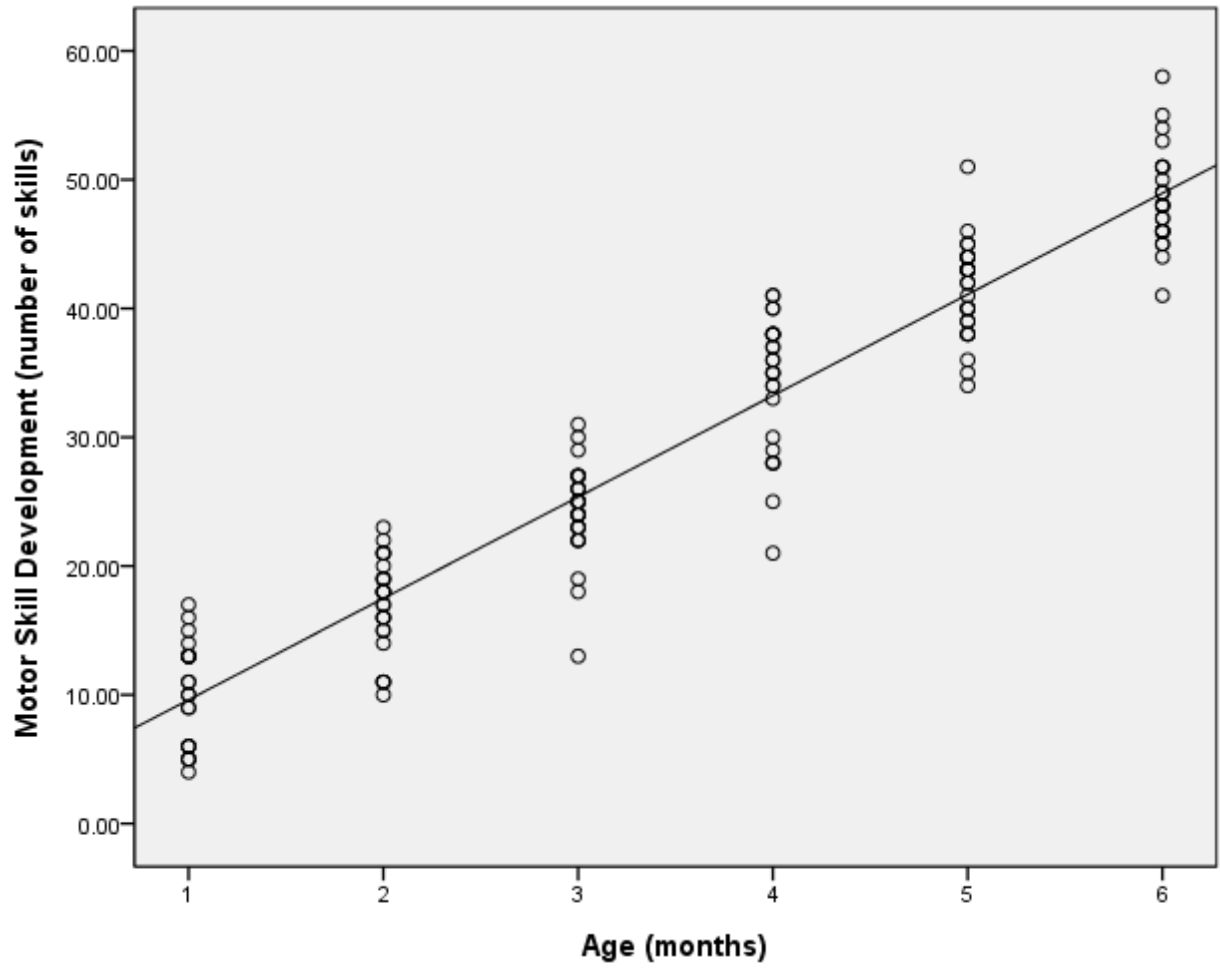


Figure 3.8. Motor skill development from one to six months of age.

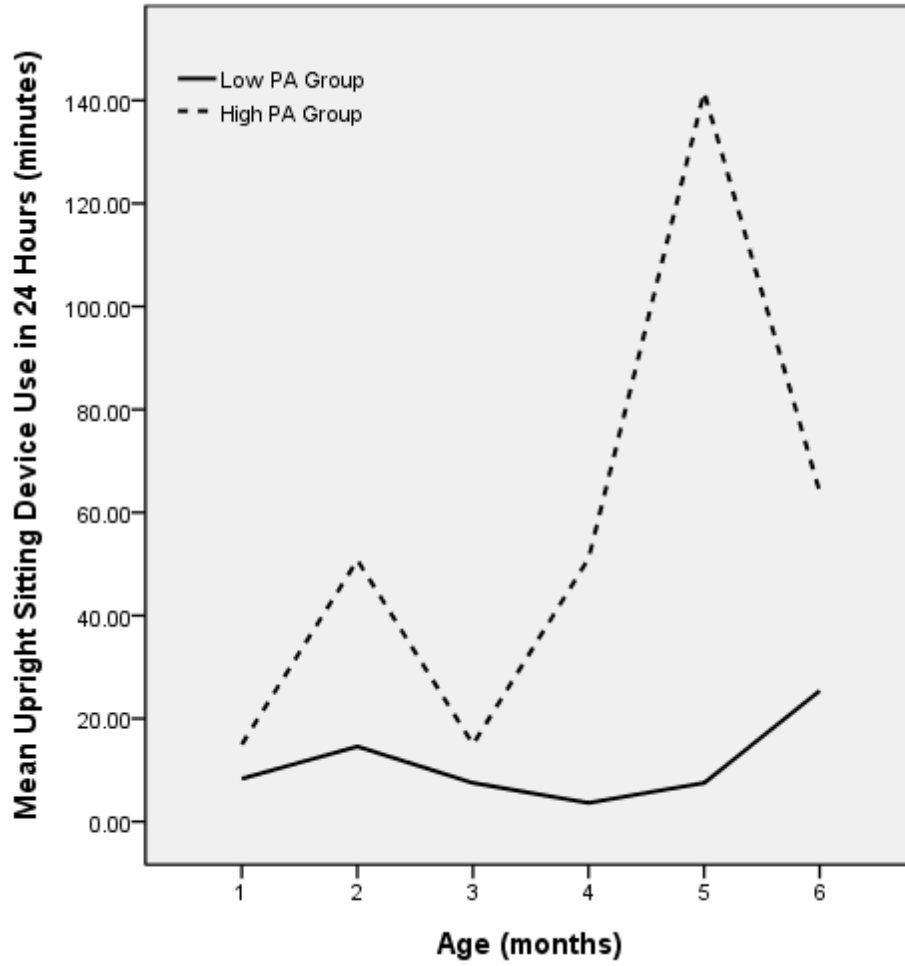


Figure 3.9. Use of an upright sitting device from one to six months of age BY physical activity (PA) group.

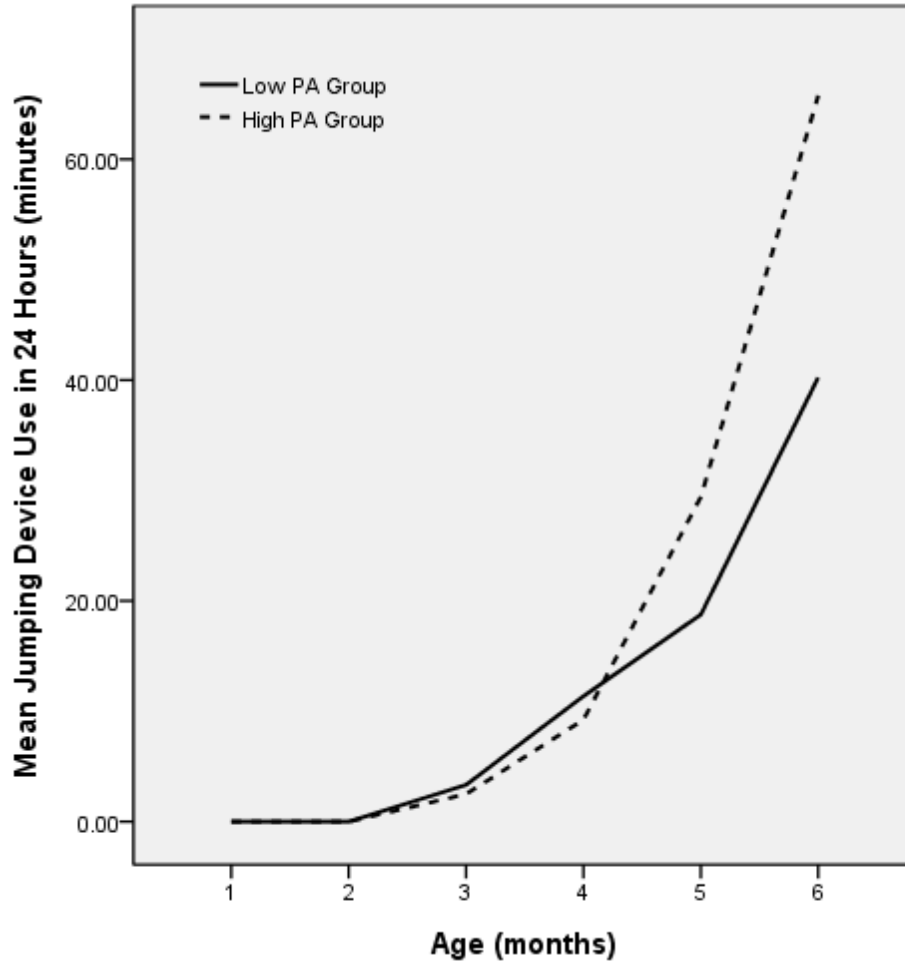


Figure 3.10. Use of a jumping device from one to six months of age BY physical activity (PA) group.

Appendix 1.1 Supplement to chapter one literature review

a) Epidemiology of infant obesity

Infant obesity is rather difficult to define. Clinical diagnoses of infant obesity are rare and definitions of infant obesity and overweight generally conflict in the literature (Heinzer, 2005). Recommendations by McCormick et al. (2010) suggest that infant obesity be defined as weight-for-length at or above the 95 percentile for age and gender using the 2000 CDC growth charts. This working definition was widely supported in the literature by those conducting childhood obesity research prior to 2006 (Heinzer, 2005). Currently, caution is advised in identifying infant obesity using these charts.

Growth reference data are useful in understanding the normal trajectory of weight and length during the first 24 months as well as identifying those that deviate from the curve (de Onis, 2007; Guo et al., 1991). Data include those from a large longitudinal study of growth called the Fels study, since replaced by NHANES derived CDC charts and the WHO Multicentre Growth Reference Study. These reference data (CDC and WHO) offer a greater depth of understanding of the rate of gain in weight from month to month than do weight-for-length charts alone. However, given the variability in methodology used to gather growth reference data, comparability is difficult and caution is still advised.

Current pediatric recommendations for referencing a child's growth include using the 2006 WHO growth charts for persons under two years of age and using the 2000 CDC charts for children aged two years or above. The 2006 WHO charts are recommended prior to two years of age for a number of reasons. First, the 2000 CDC growth charts represent growth reference data, having sampled many children cross-sectionally from 1963-1994 as part of NHANES. These children lacked racial diversity and were primarily formula fed. The 2006 WHO child growth standards represent growth standards having sampled optimal growth conditions

longitudinally at six communities around the world as part of the WHO Multicentre Growth Reference Study (MGRS) from 1997-2003 (Grummer-Strawn, Reinold, & Krebs, 2010).

Optimal nutritional conditions included exclusive breastfeeding for the first four months with continued breast feeding through 12 months and complementary feeding onset between four and six months. Second, the 2006 WHO child growth standards represent optimal growth for the breastfed infant in the first two years and the American Academy of Pediatrics (AAP) recommends breastfeeding during this time (Gartner et al., 2005). The use of these charts allows clinicians to identify infants who are either not gaining enough weight or gaining weight too rapidly.

The 2000 CDC growth charts defined underweight as below the 5th percentile and obese as above the 95th percentile for weight-for-length. The 2006 WHO child growth standards define underweight as below the 2.3rd percentile and obese as above the 97.7th percentile for weight-for-length (>3 standard deviations) (Neelon, Oken, Taveras, Rifas-Shiman, & Gillman, 2011). In a direct comparison of the 2000 CDC growth charts and the 2006 WHO child growth standards, de Onis et al. (2007) found that the CDC charts reflect a heavier and shorter infant among breastfed infants. This is because much of the reference data used for the CDC charts reflects growth of largely formula fed infants. Moreover, fewer infants are identified as underweight, slower growth is considered normal, and rapid growth is an early indicator of overweight. This is because breastfed infants gain weight fast at first, but slower rates of gain are expected for the remainder of infancy, whereas formula fed infants gain weight slow at first and experience rapid gains in later infancy (Dewey, 1998). As a result, the 2006 WHO child growth standards are an improved and more sensitive tool for monitoring infant growth (Paul et al., 2009).

In addition to undermining the significance of the issue, the “grand mothering effect” has likely led to an under-identification of infant obesity. In a study of child weight status in pediatric practice, McCormick et al. (2010) found that only 16% of obese infants at six months and 23% of obese toddlers at 24 months were diagnosed as obese using the 2000 CDC growth charts. Ignoring or under-identifying infants and toddlers experiencing obesity puts them at increased risk for remaining obese as they age. Using the descriptor overweight rather than obese largely undermines the gravity of the pediatric obesity epidemic and likely has led to poor recognition and treatment (Children’s Health Fund, 2004). Without proper diagnosis, opportunities for intervention are compromised. This lack of identification of obesity may be a reflection of a physician’s knowledge or perception of few effective treatment options (McCormick, Sarpong, Jordan, Ray, & Jain, 2010). In fact, no guidelines for treating overweight in infancy exist (Grummer-Strawn, Reinold, & Krebs, 2010). As a result, it is more likely these infants and children will continue this pattern of weight gain as they age.

From the 1980s to the 1990s, very little has changed concerning the typical weight for length and body composition of newborns born appropriate for gestational age. Results from two independent studies spaced a decade apart report similar findings on newborn size and composition with average weight at 3222 grams, length of 52.2 cm, and 82% lean body mass (Lapillonne et al., 1997; Petersen, Gotfredsen, & Knudsen, 1988). Weight gain is considered rapid when upper centile line crossing occurs, which is clinically defined as z-scores above 0.67 (Baird, 2005; Weaver, 2011). In a prospective cohort study examining the association between early life growth and body composition at 17 years of age, Ekelund and colleagues (2006) found that upward centile crossing predicted higher BMI and larger waist circumference in young

adults. Ekelund and others have implicated growth velocity as a better determinant of later life health outcomes than weight alone at birth or one year of age (Baird, 2005; Mandic, Piricki, Kenjeric, Hanicar, & Tanasic, 2011; Monteiro & Victora, 2005; Sugiura, Okada, & Murata, 2011). Rapid weight gain in the first six months greater than a z-score of 0.67 is associated with adult adiposity and obesity as well as taller stature (Patel & Srinivasan, 2011; Paul et al., 2011). Greater peak weight velocity in childhood is associated with greater risk for obesity related disease in adulthood (Huh, Rifas-Shiman, Taveras, Oken, & Gillman, 2011; Tzoulaki et al., 2010).

Infancy is a period of the most accelerated growth experience throughout life with an expected gain of six to seven kg in weight and 25 centimeters (cm) in stature during the first year (Sullivan, Leite, Shaffer, Birch, & Paul, 2011). Johnson (2011) explained that peak growth velocity is primarily affected by environmental influences, lending evidence of being programmed (Leiner, Pant, & Garcia, 2011). Consistent with other studies, they found that heritability of weight at birth and three months of age is low and rises at six months of age (Johnson, 2011). With peak growth velocity occurring at approximately six weeks, heritability is low at age of peak growth velocity. Given low heritability and the impact of environmental influences, it is important that specific environmental determinants be identified. Two periods in childhood represent critical windows associated with later obesity risk. Growth in the first six months and growth at two years and onward, which correspond to peak weight velocity and the adiposity rebound respectively (Paul et al., 2011). In a large birth cohort study investigating early childhood growth and its association with adult obesity, Eriksson et al. (2003) reported decreased adult obesity incidence among individuals who experienced adiposity rebound after eight years of age and increased obesity among those who experienced adiposity rebound prior to

five years of age. Infancy represents a period of rapid growth and developmental plasticity (Disantis, Collins, Fisher, & Davey, 2011; Modi et al., 2011). Given this, infancy is an optimal period to enact obesity prevention strategies especially if the goal is to reduce rapid weight gain (Choh et al., 2011; Patel & Srinivasan, 2011; Paul, et al., 2009).

b) Methodology in pediatric research

Common methodology used in pediatric practice to assess growth status and body composition has included BMI percentile, ponderal index, skinfold thickness, total body electrical conductivity (TBEC), and dual-energy X-ray absorptiometry (DEXA). The accuracy of these methods when used with infants varies. In addition, the feasibility of using these methods is highly variable.

Ponderal index has been widely used to estimate the nutritional state for infants and young children. It is a measure of the leanness of a child calculated as an association between mass and length (Rohrer, 1921). Patterns of early childhood BMI change are extremely complicated, therefore ponderal index is the recommended index for nutritional status from birth to two years of age (P. M. Catalano et al., 2009). It is accepted as an accurate estimator of infant growth, better than weight-for-length percentiles in many cases as it is independent of demographic influences such as gender, race, and gestational age (Catalano, Tyzbitz, Allen, McBean, & McAuliffe, 1992). Ponderal index at birth has been implicated as a reliable predictor of later obesity, with a six time increase in adult obesity risk for those born with a ponderal index in the highest centile (Meas, Deghmoun, Armoogum, Alberti, & Levy-Marchal, 2008). In a study measuring the associations of change in ponderal index and BMI throughout childhood, Howe et al. (2010) reports that ponderal index is associated with fat mass at 15 years of age. Conversely, there have been arguments that ponderal index is less explanatory of

differences in infant weight. In a study measuring neonatal body composition, Catalano et al. (1992) reported that body composition explained 83% of the variance in birth weight whereas ponderal index explained only 22% of the variance. Even so, ponderal index is highly recommended as the best measure when interpreting change in growth over time during the first 24 months of life.

Skinfold thickness is commonly used as a measurement of subcutaneous fat in individuals of all ages. Despite its common use, this method is far from perfect. Skinfold thickness is notorious for low interrater reliability. In addition, trend analysis of mean skinfold values tend to be influenced by extreme outliers artificially raising or lowering a curve, suggesting a trend that may not be present. For this reason, trend analysis using median values is suggested as median values are less influenced by extreme values (Kuczmarski, 1993). Making interpretation more difficult, national reference data used in normative comparisons employ multiple assessors of skinfold measurement which can negatively impact the data given the nature of skinfold measurement (de Bruin, 1996; Kuczmarski, 1993). To deal with this discrepancy, an error rate of 4.0 millimeter (mm) has been suggested when interpreting skinfold thickness data when multiple assessors are used (Chumlea, 1990). This means that small differences in normative data may in fact be within the range of measurement error and therefore are less meaningful. Also, an interrater error of no more than 5% in most repeated measurements indicates strong accuracy (Edwards, 1955). This suggests that skinfold data collected by one assessor with strong intrarater reliability is more accurate with a smaller rate of error. Comparisons within the population are less meaningful while comparison with the sample will provide richer interpretation.

Physical activity measurement is common in health related research. Unfortunately, there is little study to support the methodology of measuring infant PA. Infants six months of age or less are primarily lying or sitting, meaning there is more acceleration of the legs than any other body segment. With a majority of PA occurring in the legs, it is suggested that PA monitors are worn on the ankle (Angulo-Barroso, et al., 2008; Tolve, Jones, McCurdy, & Croghan, 2007). It is also suggested that parental activity monitoring logs be used in order to substantiate the data received from the monitor as well as to better interpret the level of intensity of the data. In a study measuring the association of parental interpretation of physical activity with objective PA monitoring, Tolve et al. (2007) reports a 70% agreement between parental report of activity on a log and objective monitoring. Consequently, a study measuring the agreement between objective PA monitoring of an infant during typical daily activities and that of a doll mimicking these same activities was 55% (Worobey, Vetrini, & Rozo, 2009). This indicates the extreme effect of mechanical handling of the infant on objective monitoring. These findings highlight the value in gathering parental interpretation and their usefulness in interpreting activity intensity in infancy.

c) Environmental and innate contributors to infant obesity

There is growing evidence and acceptance of the presence of a sensitive period for developing obesity (Olson, Strawderman, & Dennison, 2009). One period of particular vulnerability is the prenatal period. Within this period, there are many known determinants of rapid weight gain. It is widely accepted that many maternal factors exist which could contribute to rapid weight gain in her offspring. Common maternal factors include obesity status or BMI, pregnancy weight gain, pregnancy diet, smoking, and possible genetic or phenotypic links.

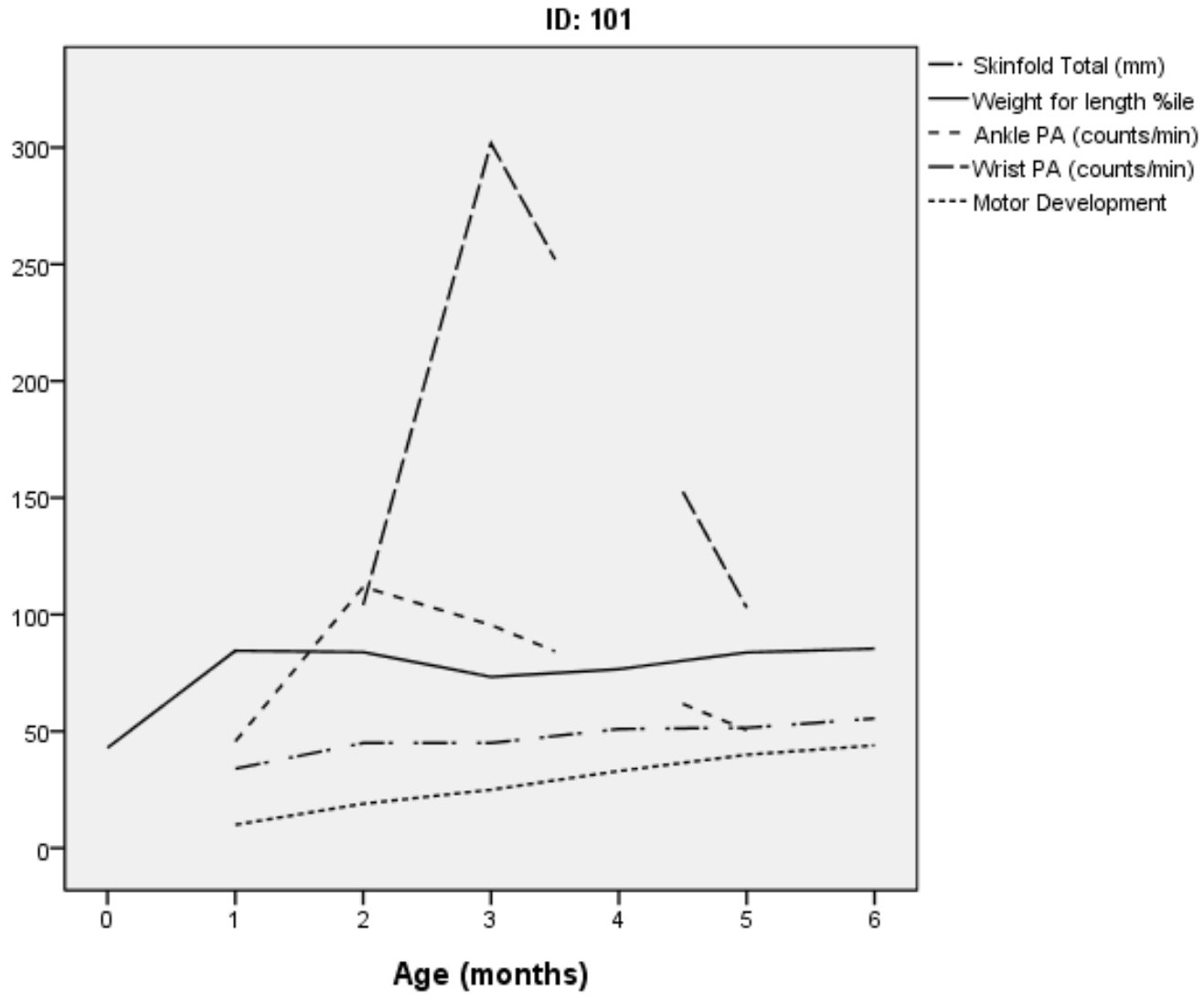
Surprisingly, little is known or reported about the influence of PA level to rapid weight gain during infancy.

Maternal obesity before and during pregnancy is associated with increased risk of rapid weight gain during infancy and obesity throughout early childhood (Berkowitz, 2005; Eisenman, Sarzynski, Tucker, & Heelan, 2010; Kramer et al., 2002; Olson, et al., 2009; Sowan & Stember, 2000; Whitaker, 2004). There is a positive association between maternal pre-gravid BMI and infant weight gain at one year (Baker, 2004). Pre-gravid obesity has been shown to affect a child's PA behavior as well. Children of mothers who experienced pre-gravid obesity display fewer minutes of moderate-to-vigorous PA than what is recommended (Eisenman, et al., 2010). These children tend to be heavier than children of mothers who have normal weight prior to pregnancy.

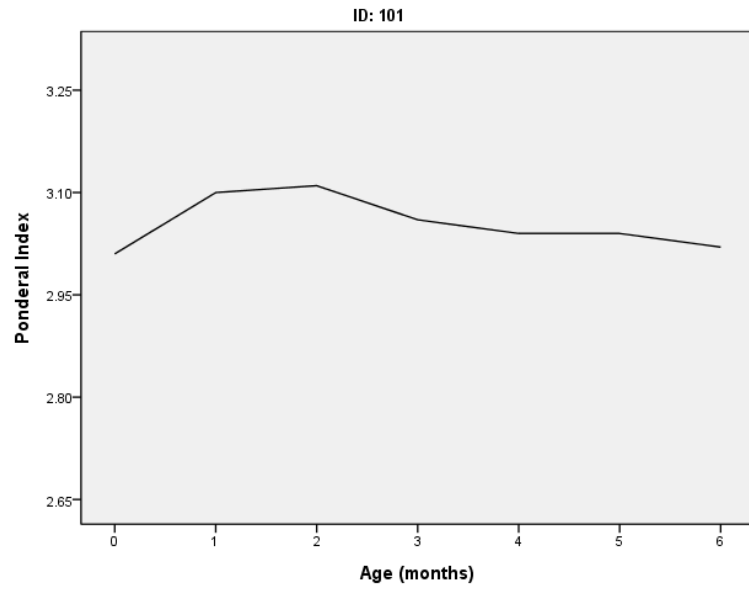
Excess weight gain during pregnancy has also been shown to increase the risk of obesity during childhood. In an observational study of 208 mothers and their children, Olson et al., (2009) reported a significant relationship of increased maternal BMI during pregnancy and overweight in offspring. Not only is this relationship established for young children, higher maternal BMI is associated with higher adiposity and weight persisting into adulthood (Reynolds, Osmond, Phillips, & Godfrey, 2010). Given these results, recognizing pre-gravid obesity or excess weight gain during pregnancy suggests an opportunity to identify children early who are at risk for rapid weight gain during infancy. It also presents an opportunity to recognize early risk for sedentary lifestyle and resulting weight gain and to encourage interventions to increase PA behavior early in life. However before such interventions can be prescribed, a detailed account and interpretation of infant PA must first be studied.

Appendix 2.1 Overlay line graphs of all variables BY age for ID 101

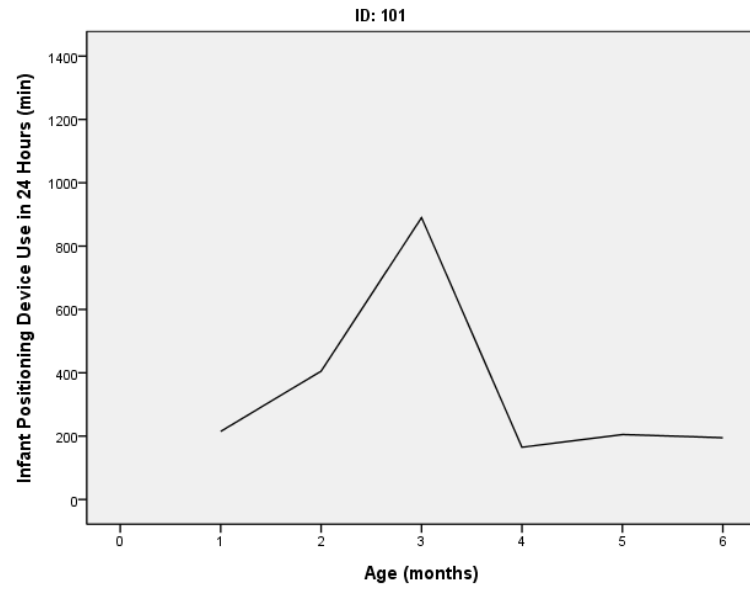
a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development



b) Ponderal index

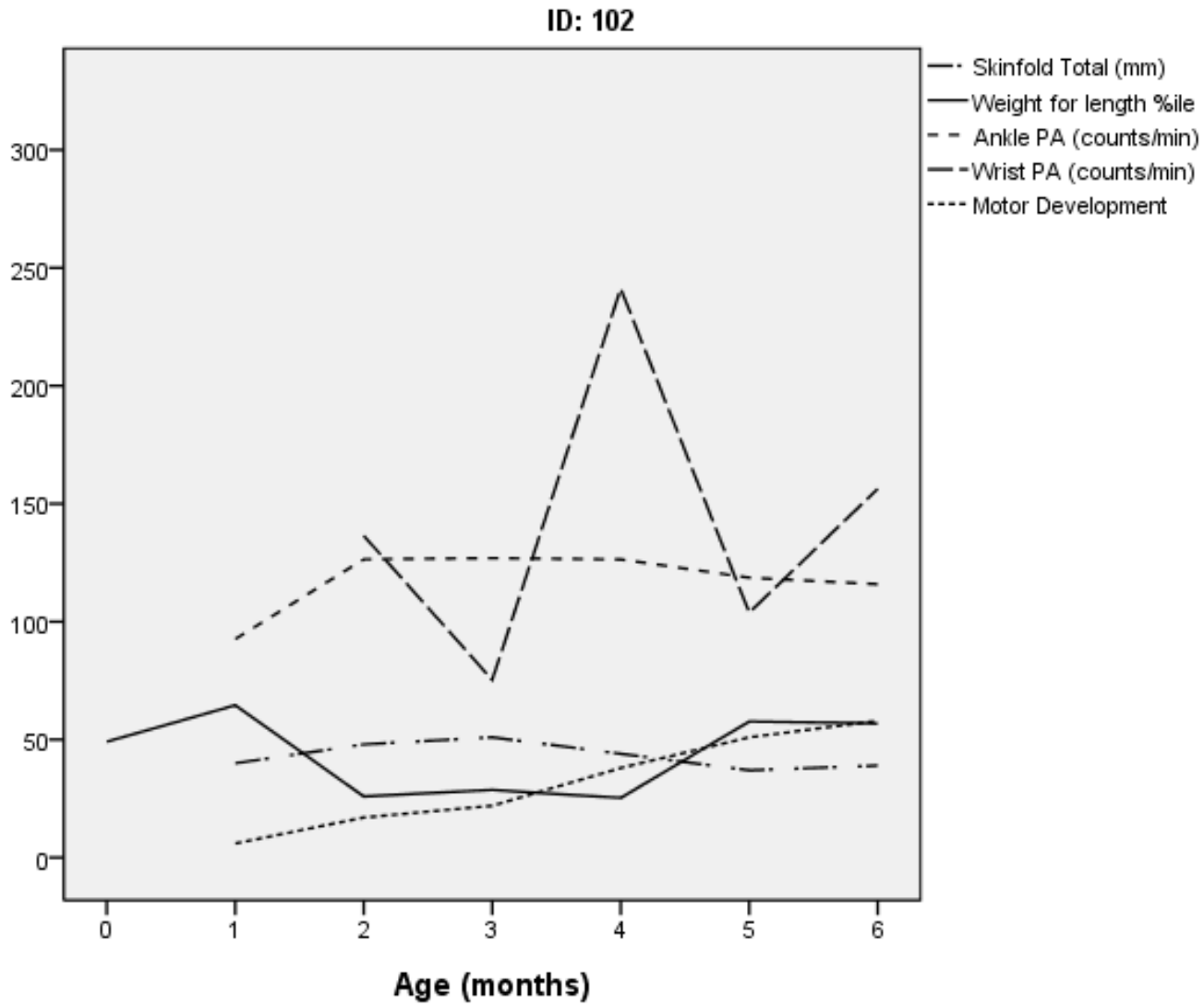


c) Infant positioning device use

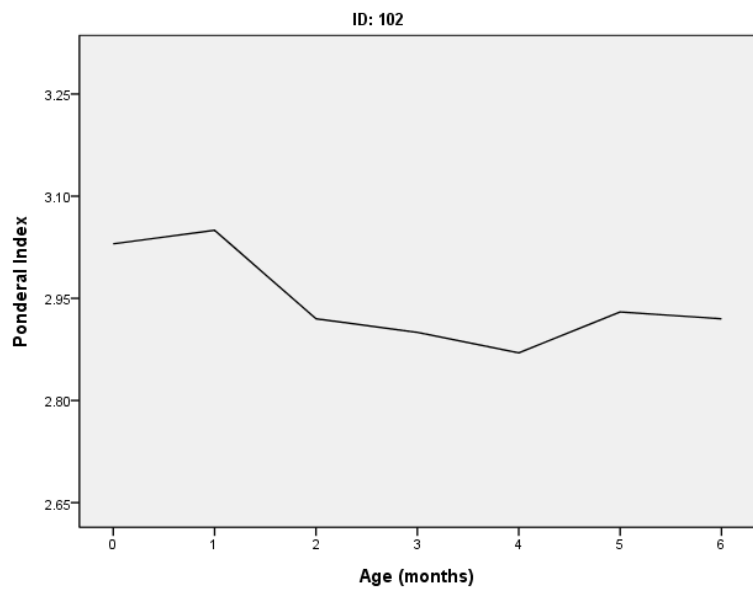


Appendix 2.2 Overlay line graphs of all variables BY age for ID 102

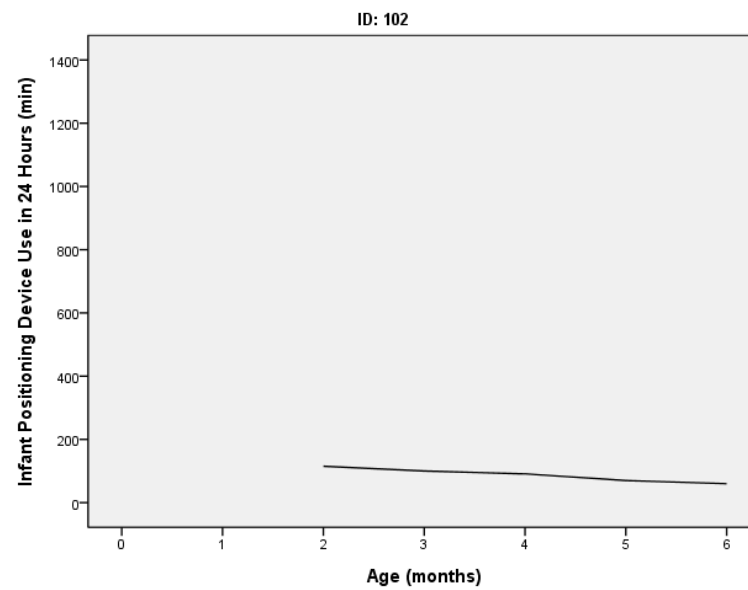
a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development



b) Ponderal index

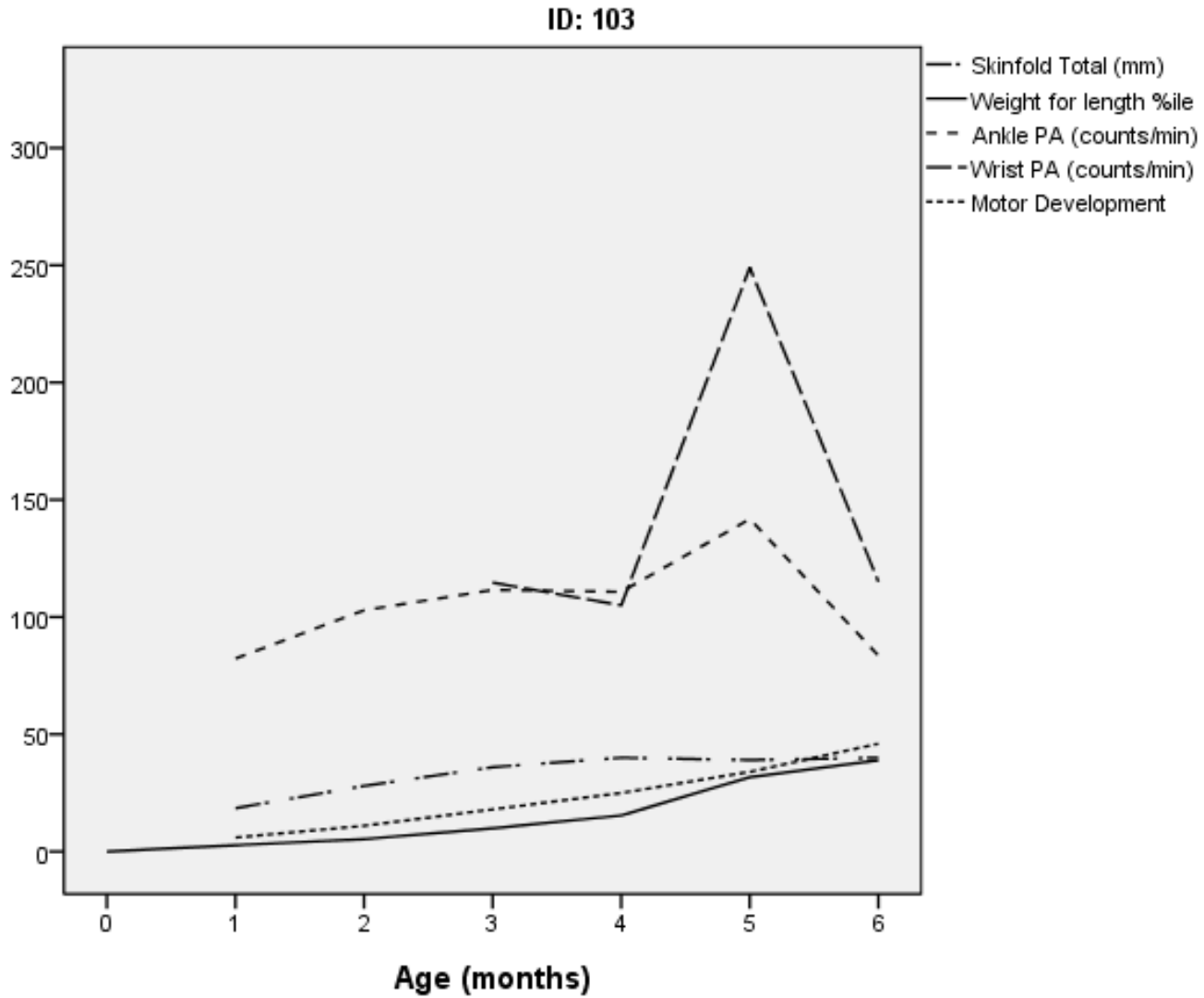


c) Infant positioning

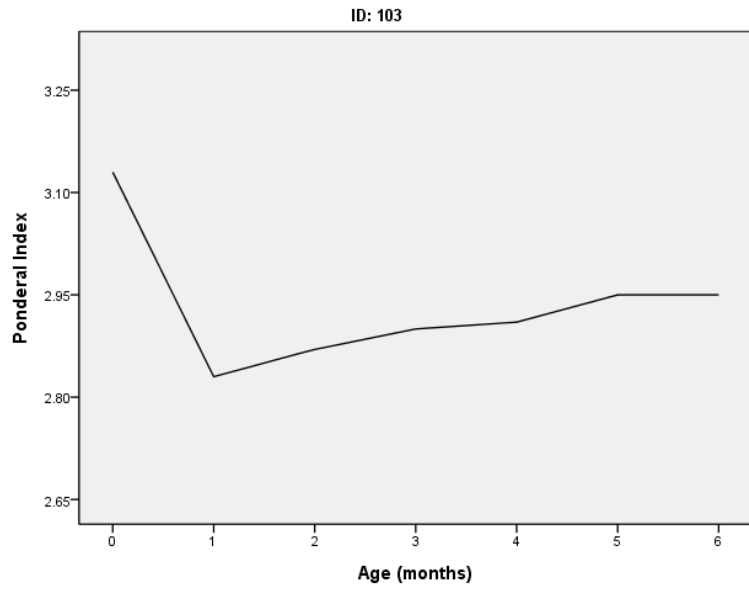


Appendix 2.3 Overlay line graphs of all variables BY age for ID 103

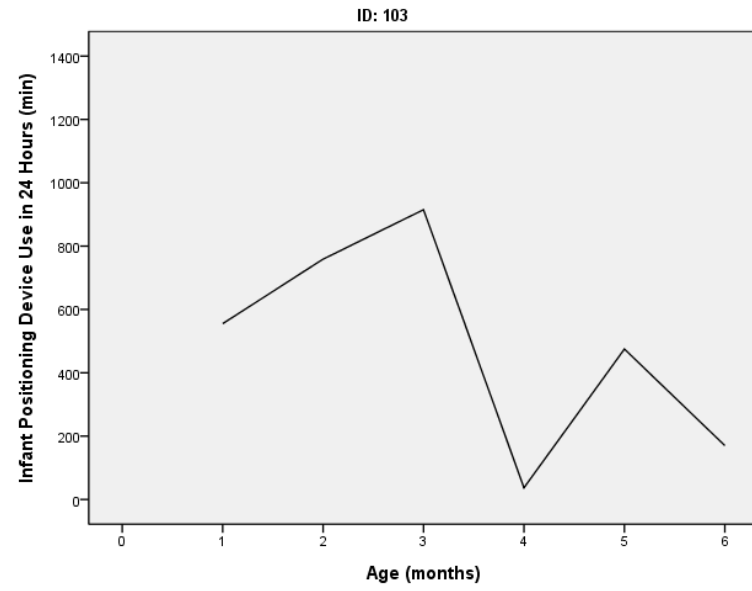
a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development



a) Ponderal index

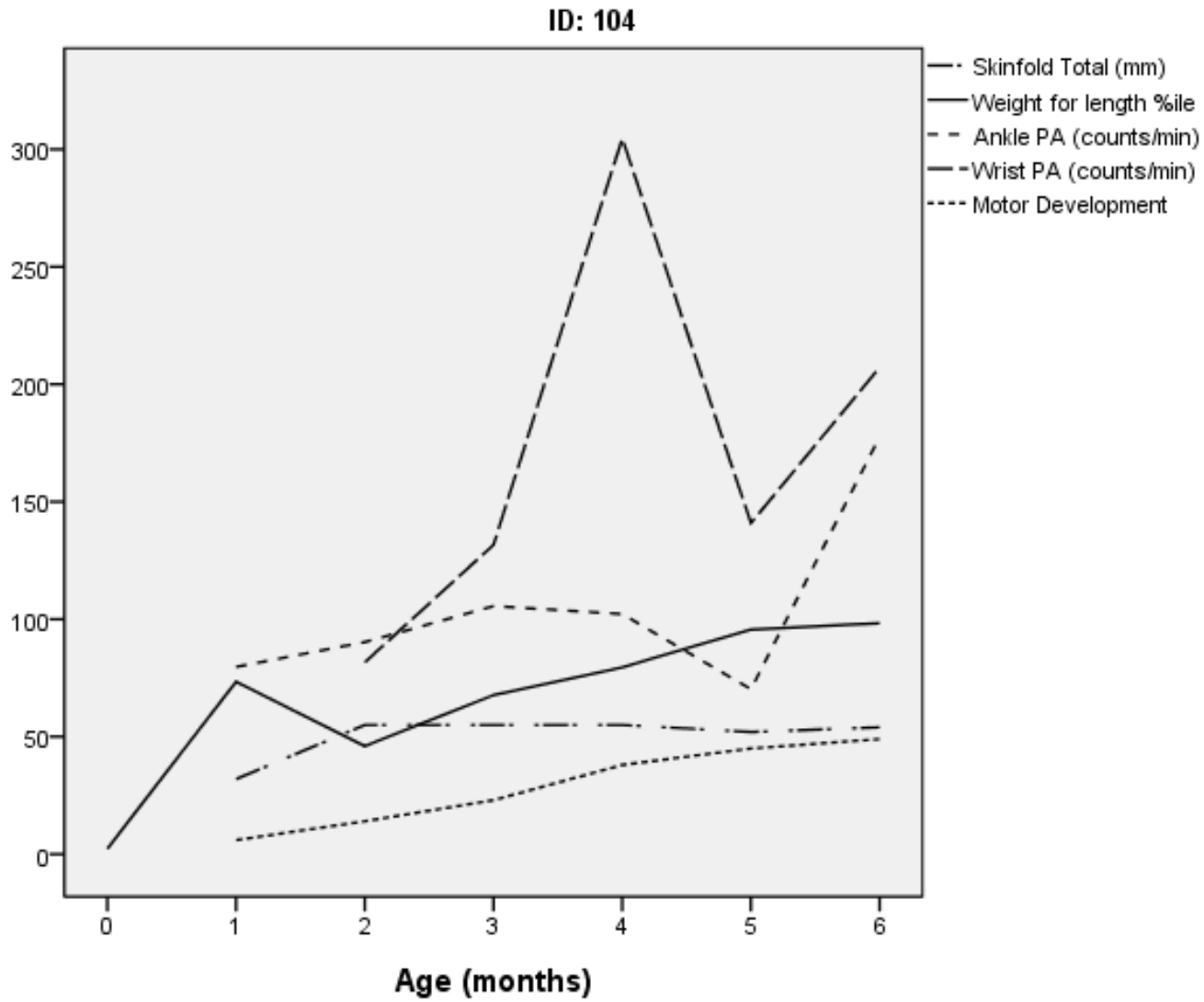


c) Infant positioning device

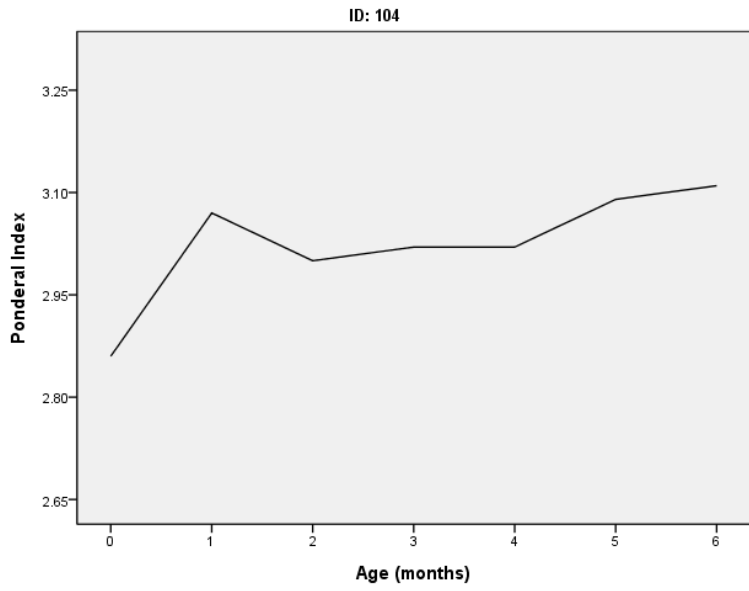


Appendix 2.4 Overlay line graphs of all variables BY age for ID 104

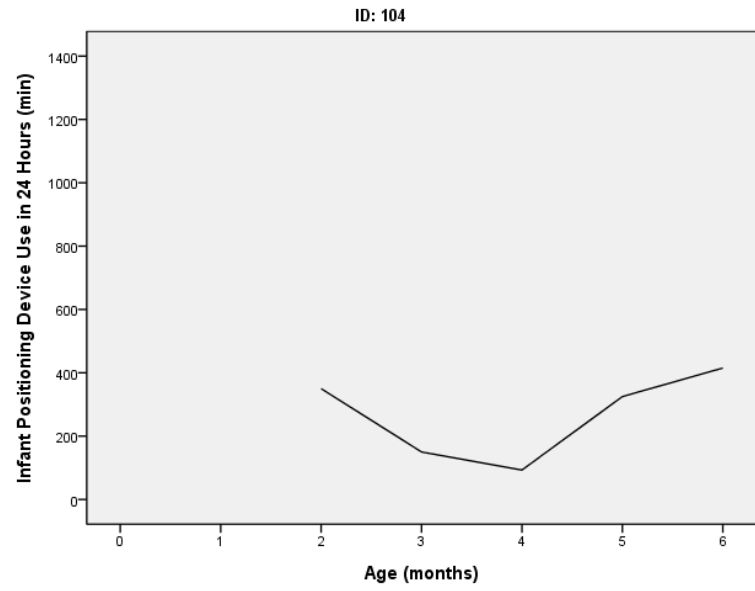
a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development



b) Ponderal index

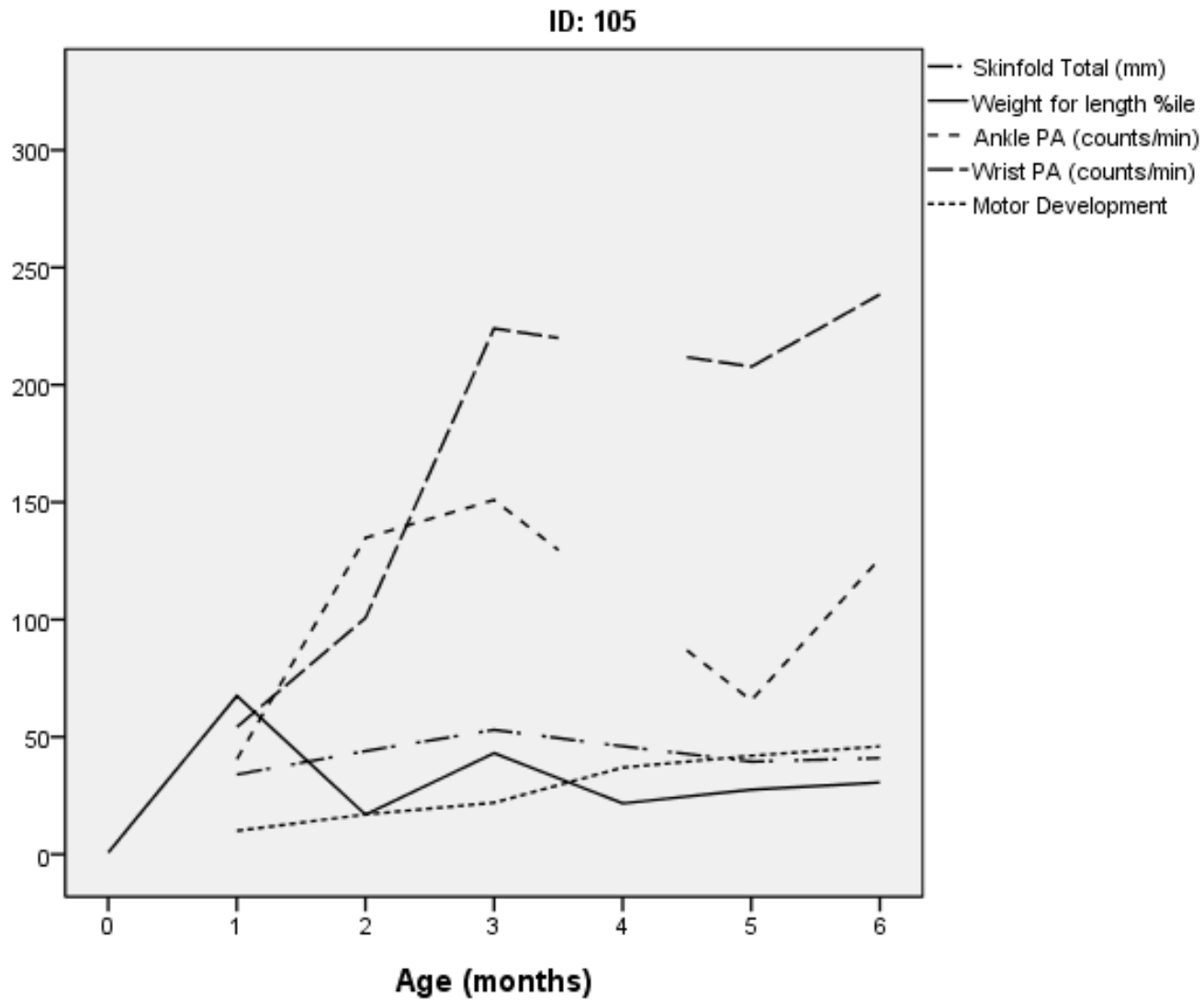


c) Infant positioning device

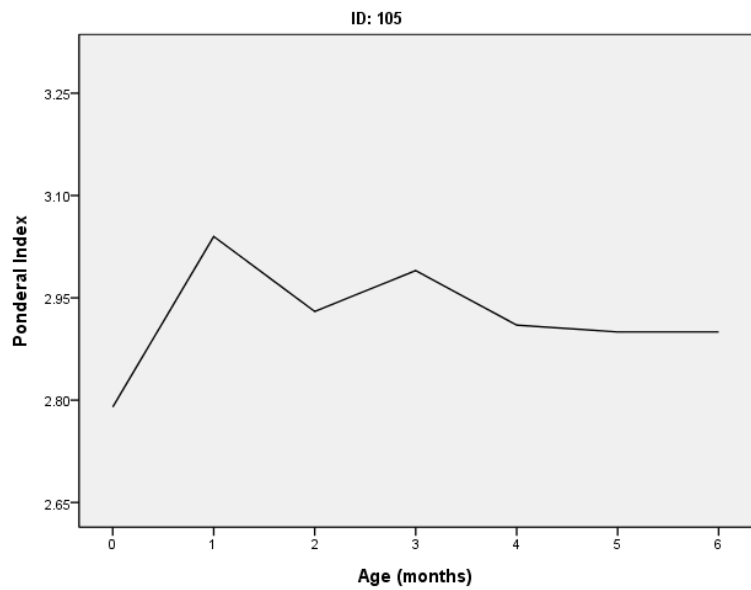


Appendix 2.5 Overlay line graphs of all variables BY age for ID 105

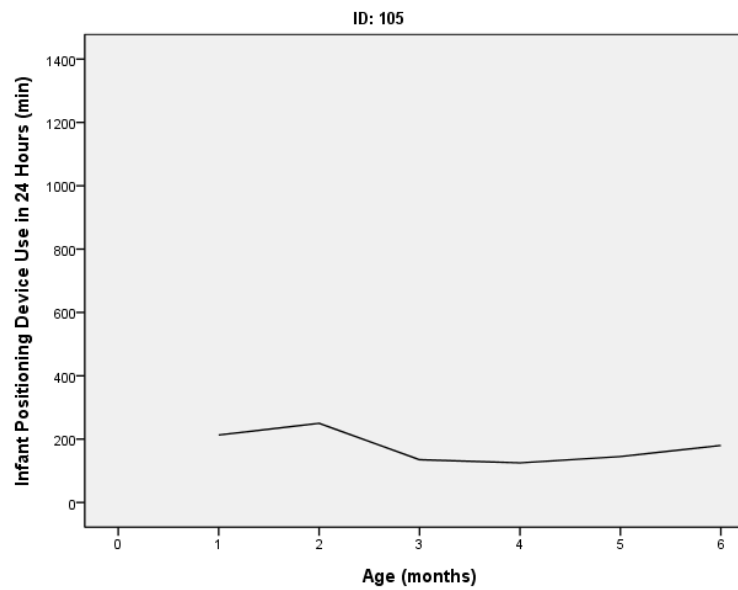
a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development



b) Ponderal index

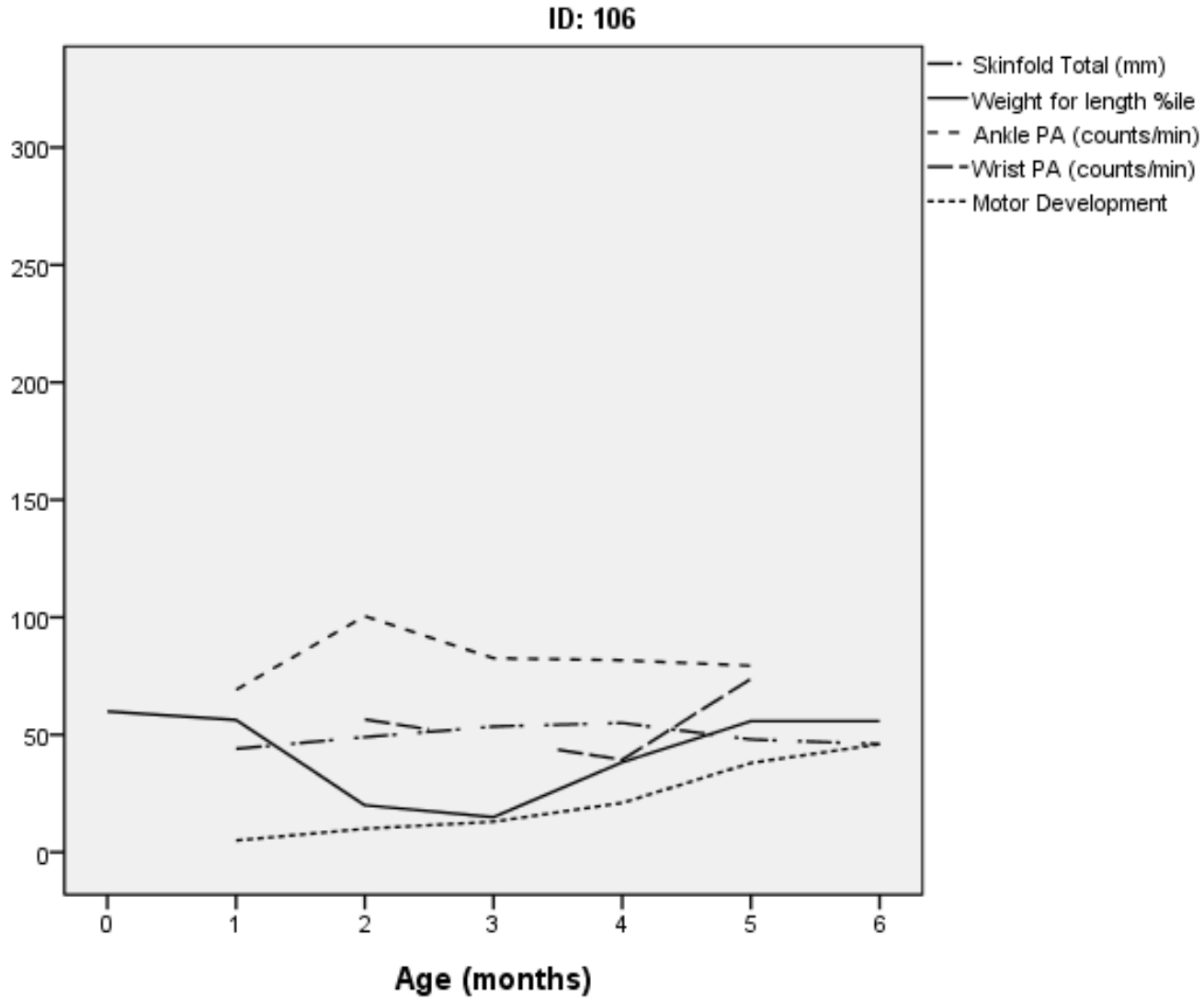


c) Infant positioning device

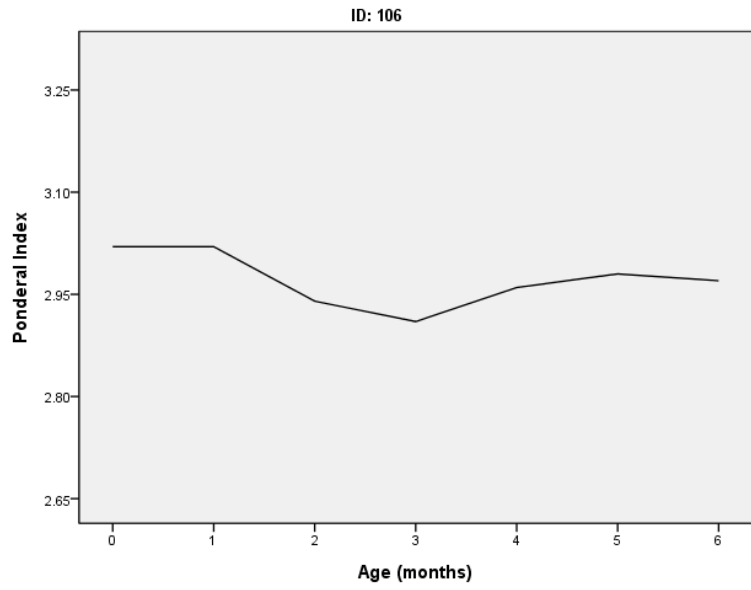


Appendix 2.6 Overlay line graphs of all variables BY age for ID 106

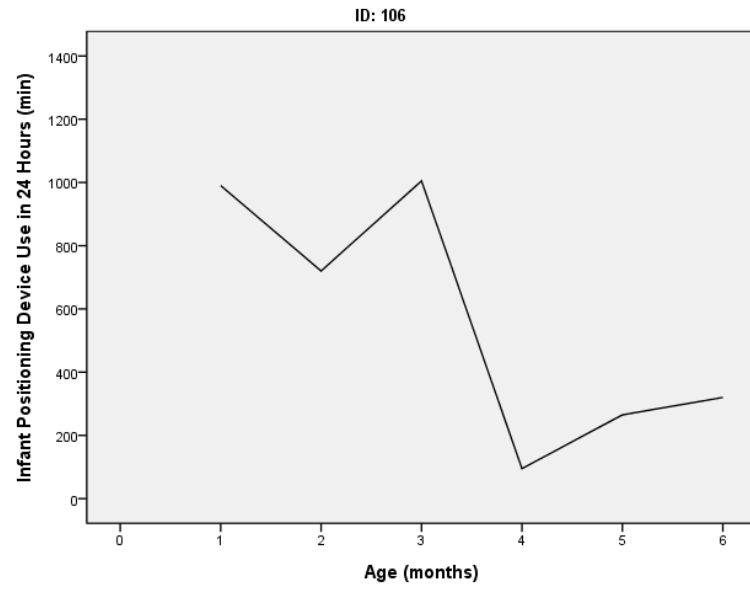
a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development



b) Ponderal index

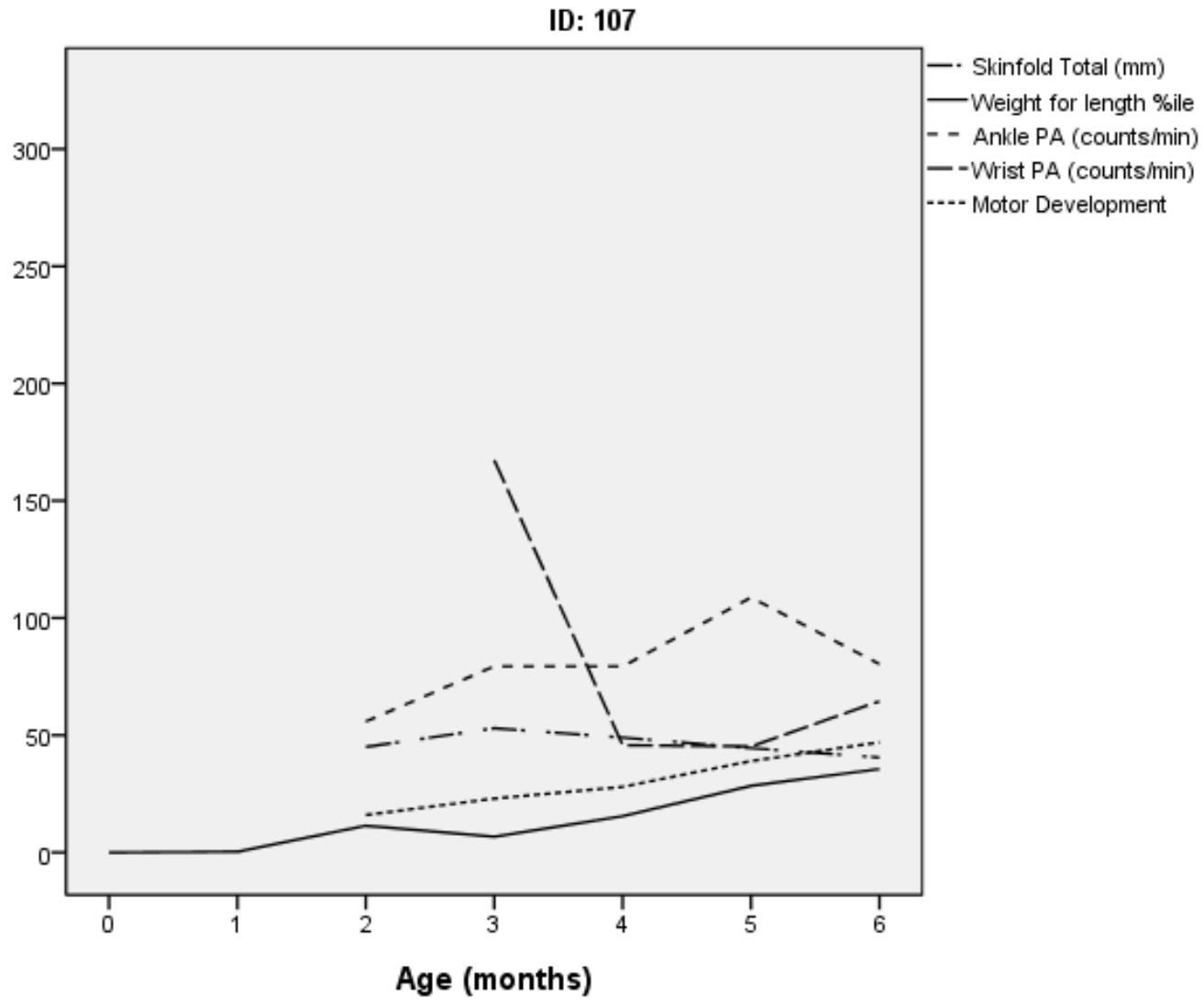


c) Infant positioning device

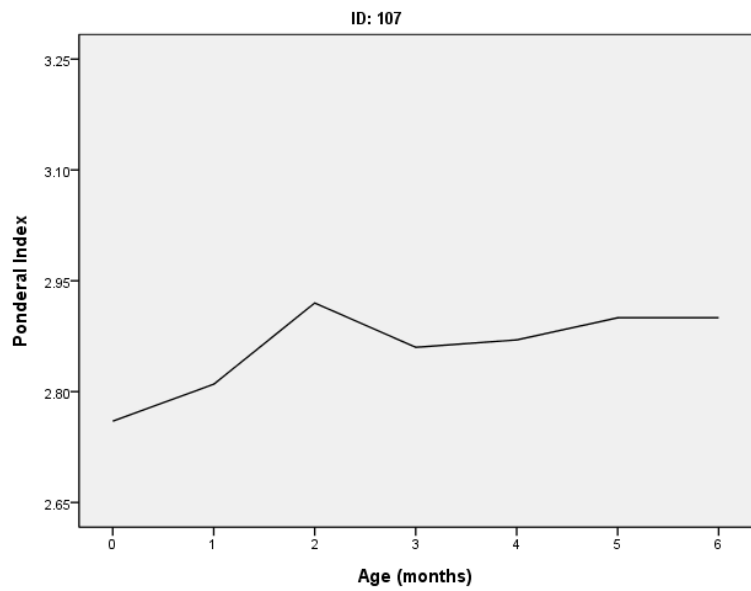


Appendix 2.7 Overlay line graphs of all variables BY age for ID 107

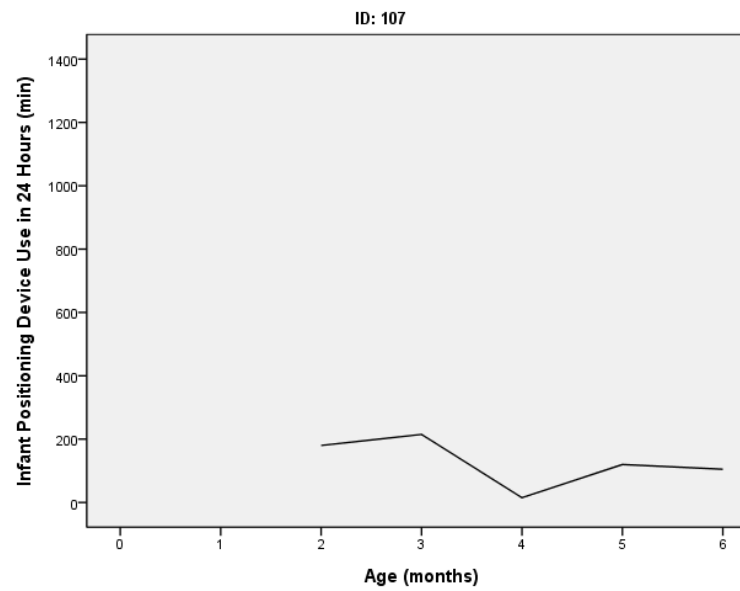
a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development



b) Ponderal index

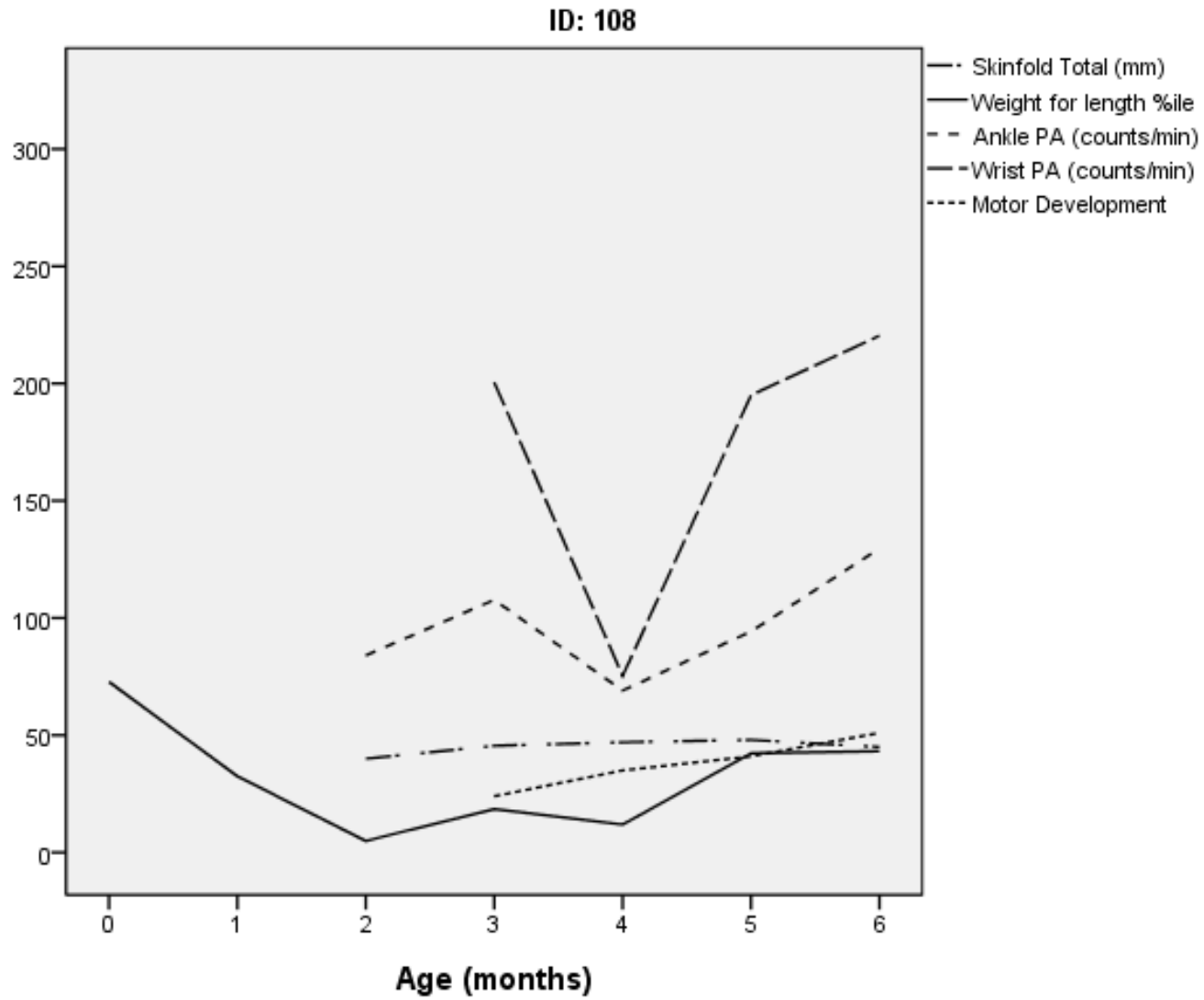


c) Infant positioning device

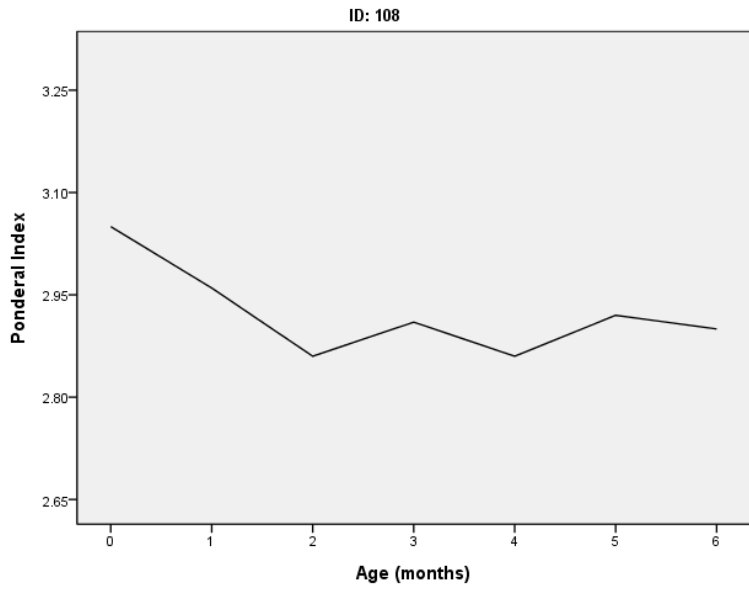


Appendix 2.8 Overlay line graphs of all variables BY age for ID 108

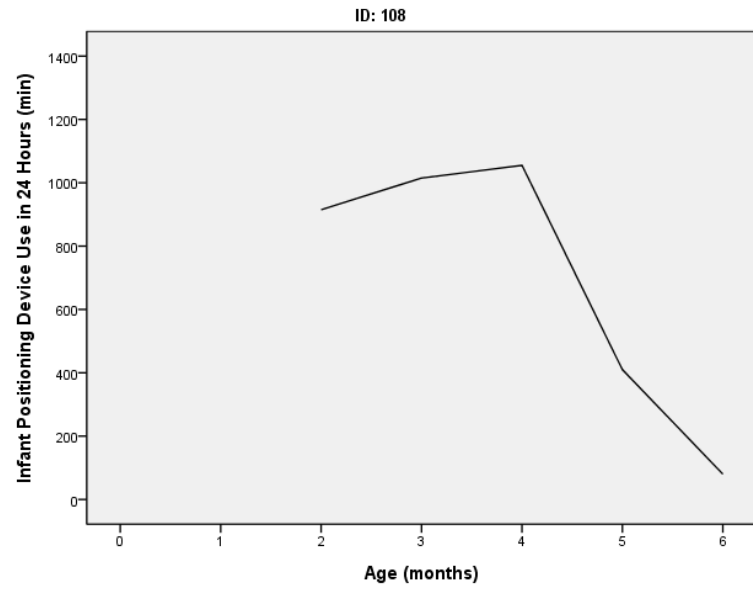
a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development



b) Ponderal index



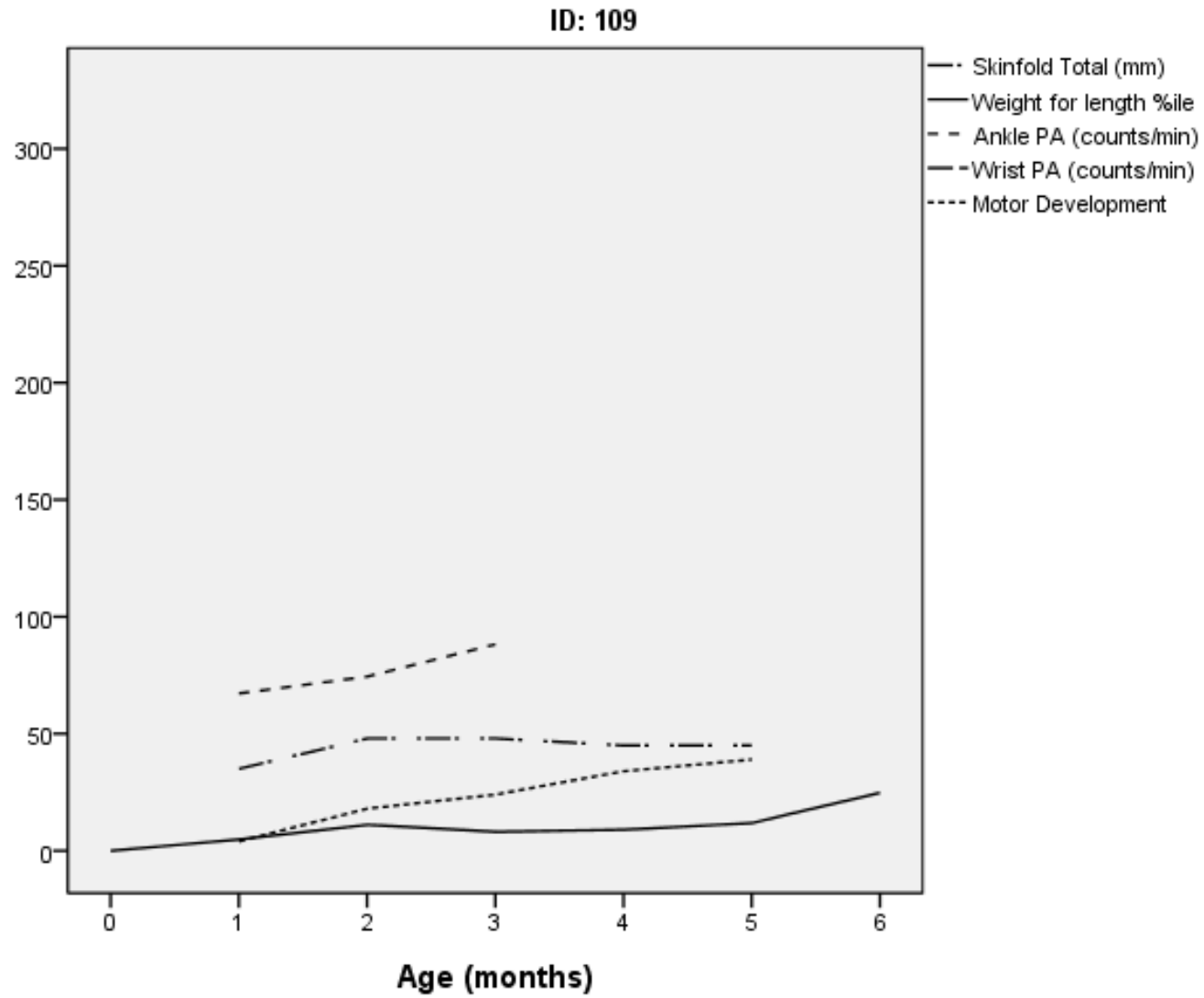
c) Infant positioning device



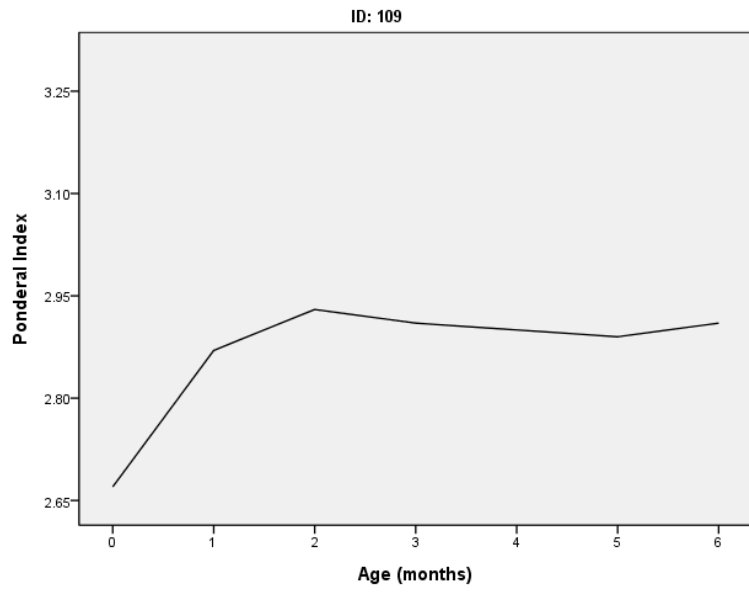
Appendix 2.9 Overlay line graphs of all variables BY age for ID 109

a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development

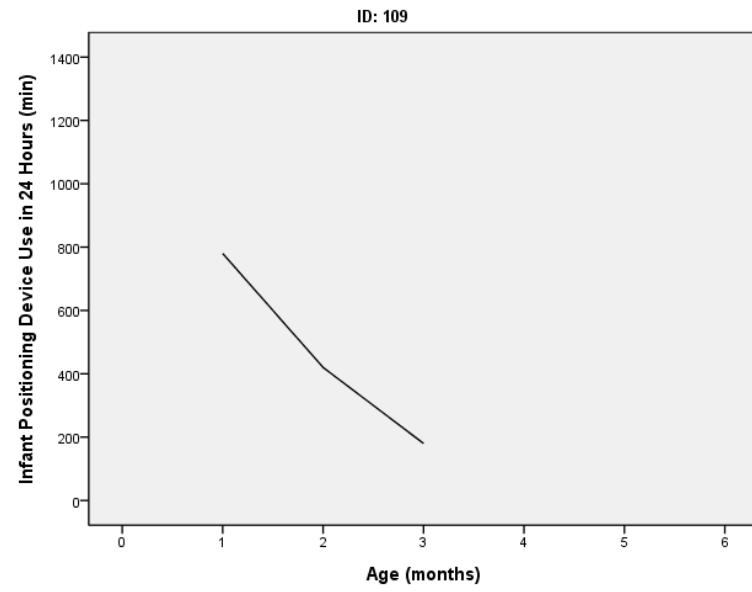
130



b) Ponderal index

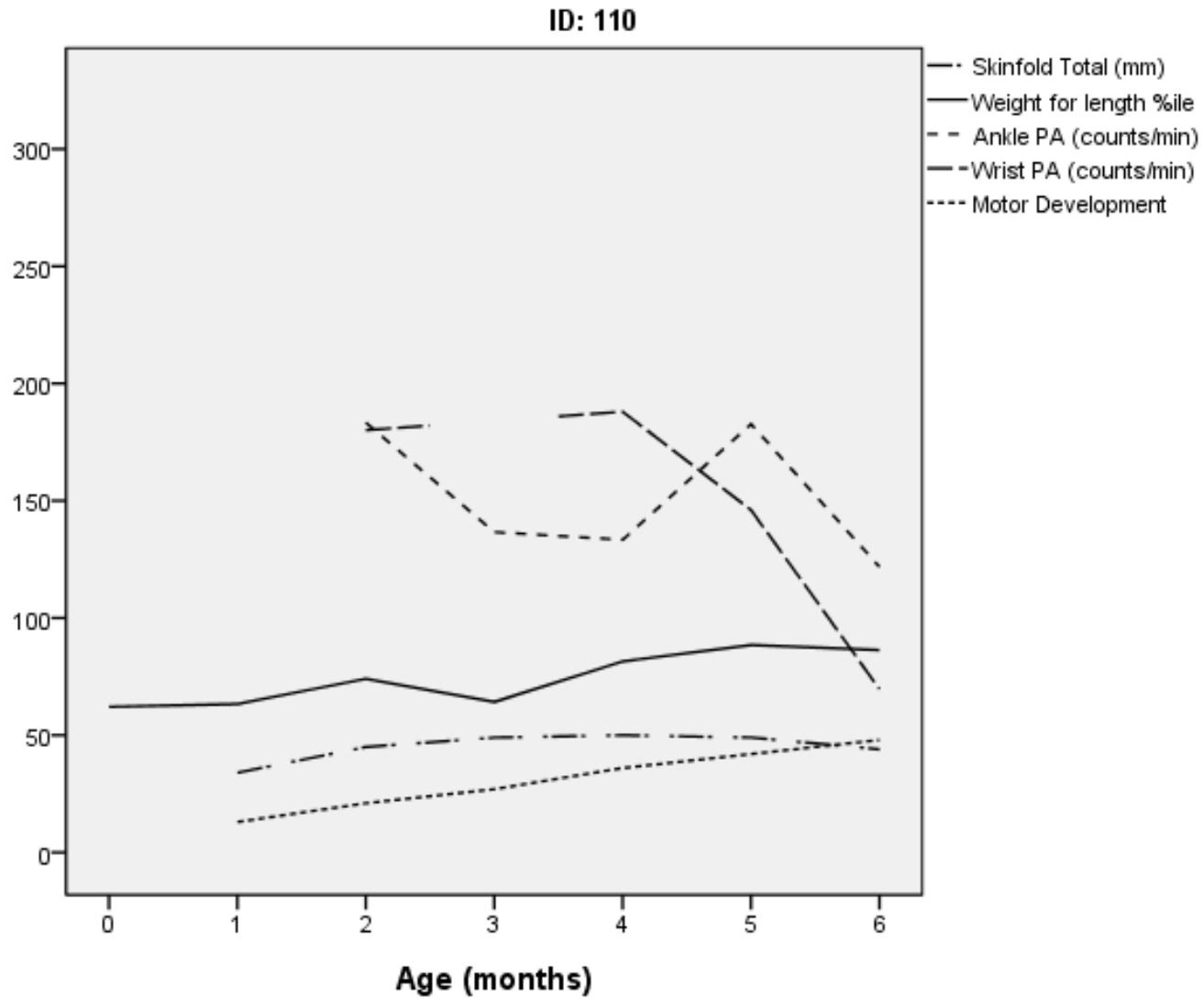


c) Infant positioning device

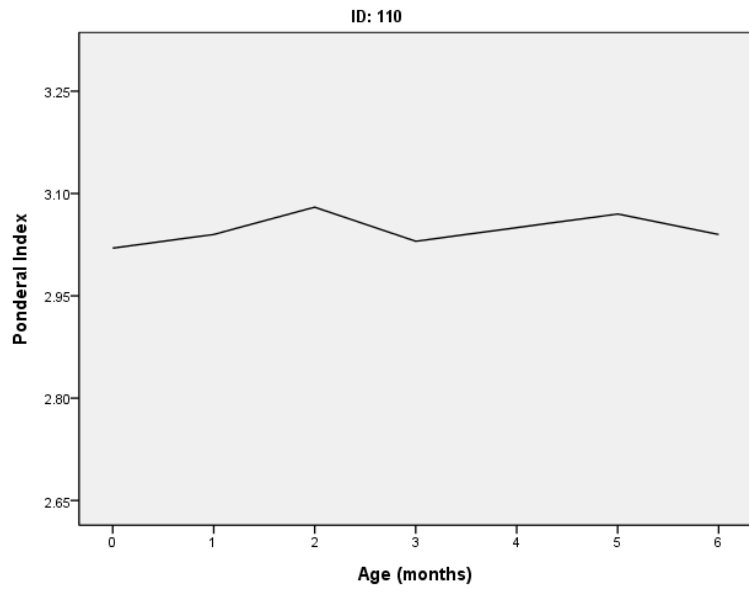


Appendix 2.10 Overlay line graphs of all variables BY age for ID 110

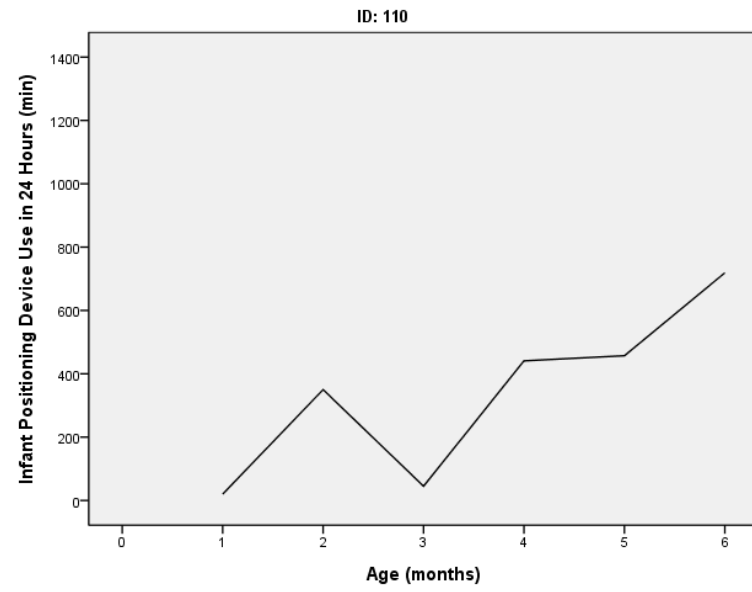
a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development



b) Ponderal index



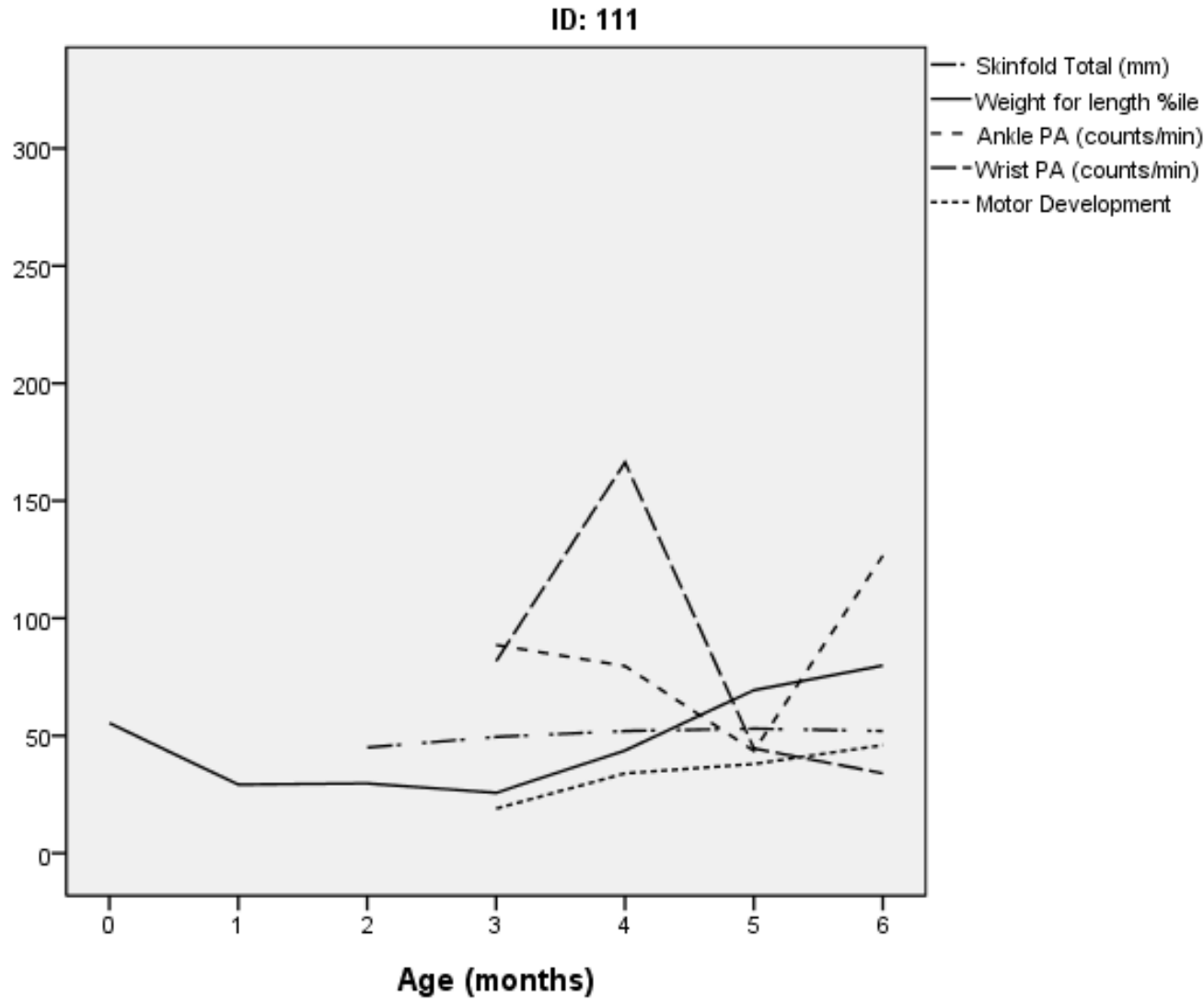
c) Infant positioning device



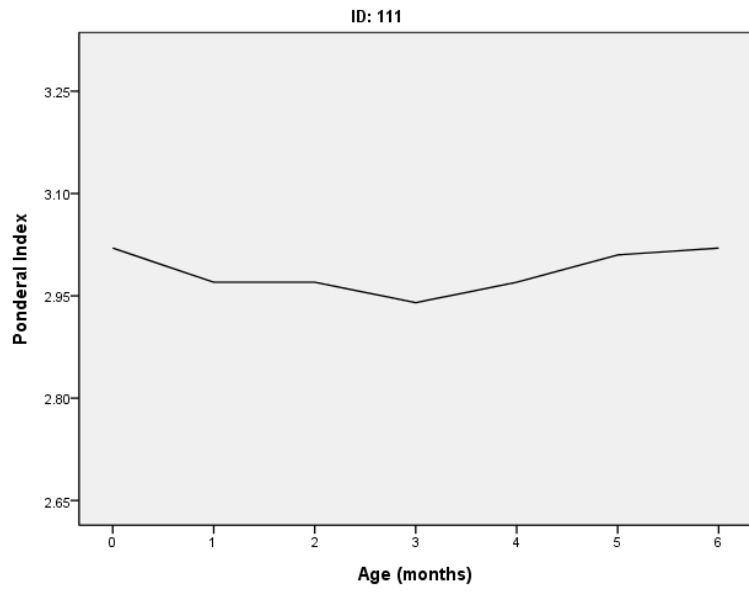
Appendix 2.11 Overlay line graphs of all variables BY age for ID 111

a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development

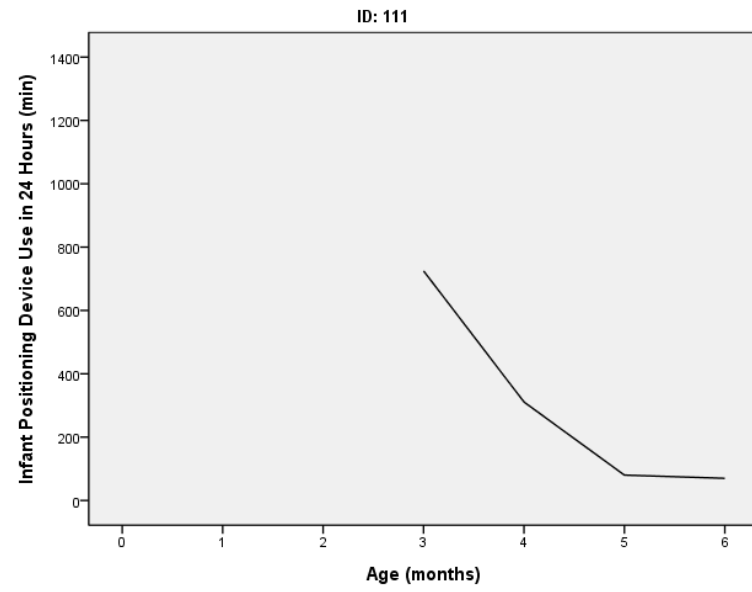
134



b) Ponderal index



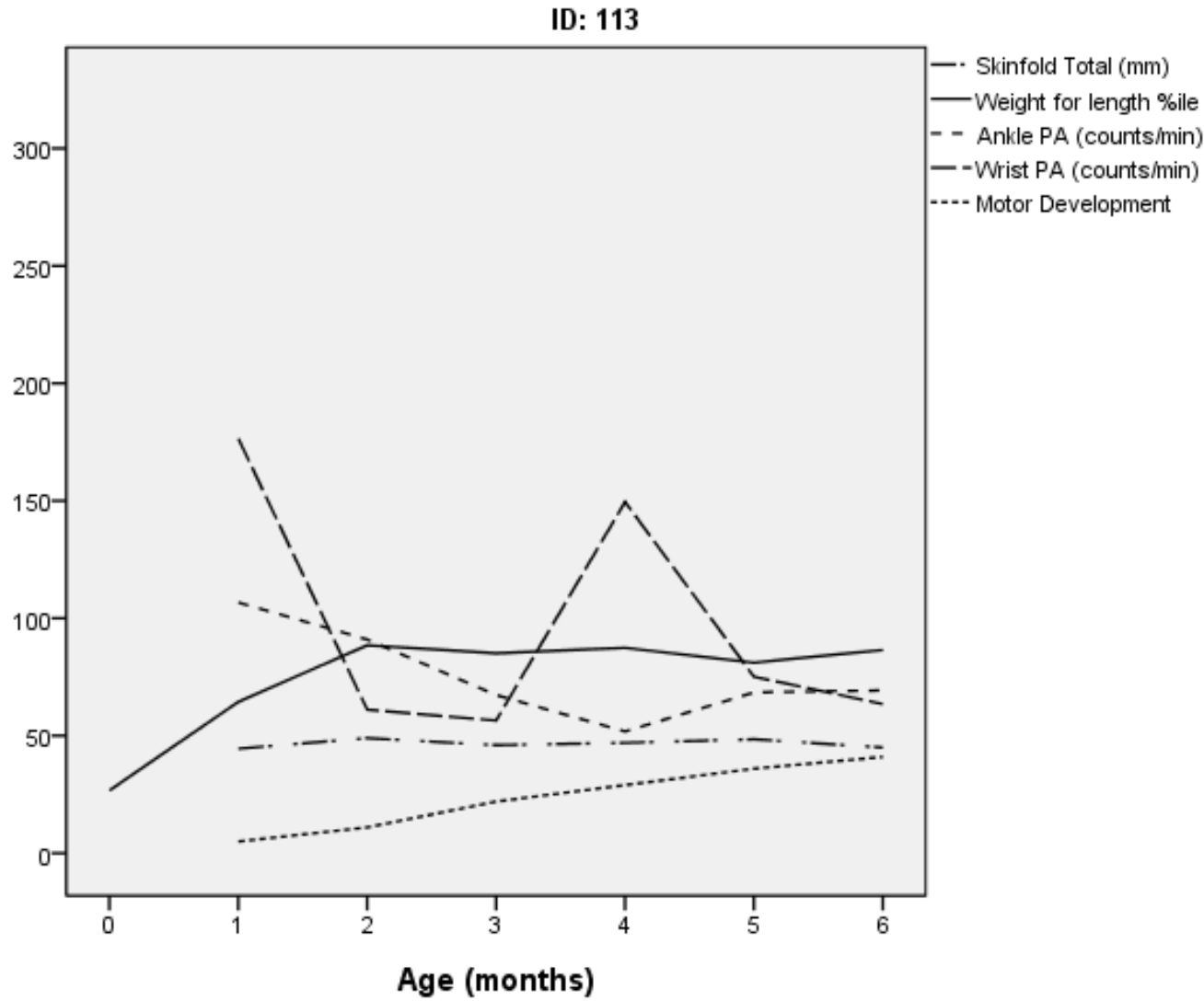
c) Infant positioning device



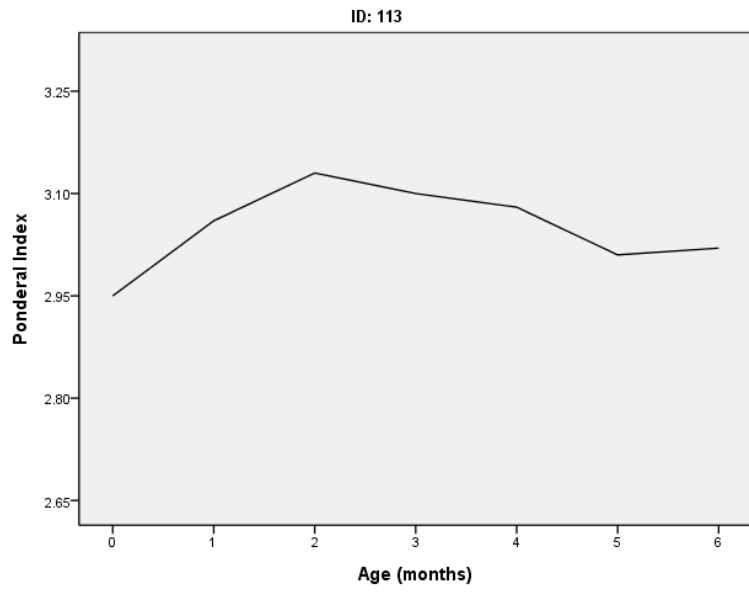
Appendix 2.12 Overlay line graphs of all variables BY age for ID 113

a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development

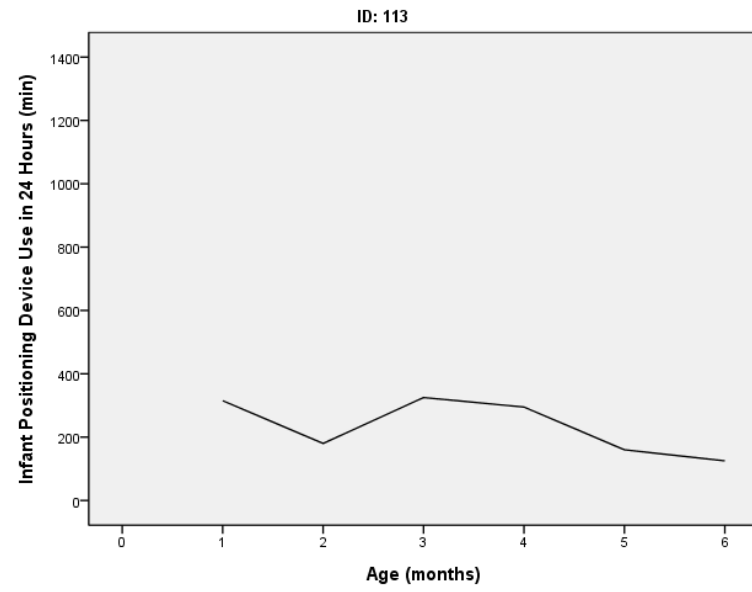
136



b) Ponderal index



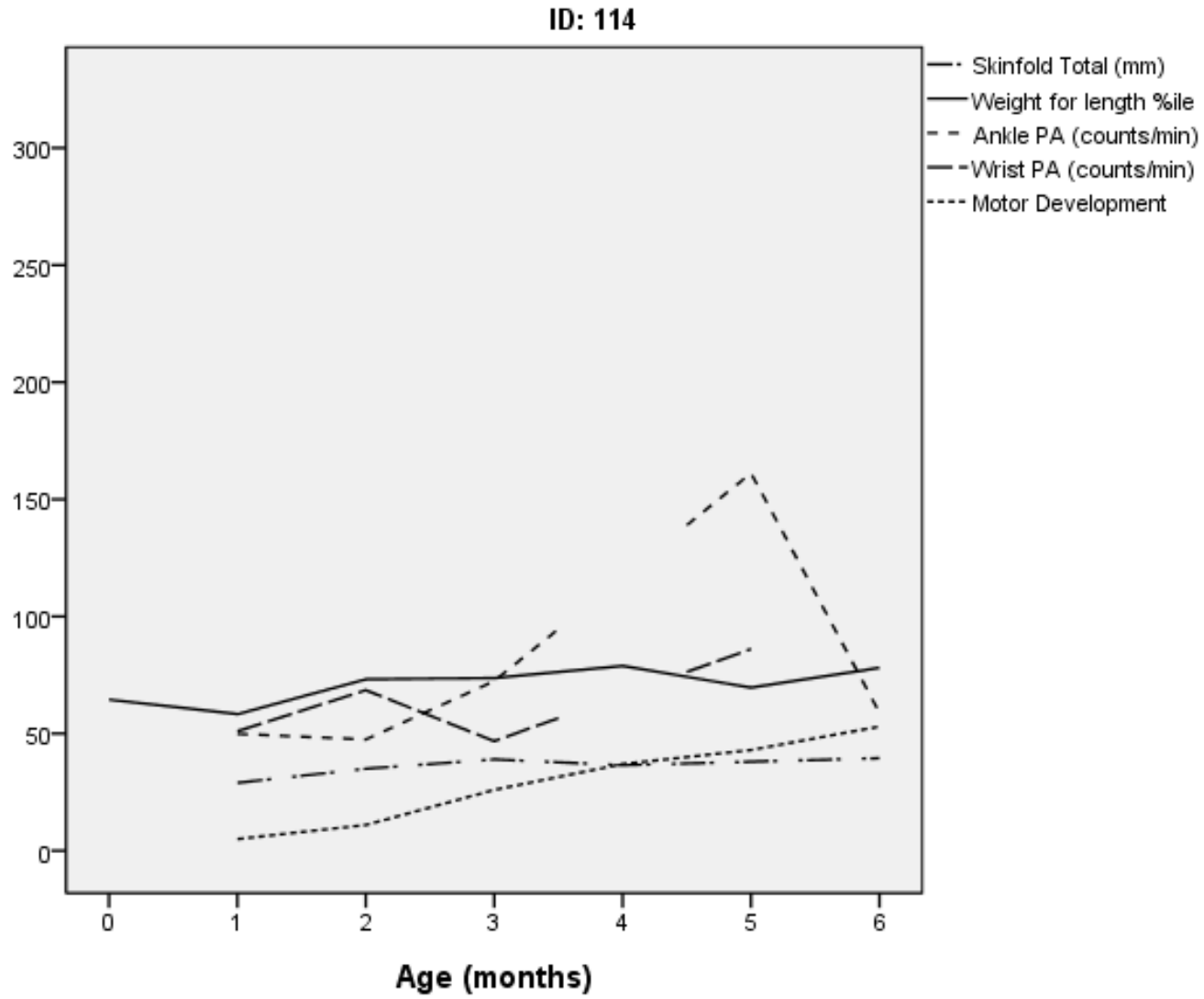
c) Infant positioning device



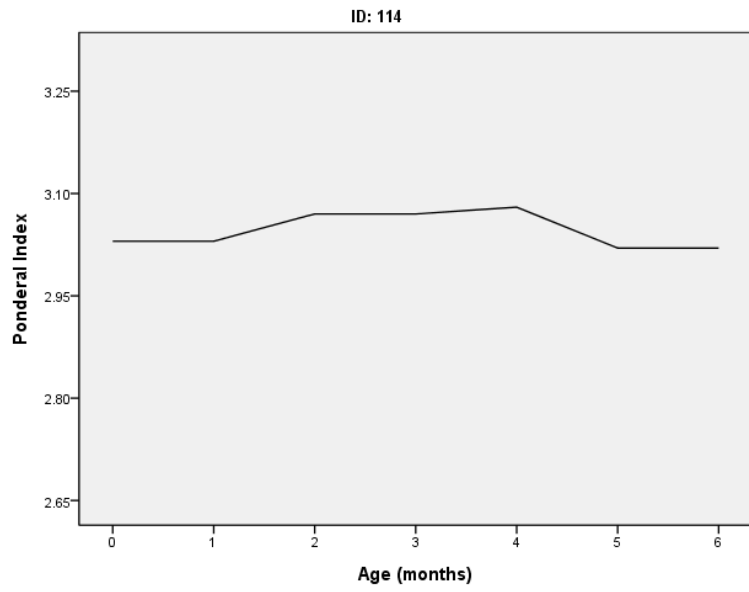
Appendix 2.13 Overlay line graphs of all variables BY age for ID 114

a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development

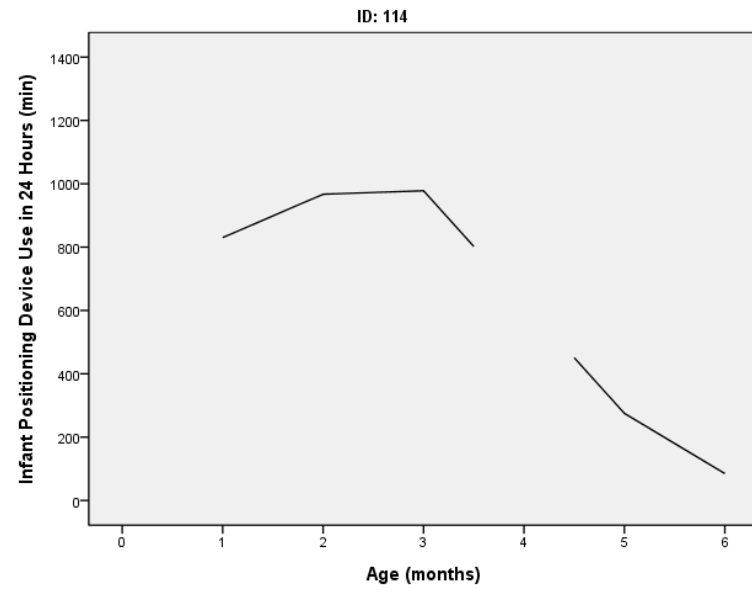
138



b) Ponderal index



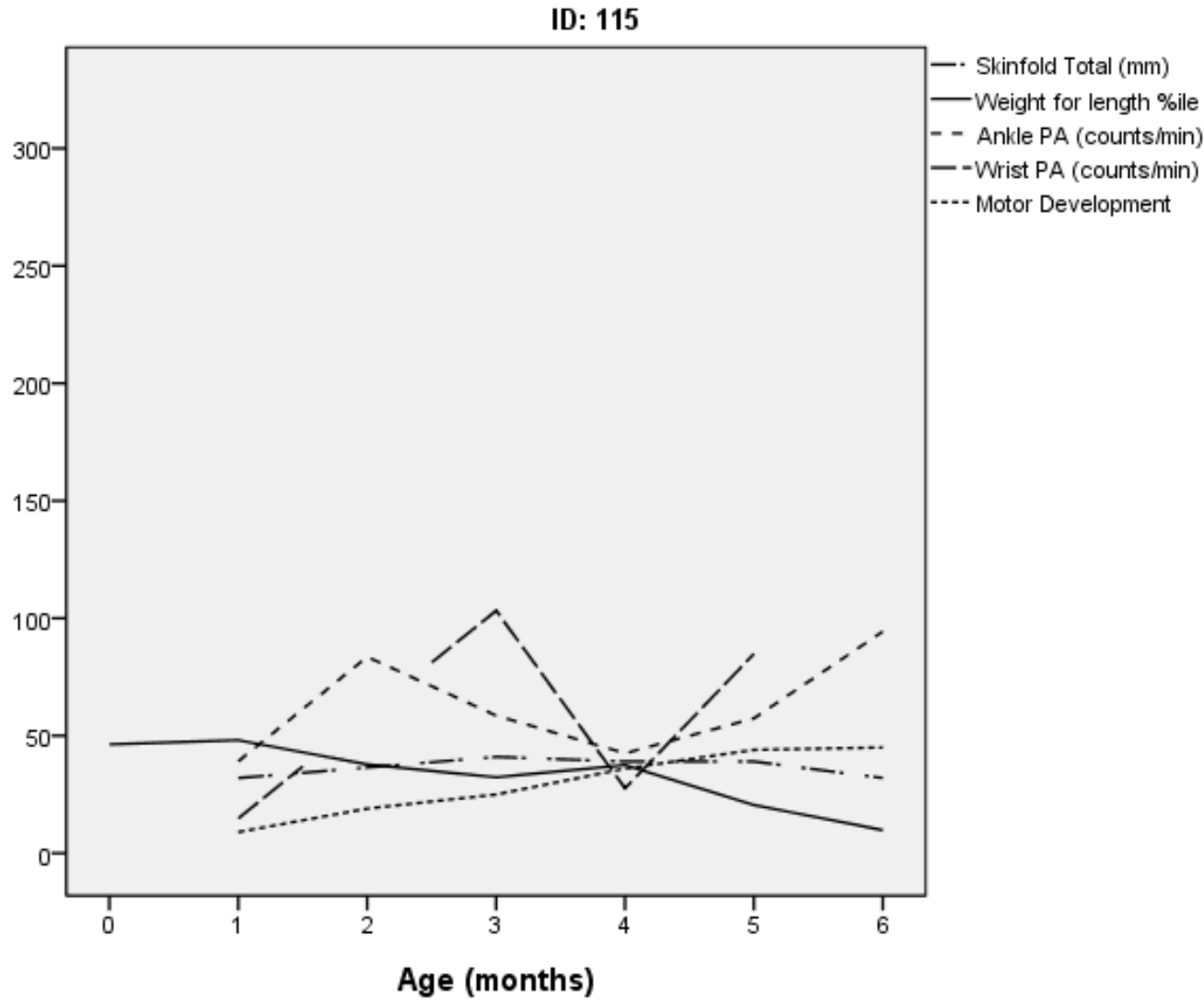
c) Infant positioning device



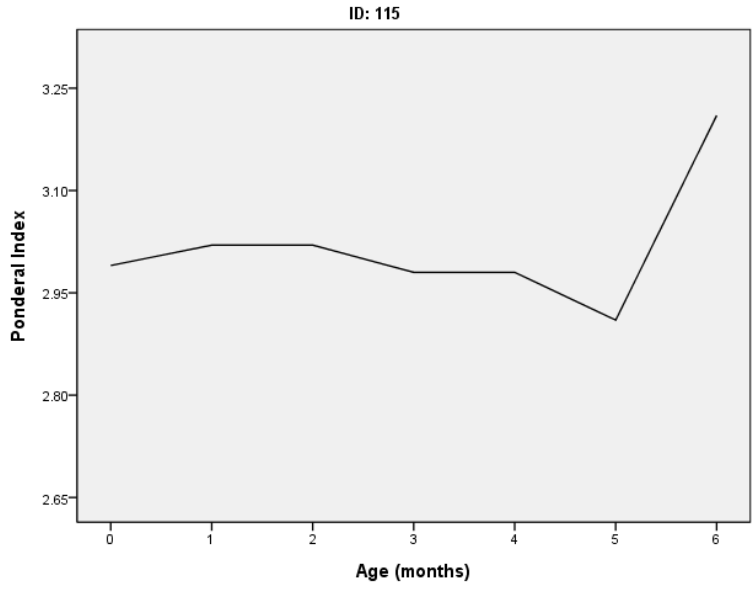
Appendix 2.14 Overlay line graphs of all variables BY age for ID 115

a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development

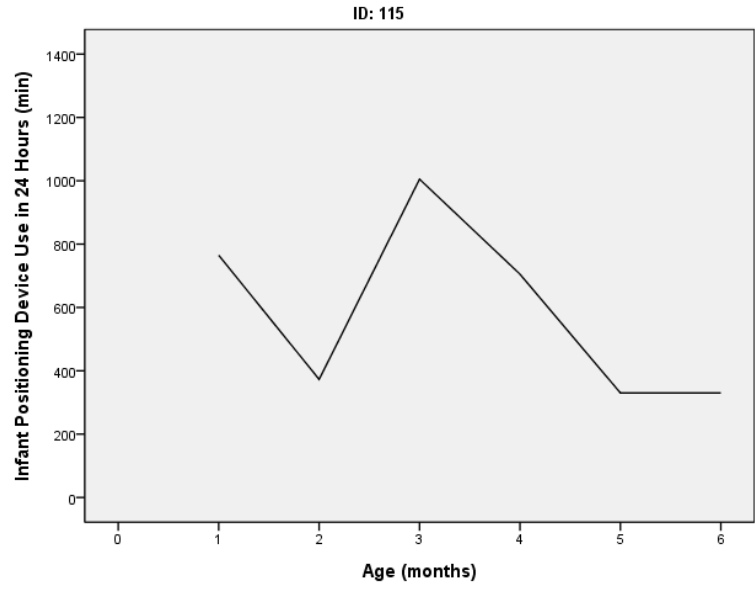
140



b) Ponderal index



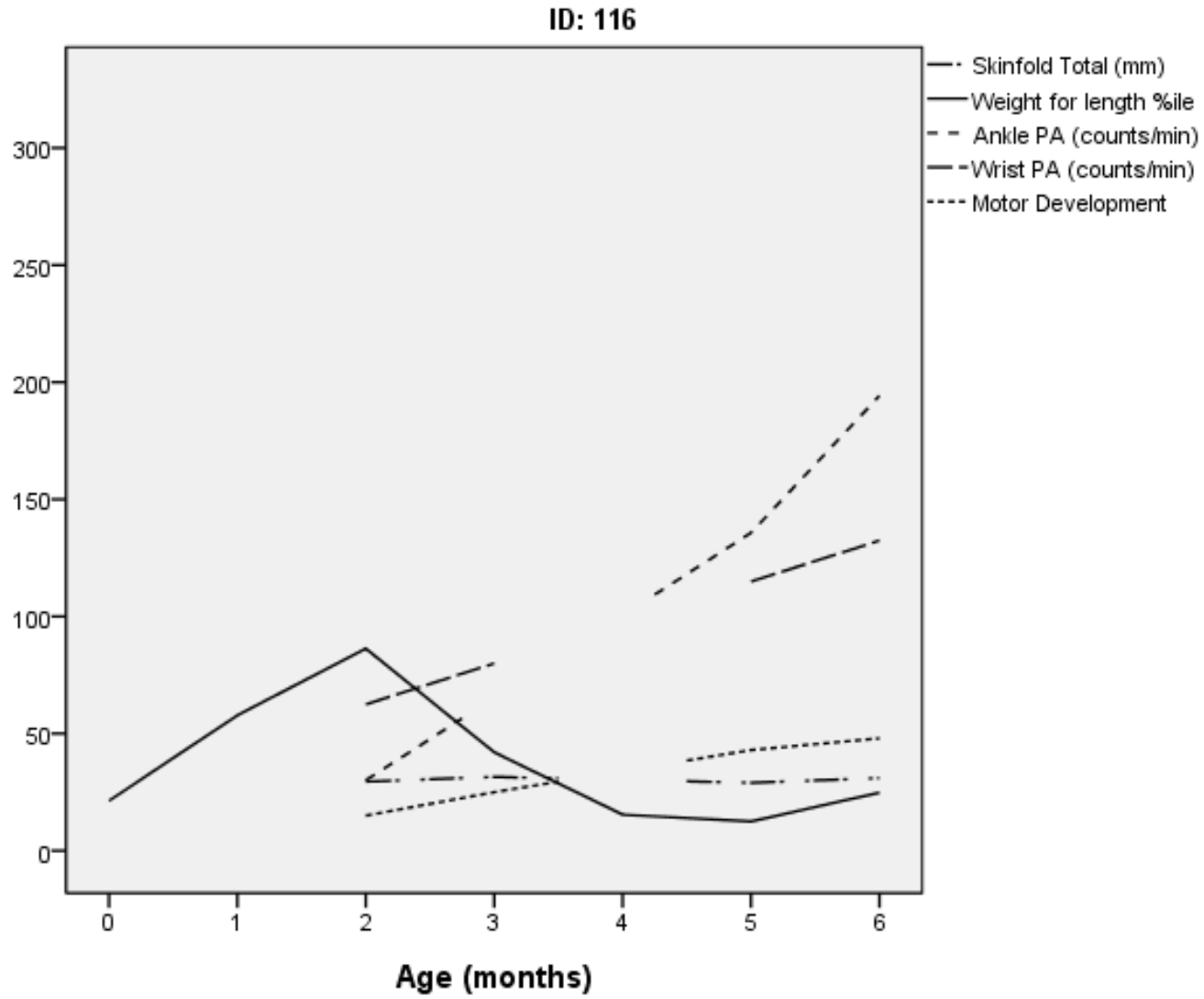
c) Infant positioning device



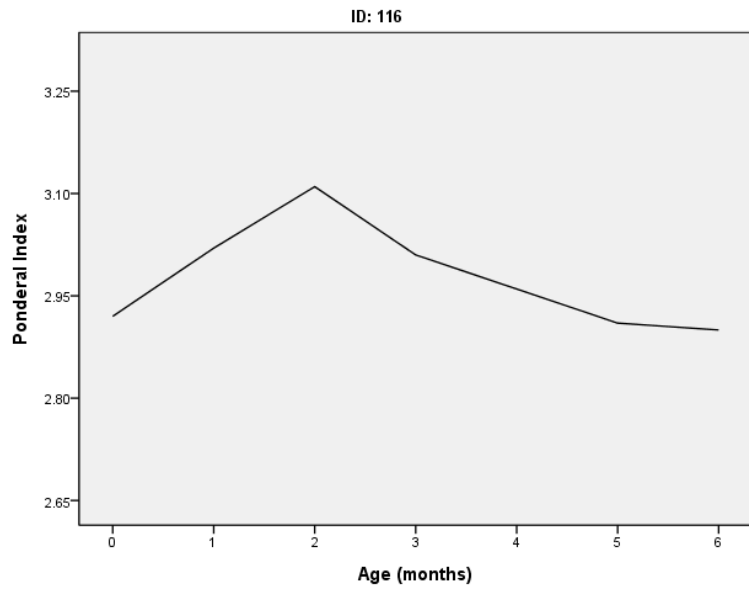
Appendix 2.15 Overlay line graphs of all variables BY age for ID 116

a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development

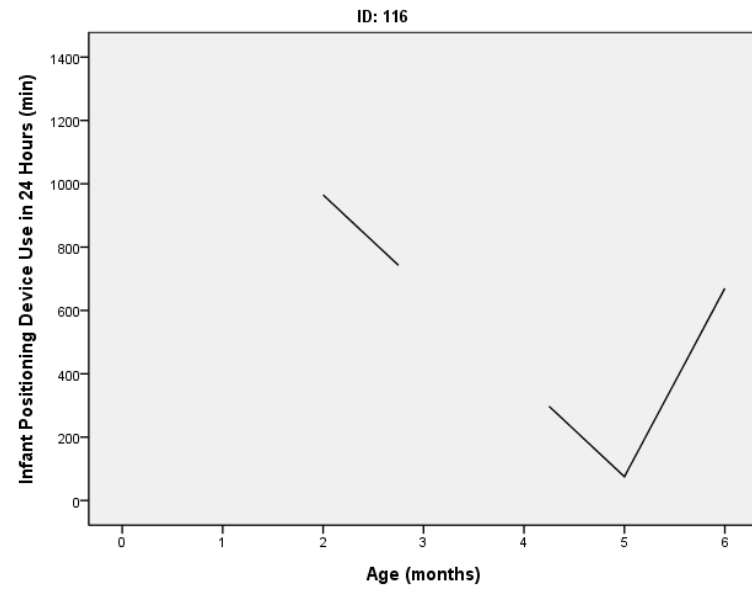
142



b) Ponderal index



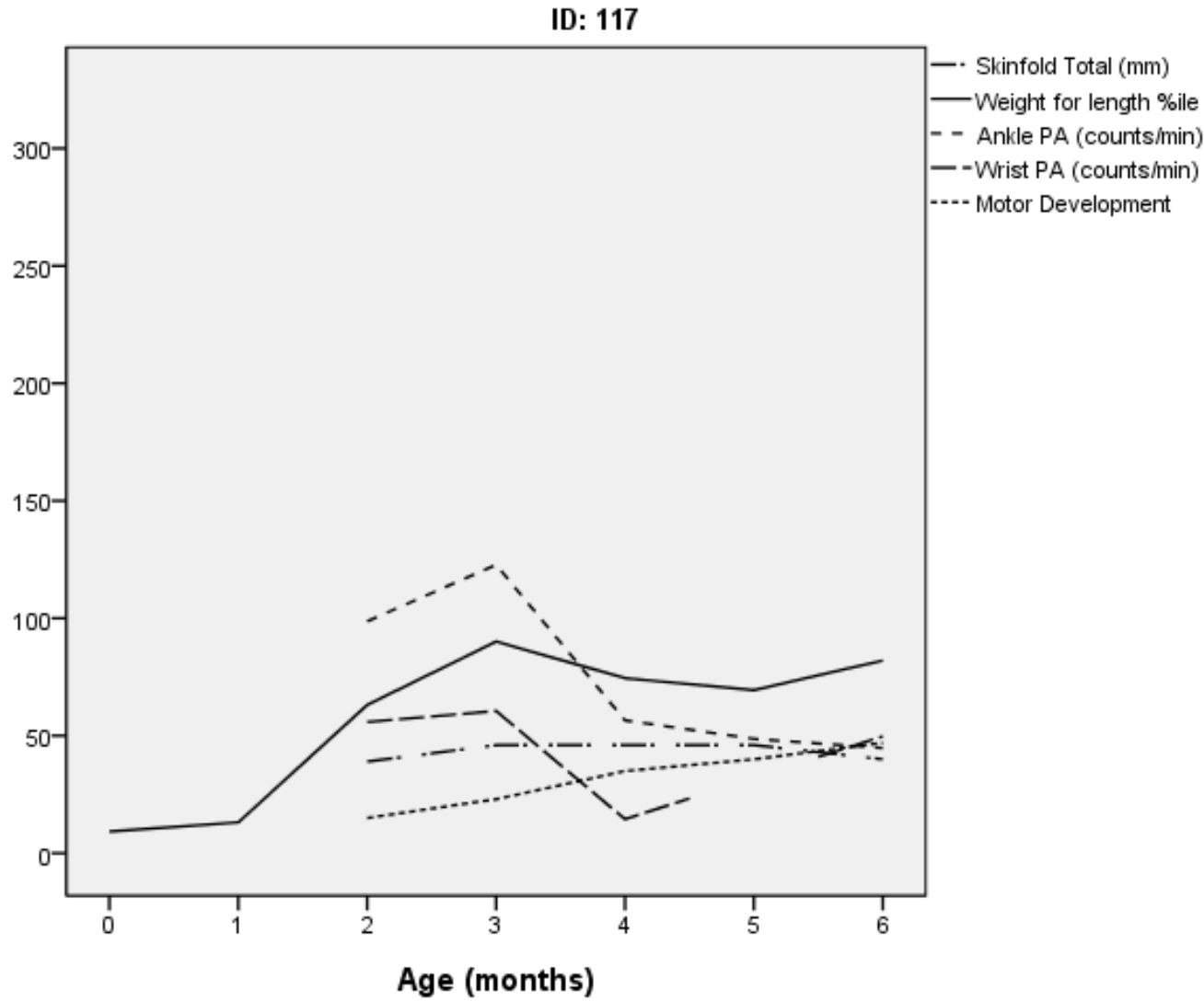
c) Infant positioning device



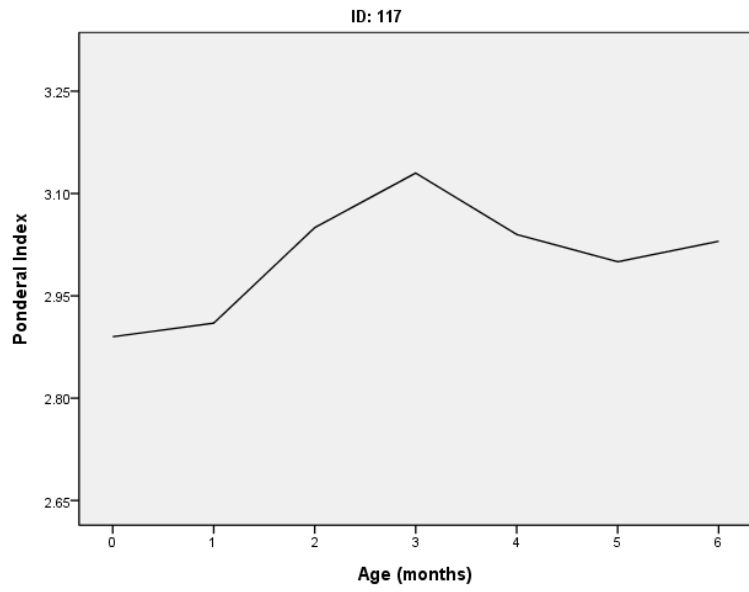
Appendix 2.16 Overlay line graphs of all variables BY age for ID 117

a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development

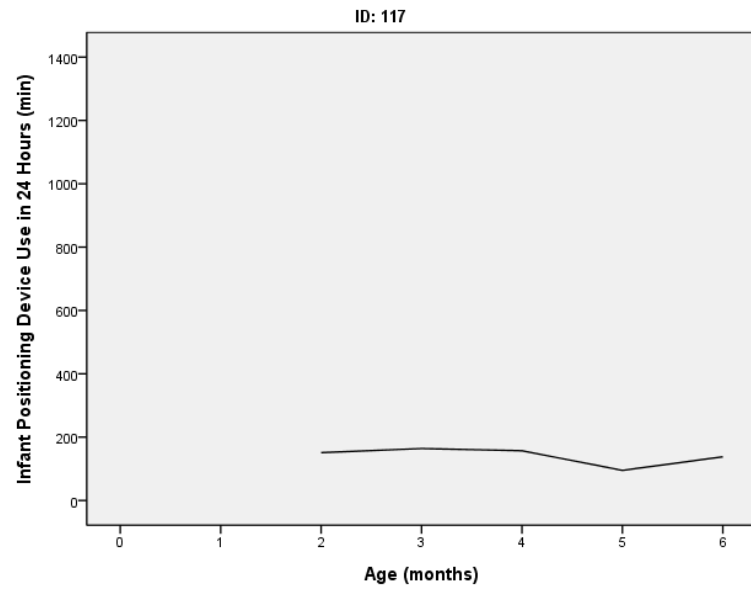
144



b) Ponderal index



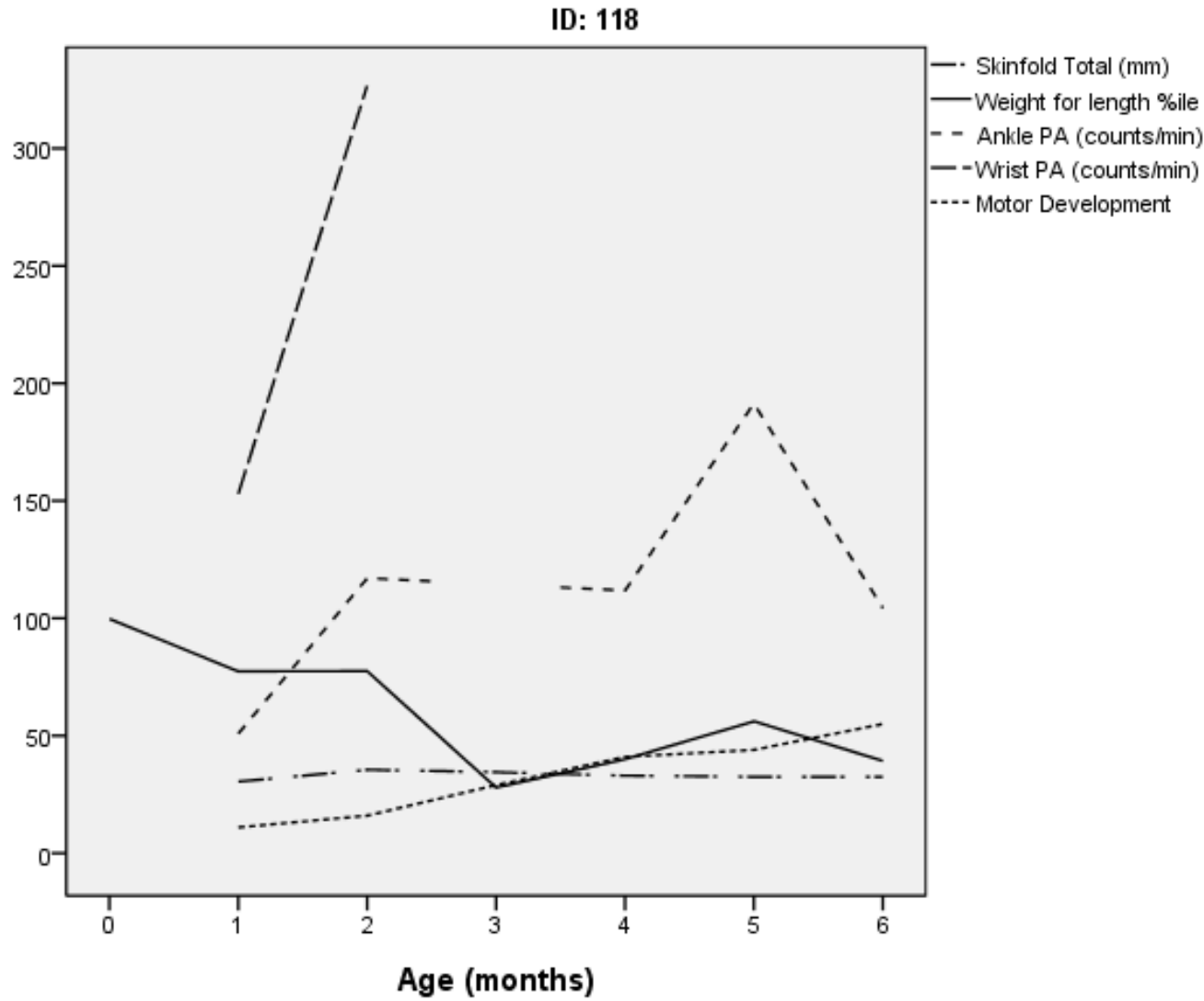
c) Infant positioning device



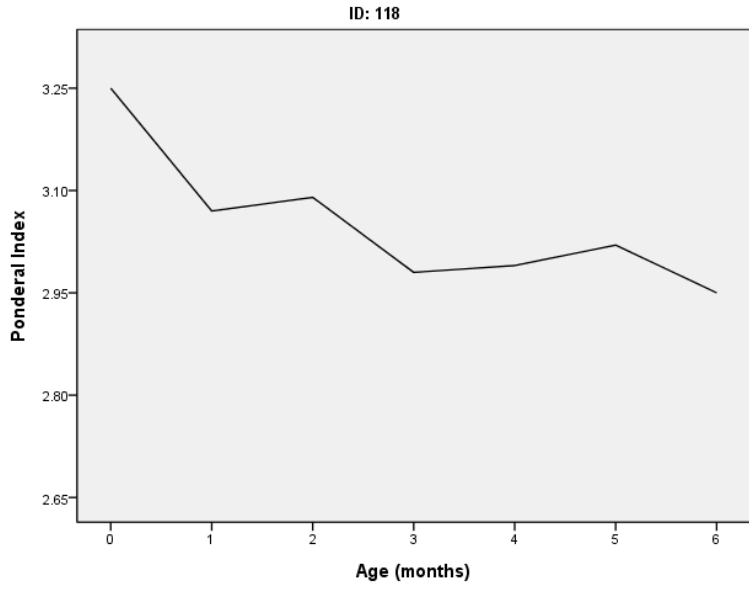
Appendix 2.17 Overlay line graphs of all variables BY age for ID 118

a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development

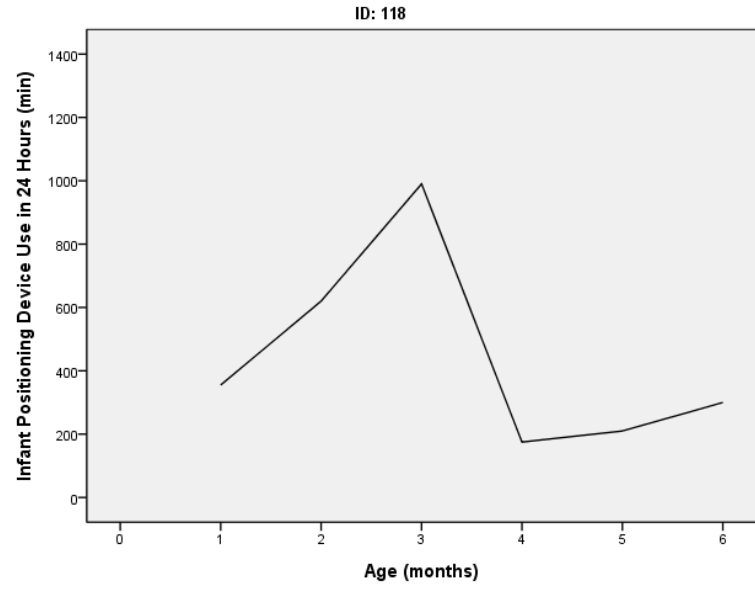
146



b) Ponderal index

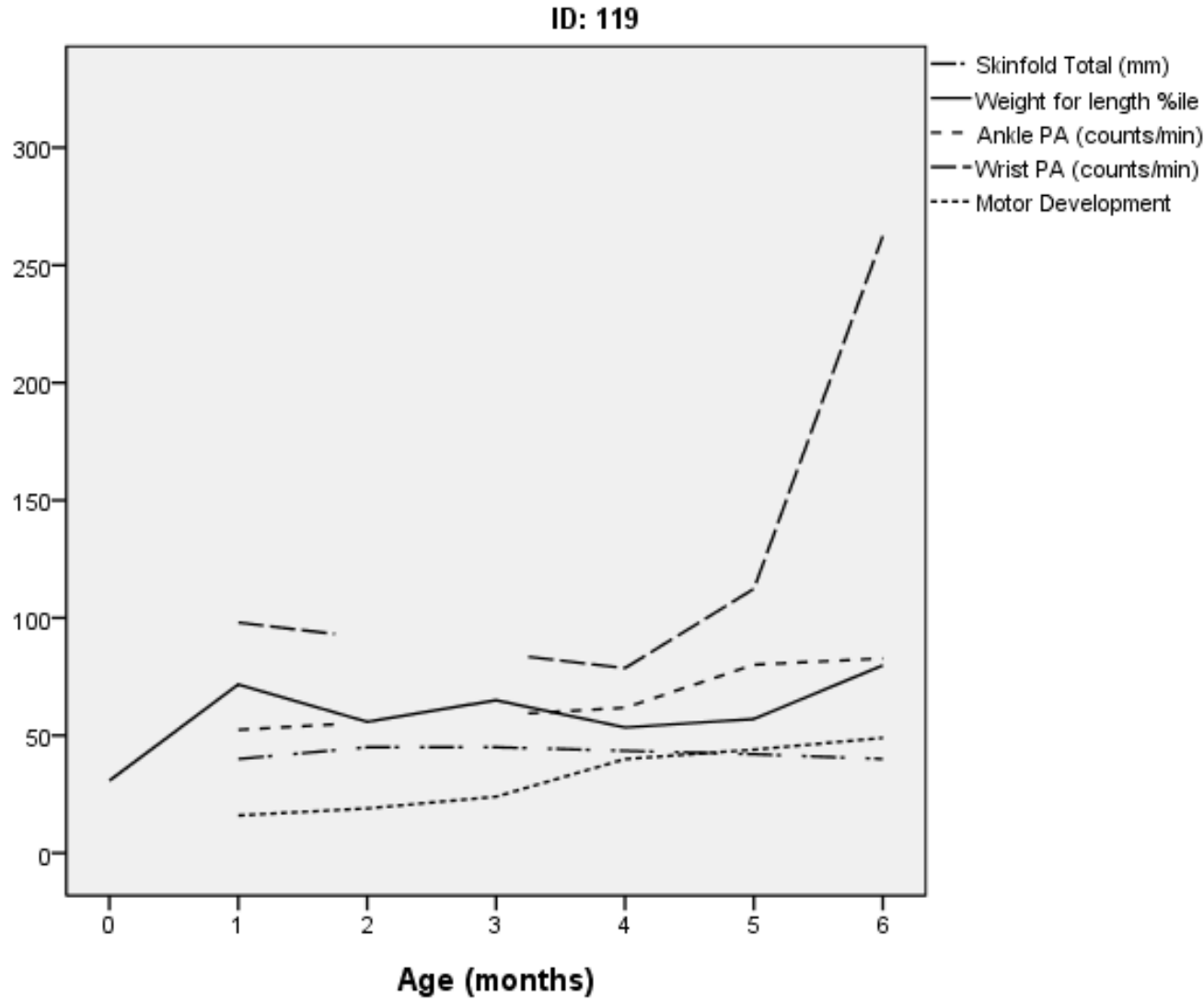


c) Infant positioning device

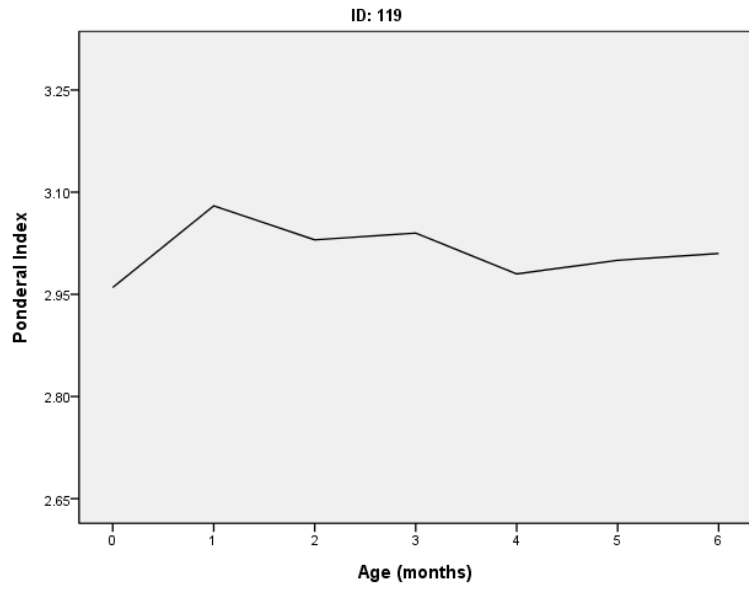


Appendix 2.18 Overlay line graphs of all variables BY age for ID 119

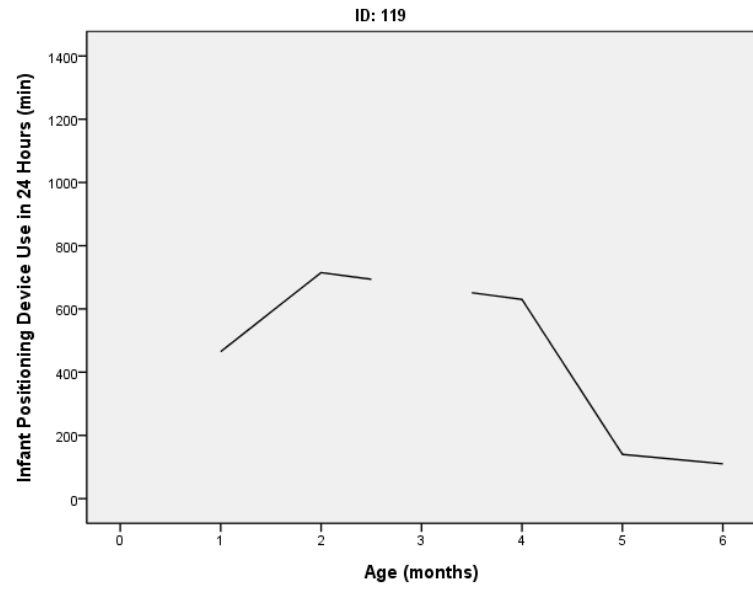
a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development



b) Ponderal index

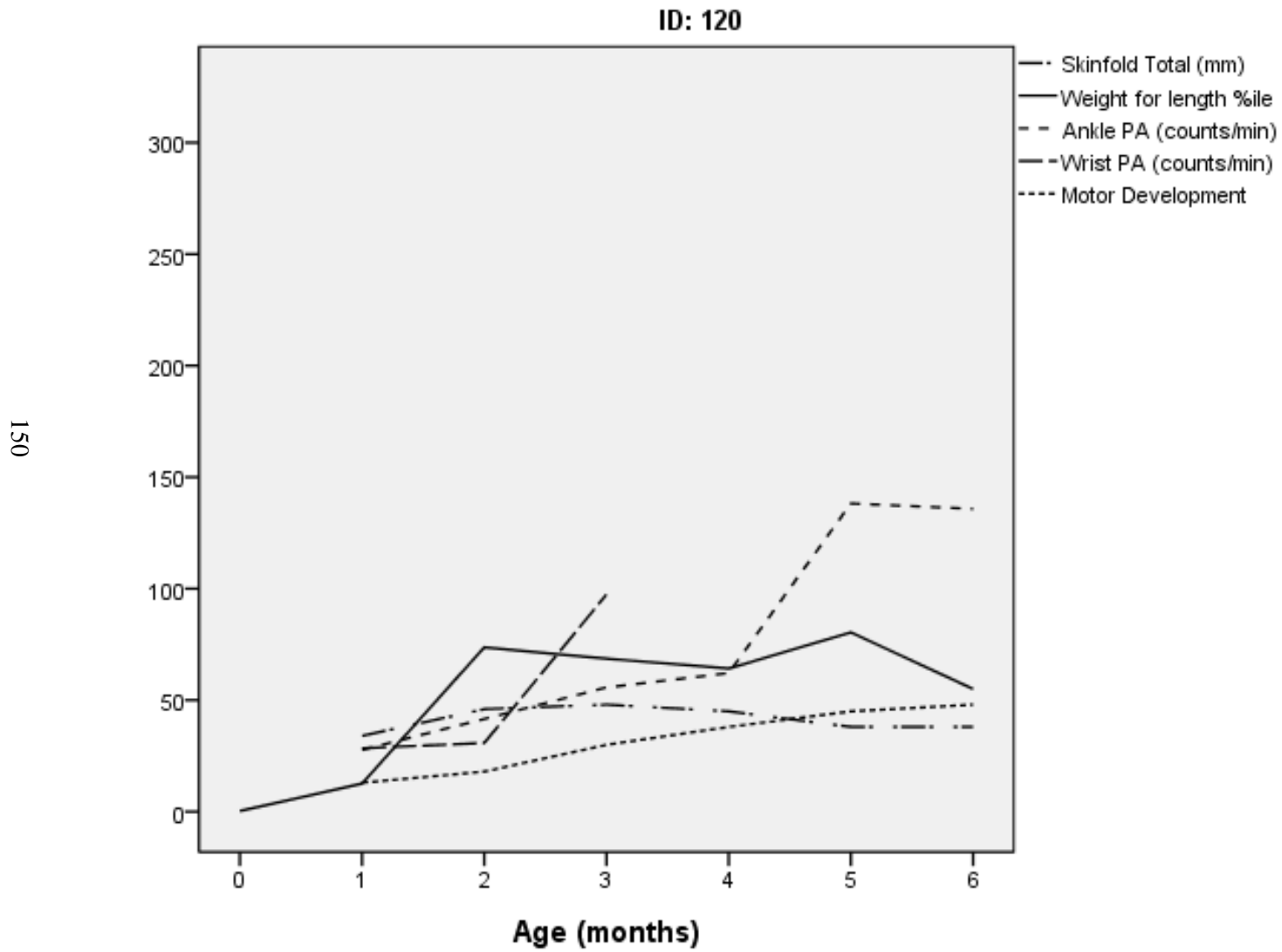


c) Infant positioning device

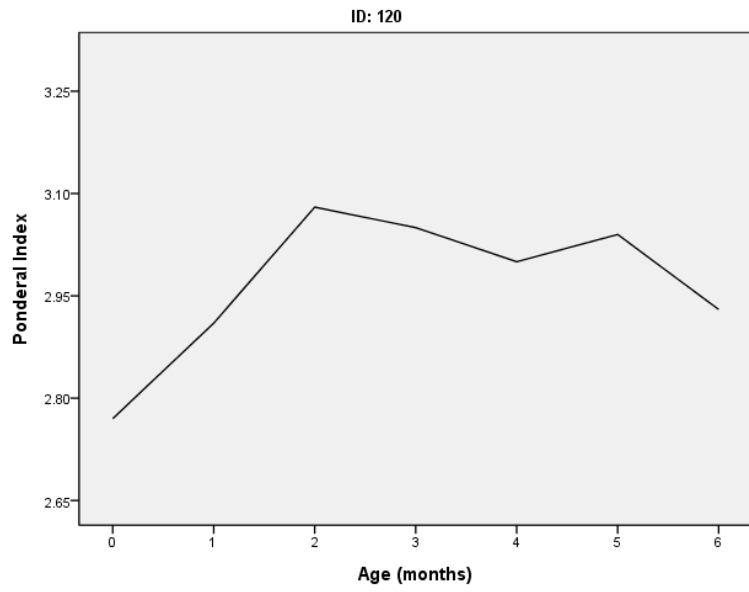


Appendix 2.19 Overlay line graphs of all variables BY age for ID 120

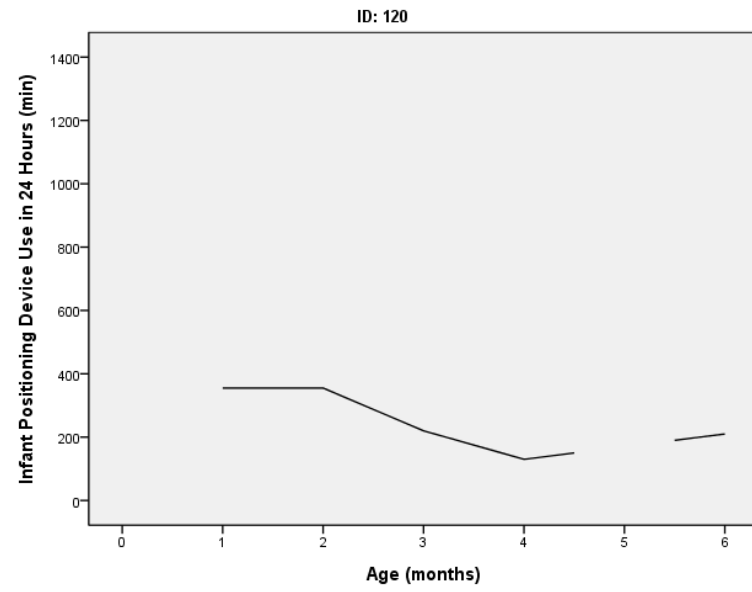
a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development



b) Ponderal index



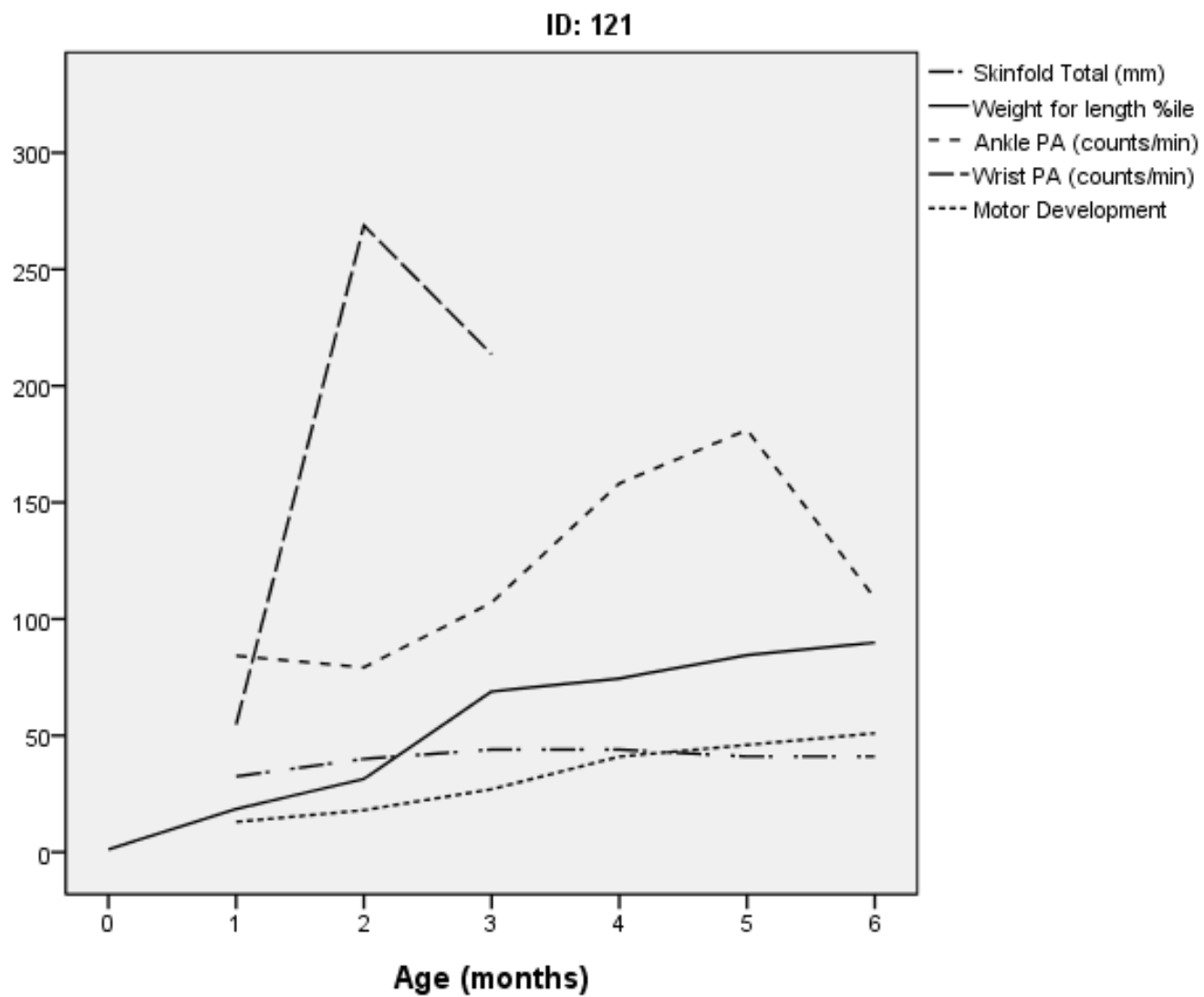
c) Infant positioning device



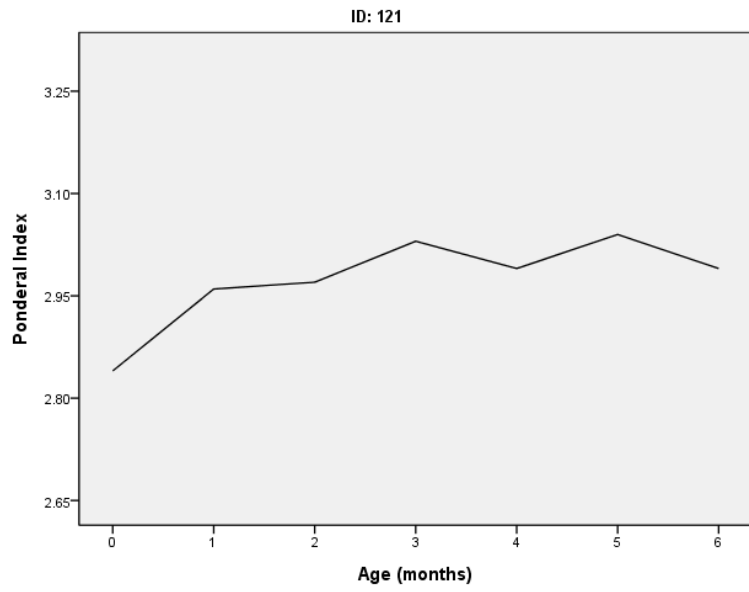
Appendix 2.20 Overlay line graphs of all variables BY age for ID 121

a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development

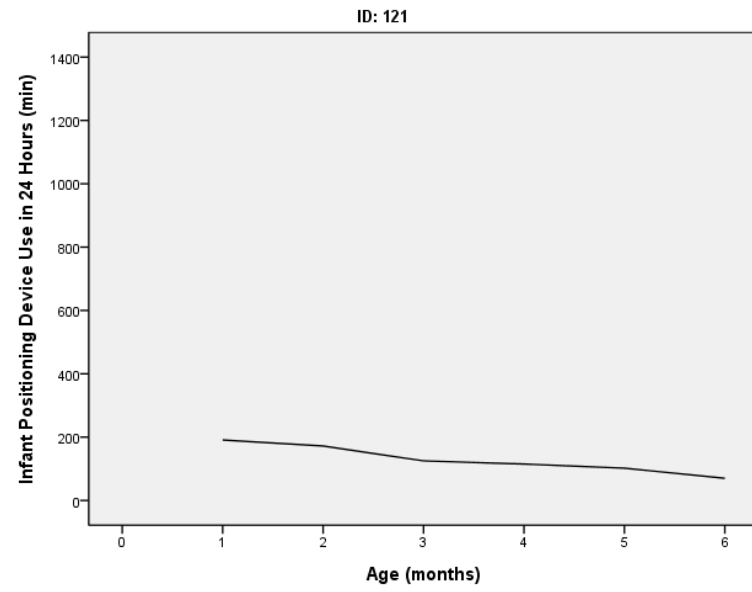
152



b) Ponderal index



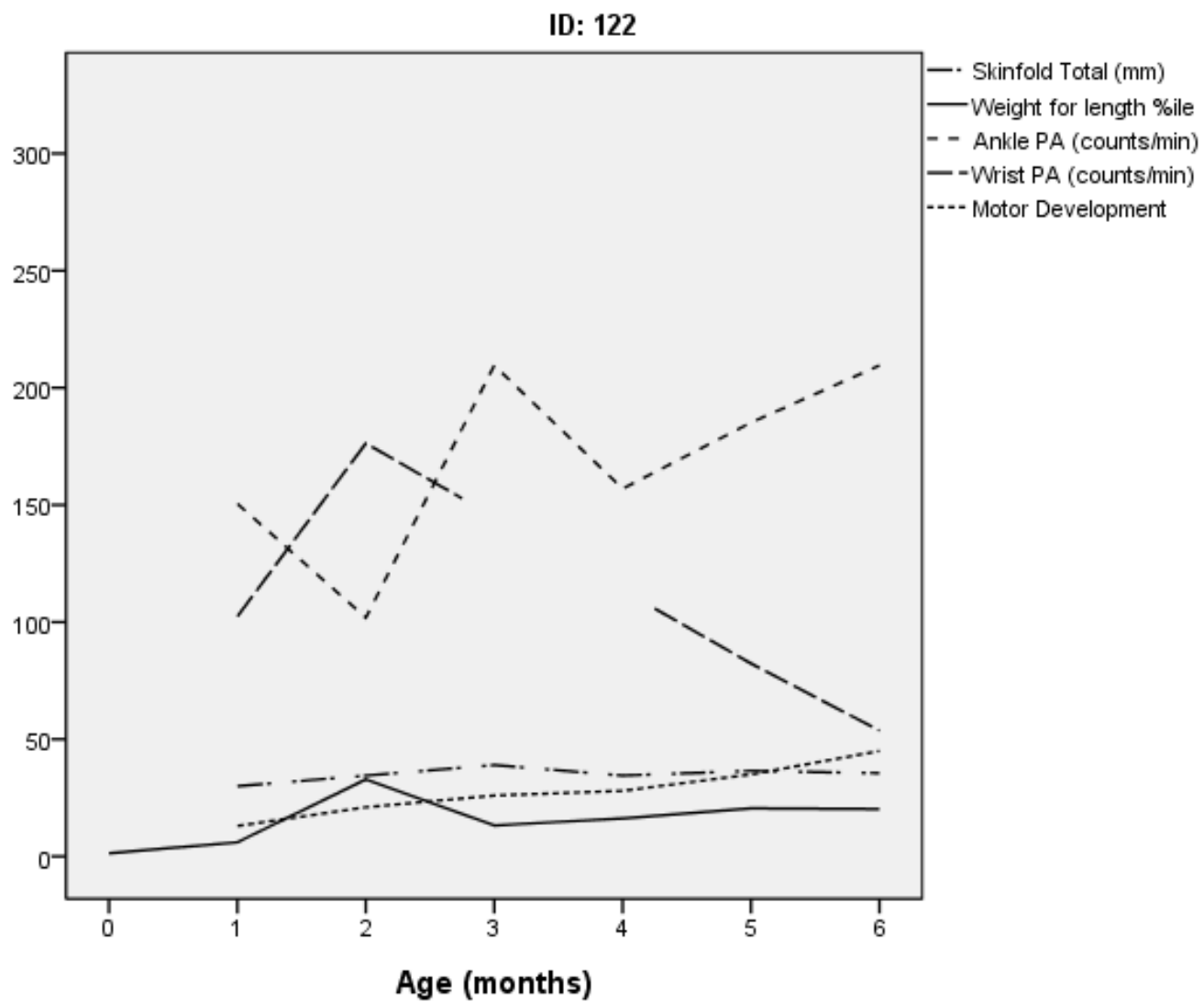
c) Infant positioning device



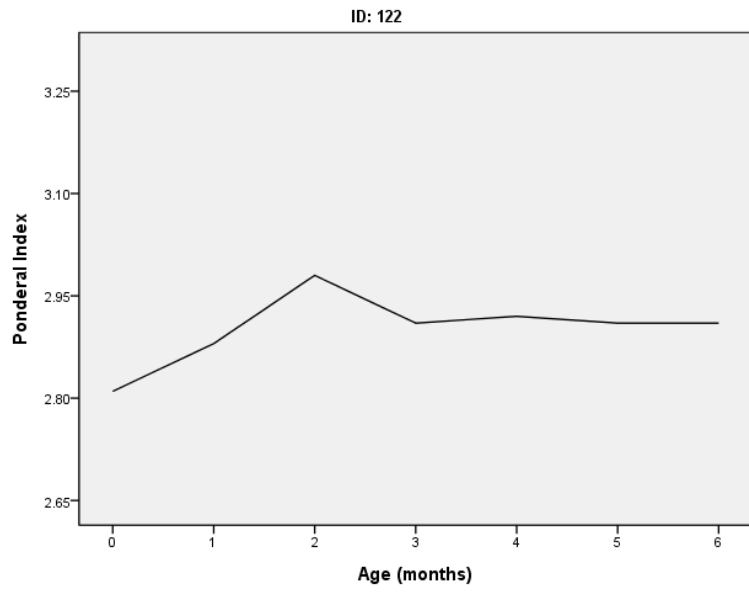
Appendix 2.21 Overlay line graphs of all variables BY age for ID 122

a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development

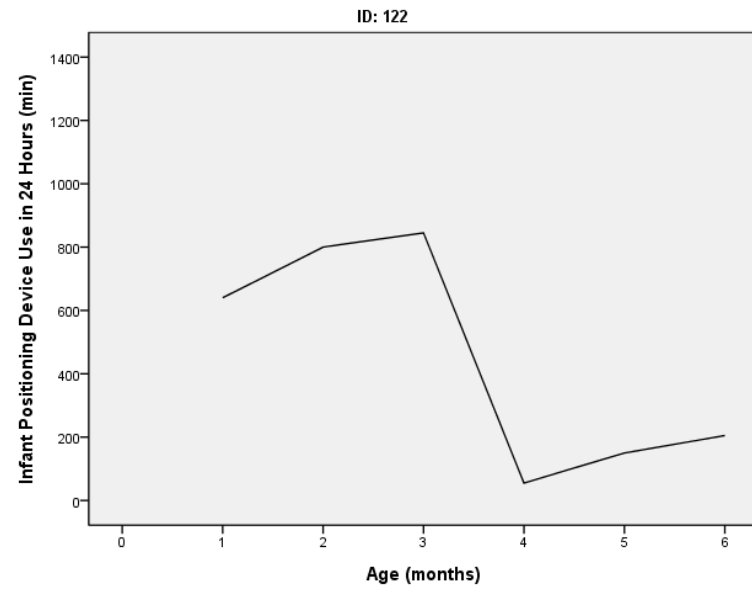
154



b) Ponderal index



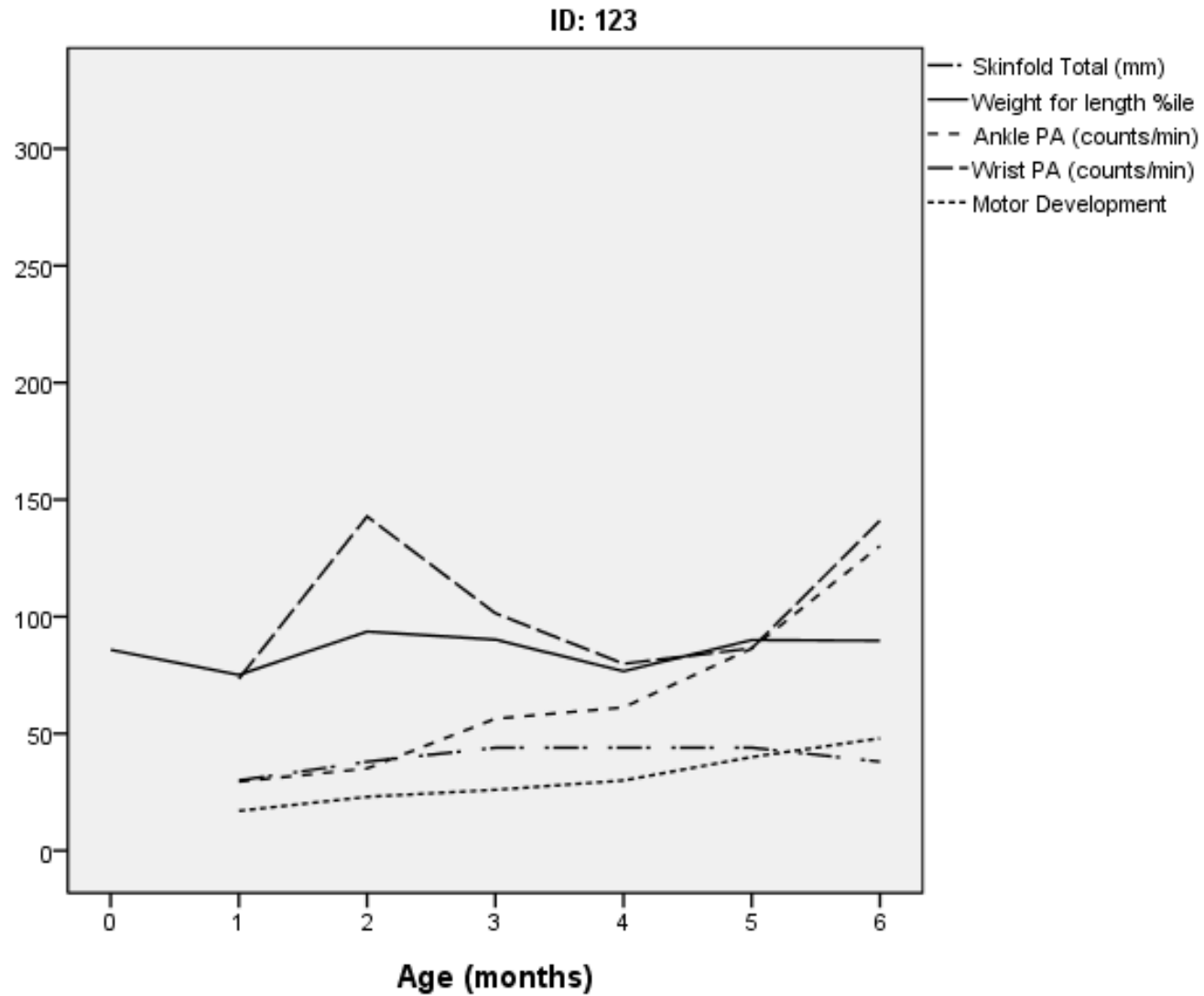
c) Infant positioning device



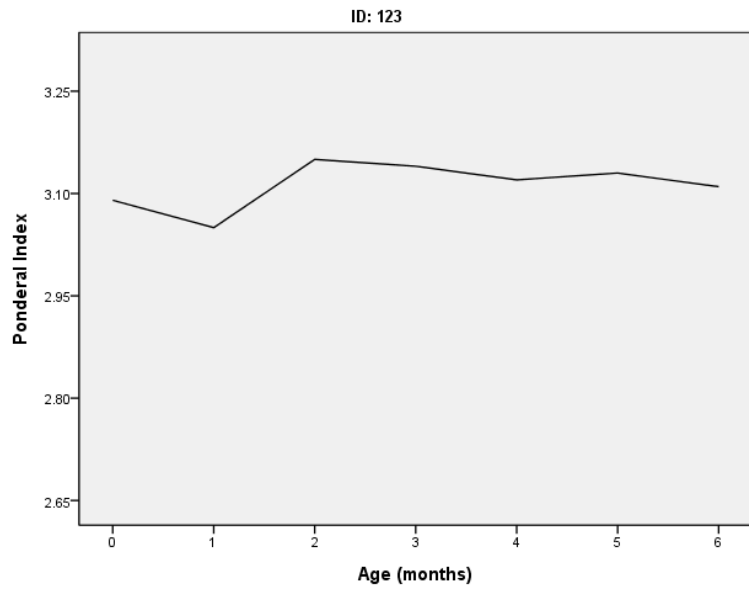
Appendix 2.22 Overlay line graphs of all variables BY age for ID 123

a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development

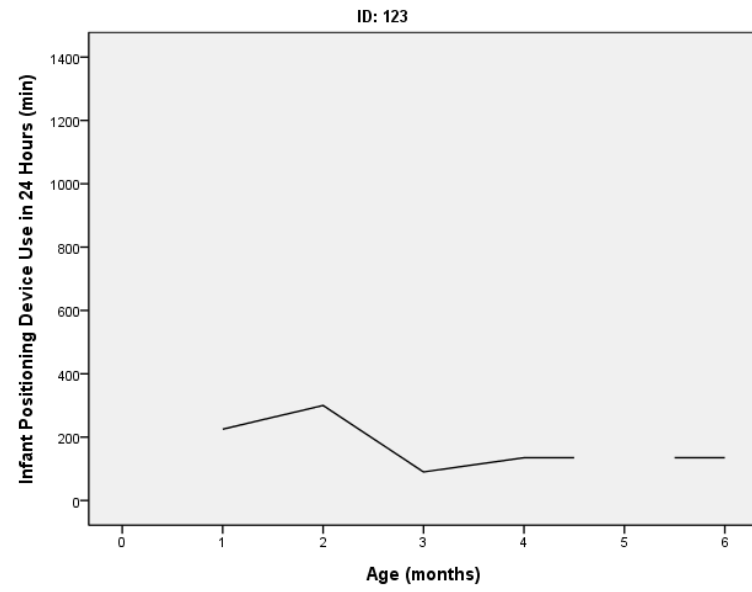
156



b) Ponderal index



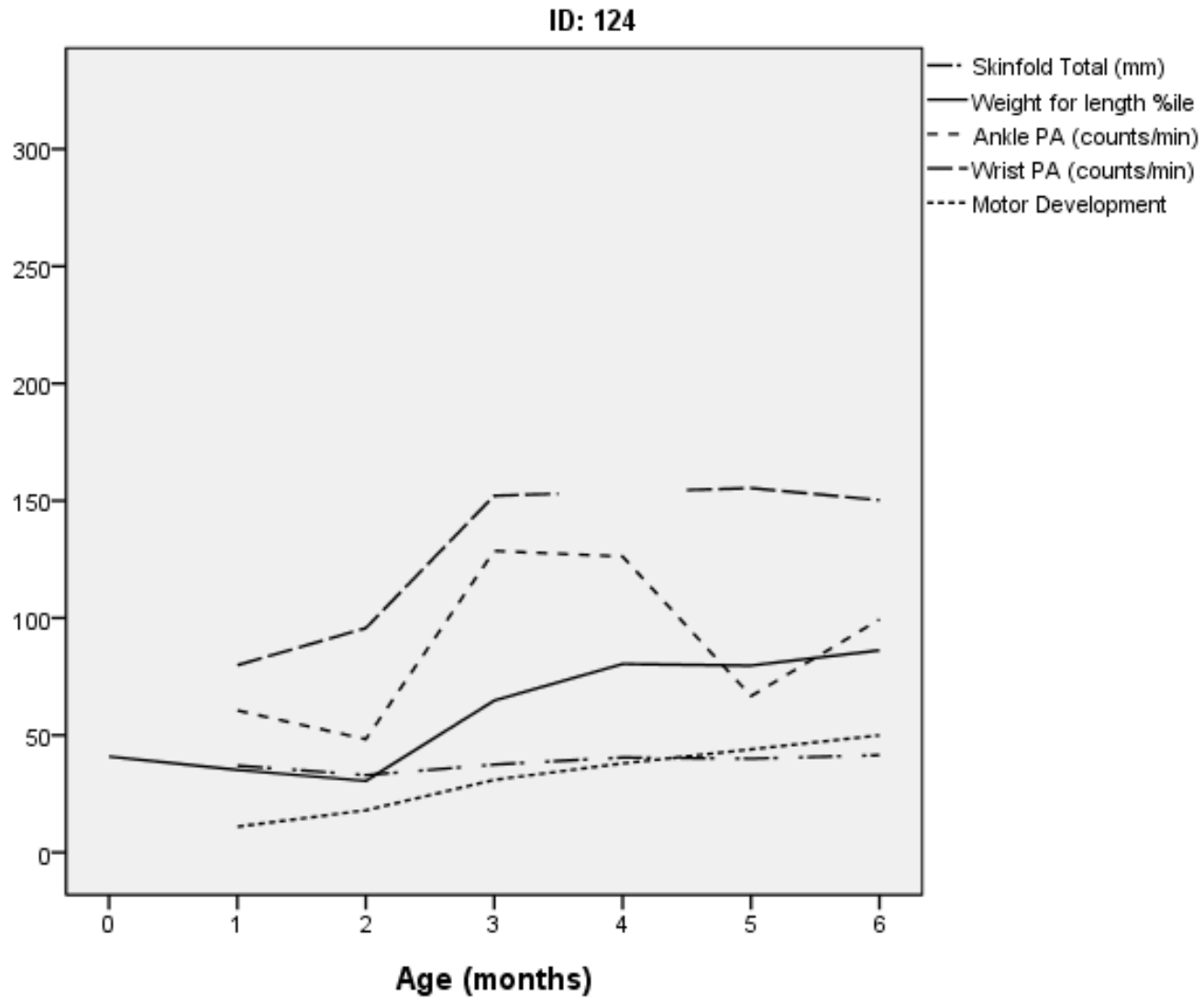
c) Infant positioning device



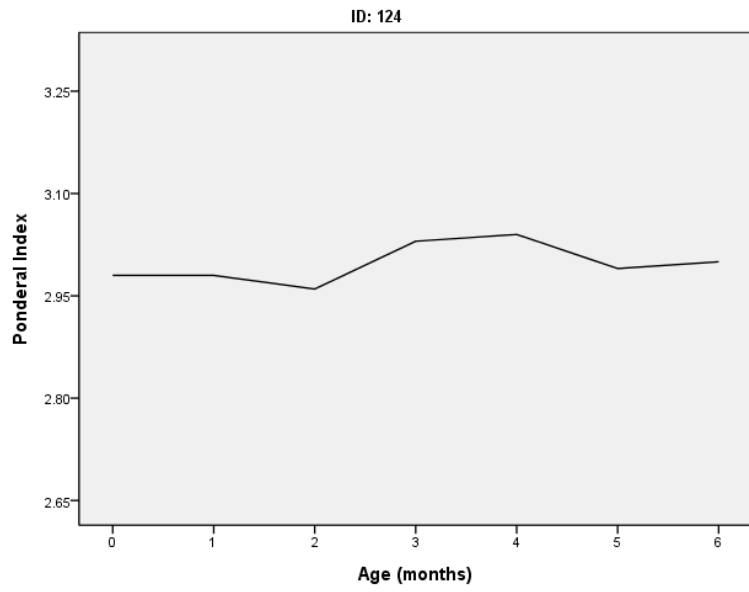
Appendix 2.23 Overlay line graphs of all variables BY age for ID 124

a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development

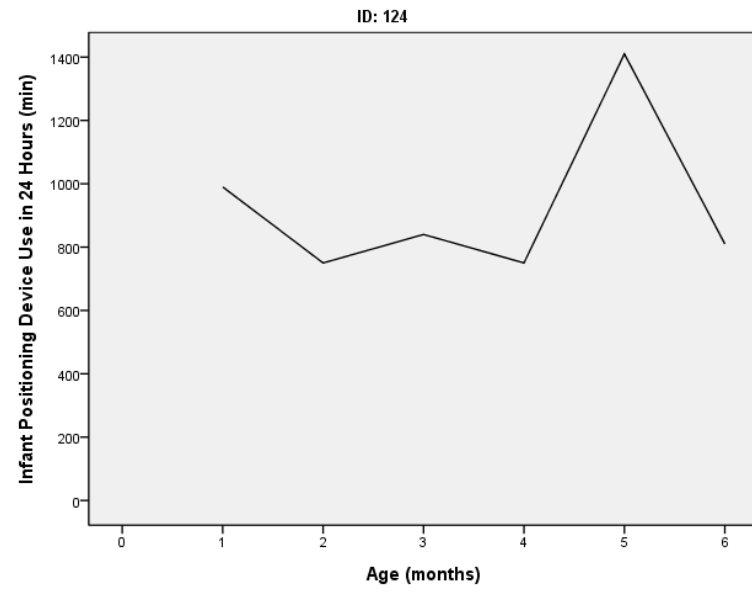
158



b) Ponderal index



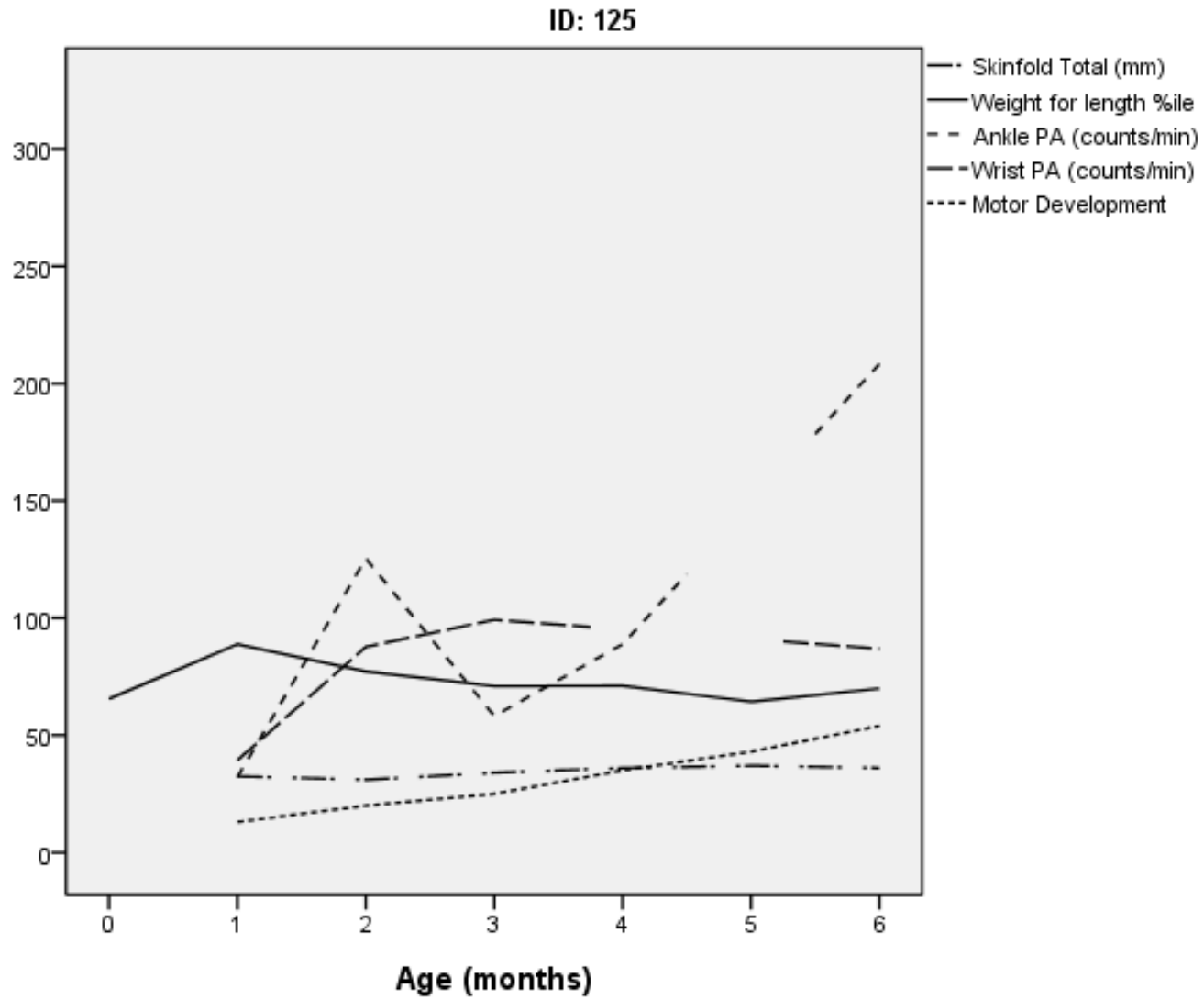
c) Infant positioning device



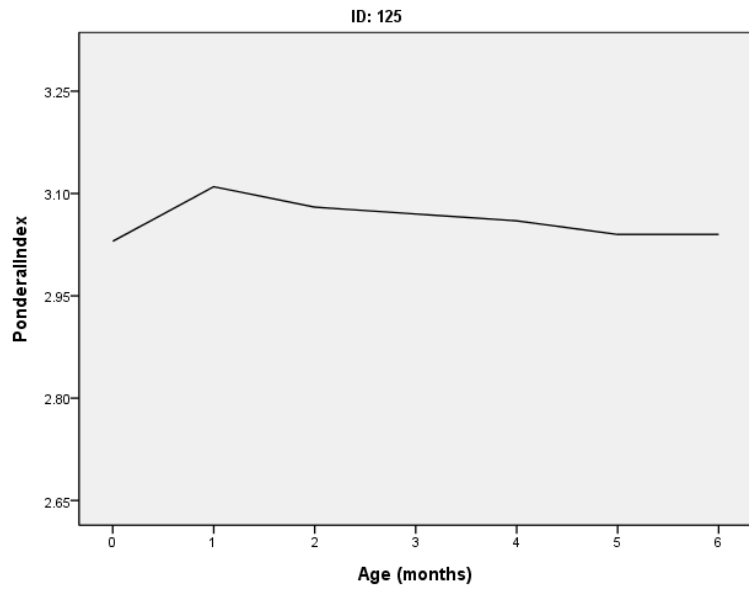
Appendix 2.24 Overlay line graphs of all variables BY age for ID 125

a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development

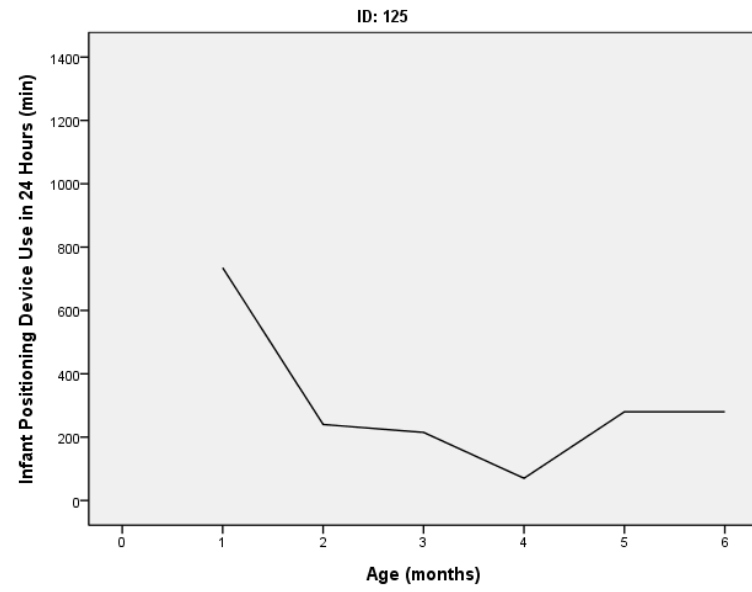
160



b) Ponderal index

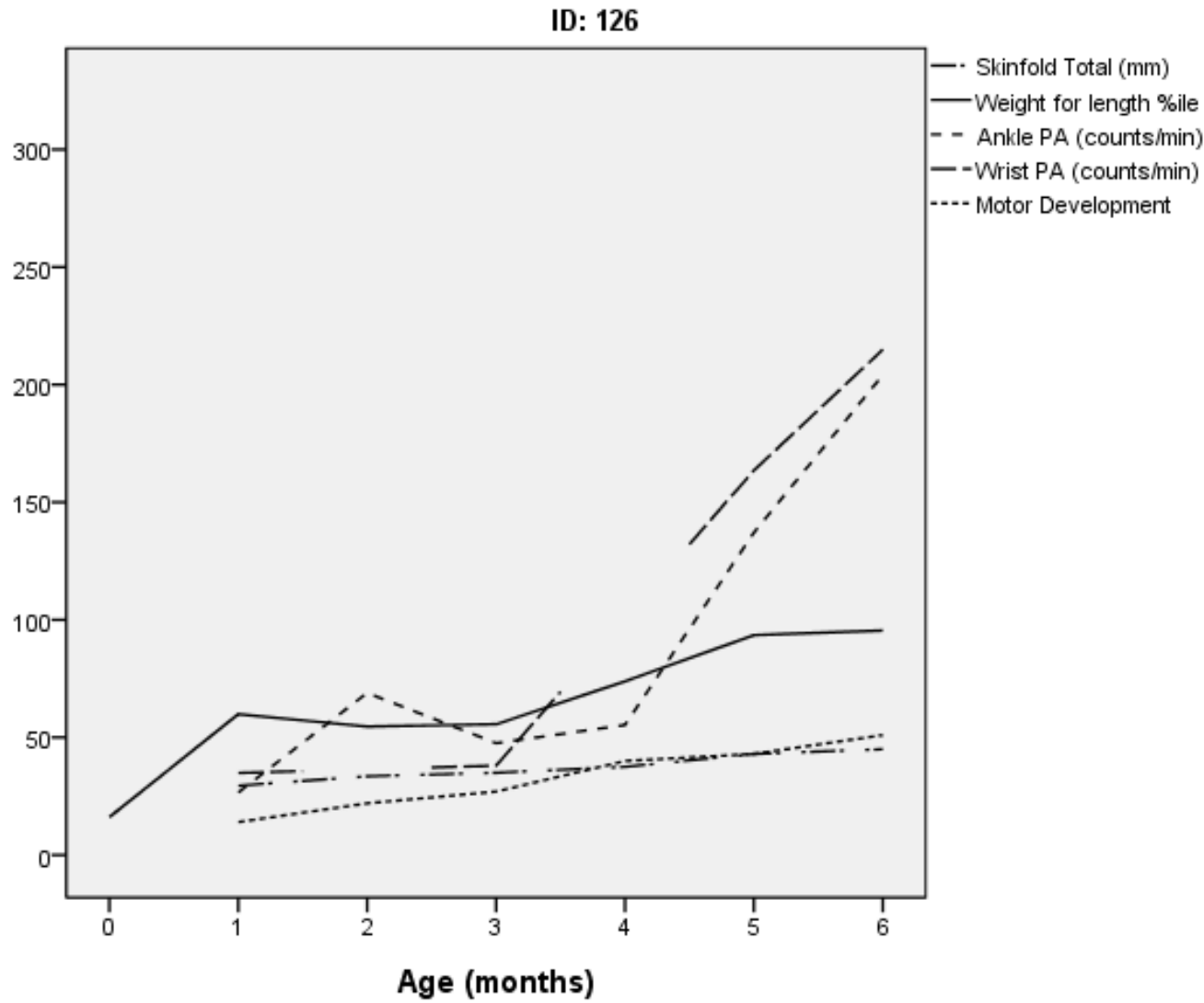


c) Infant positioning device

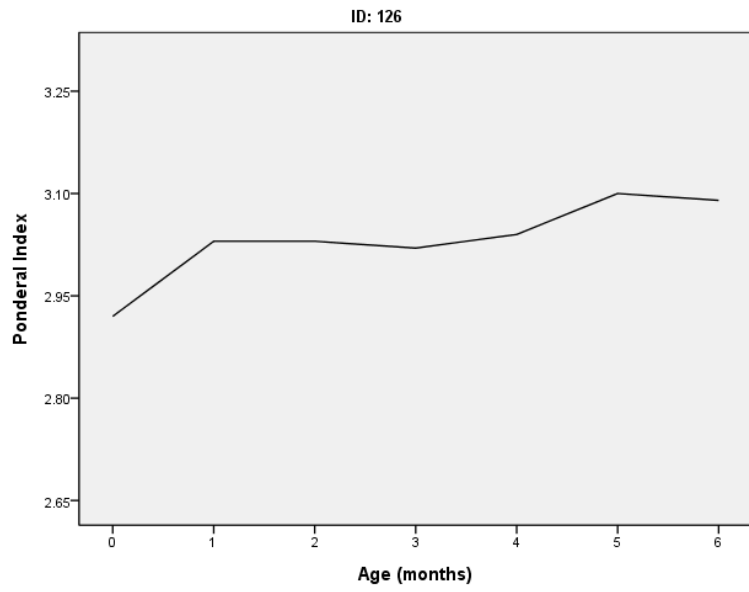


Appendix 2.25 Overlay line graphs of all variables BY age for ID 126

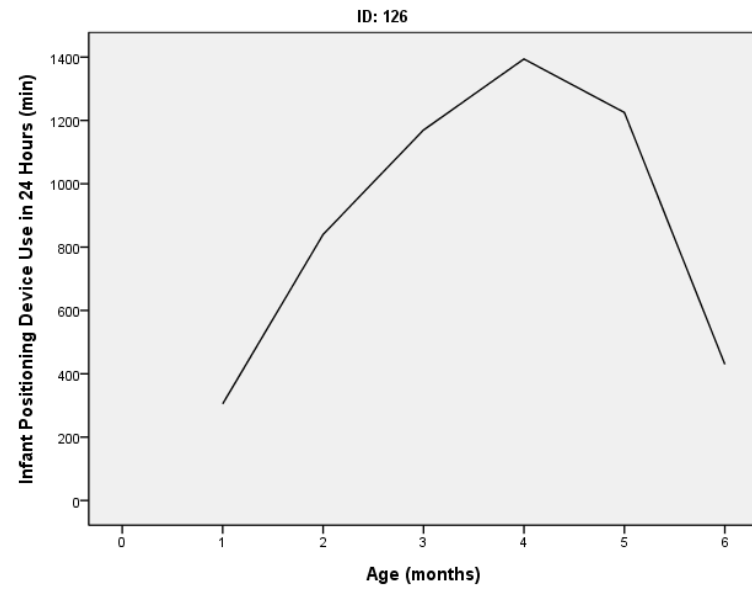
a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development



b) Ponderal index



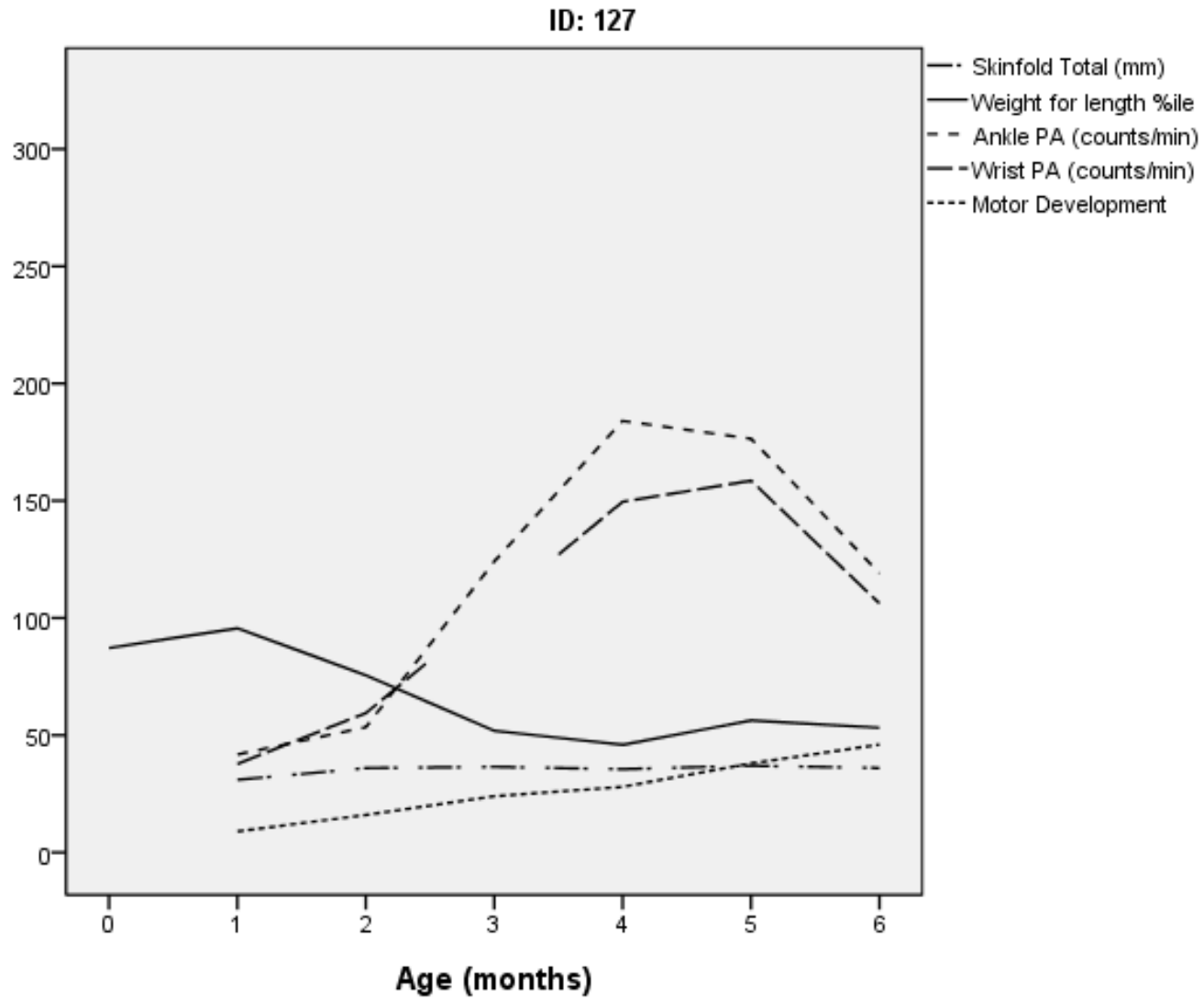
c) Infant positioning device



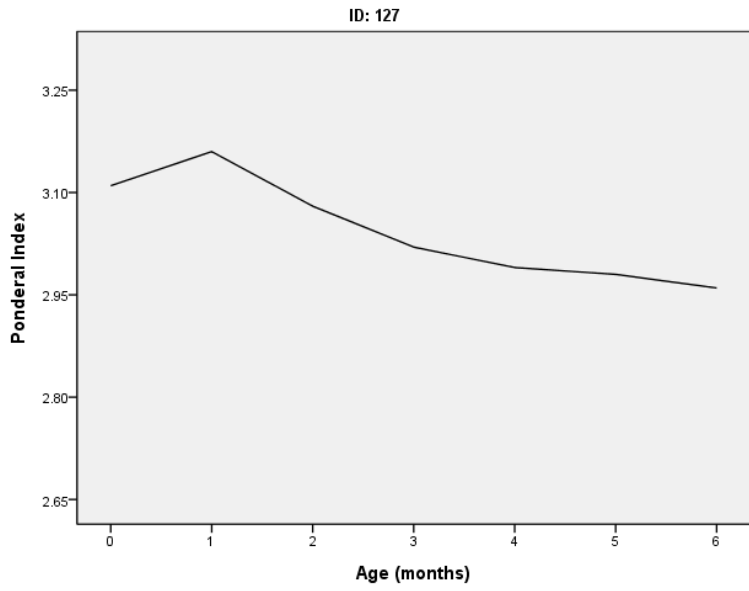
Appendix 2.26 Overlay line graphs of all variables BY age for ID 127

a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development

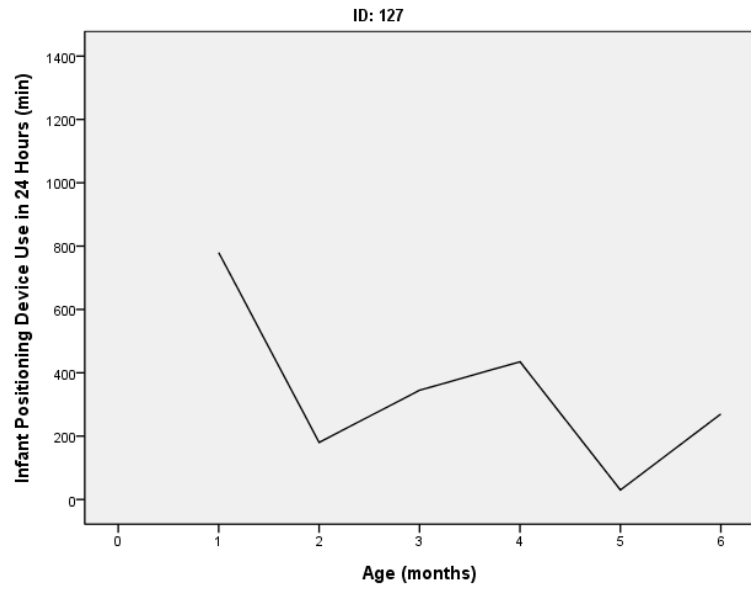
164



b) Ponderal index

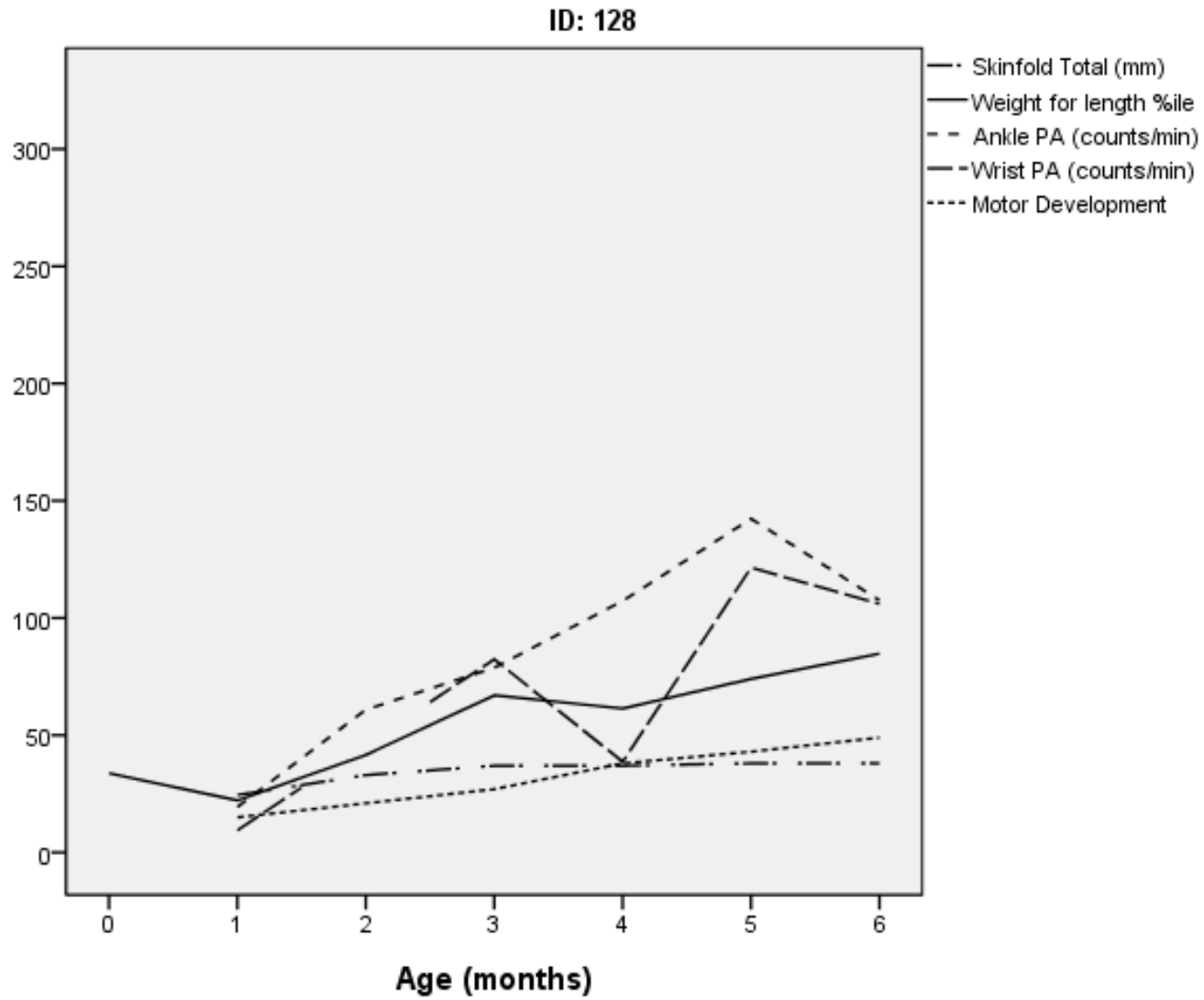


c) Infant positioning device

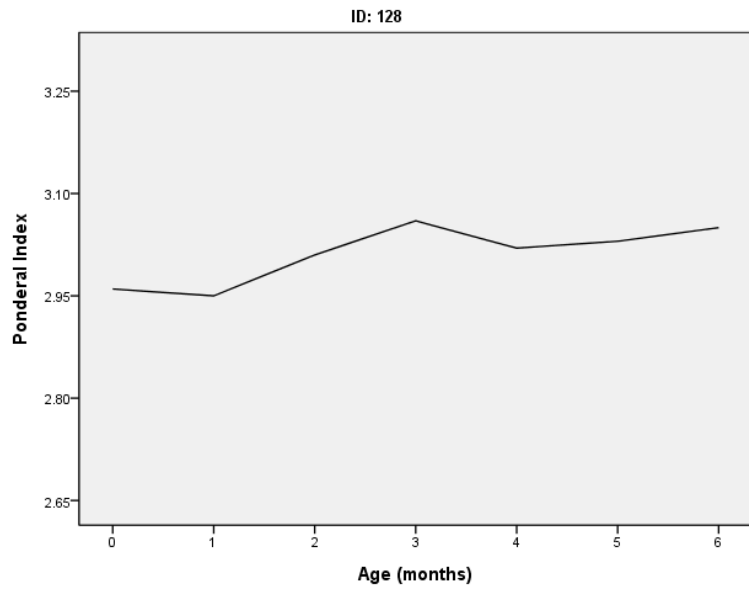


Appendix 2.27 Overlay line graphs of all variables BY age for ID 128

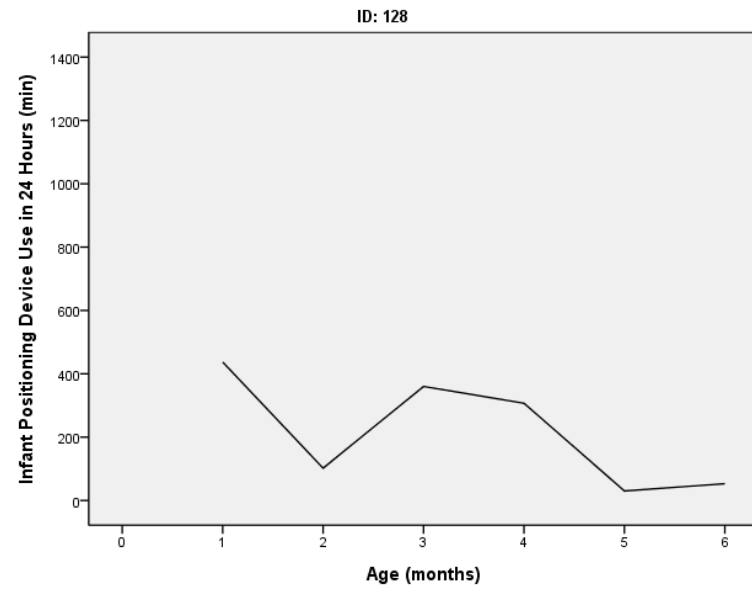
a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development



b) Ponderal index



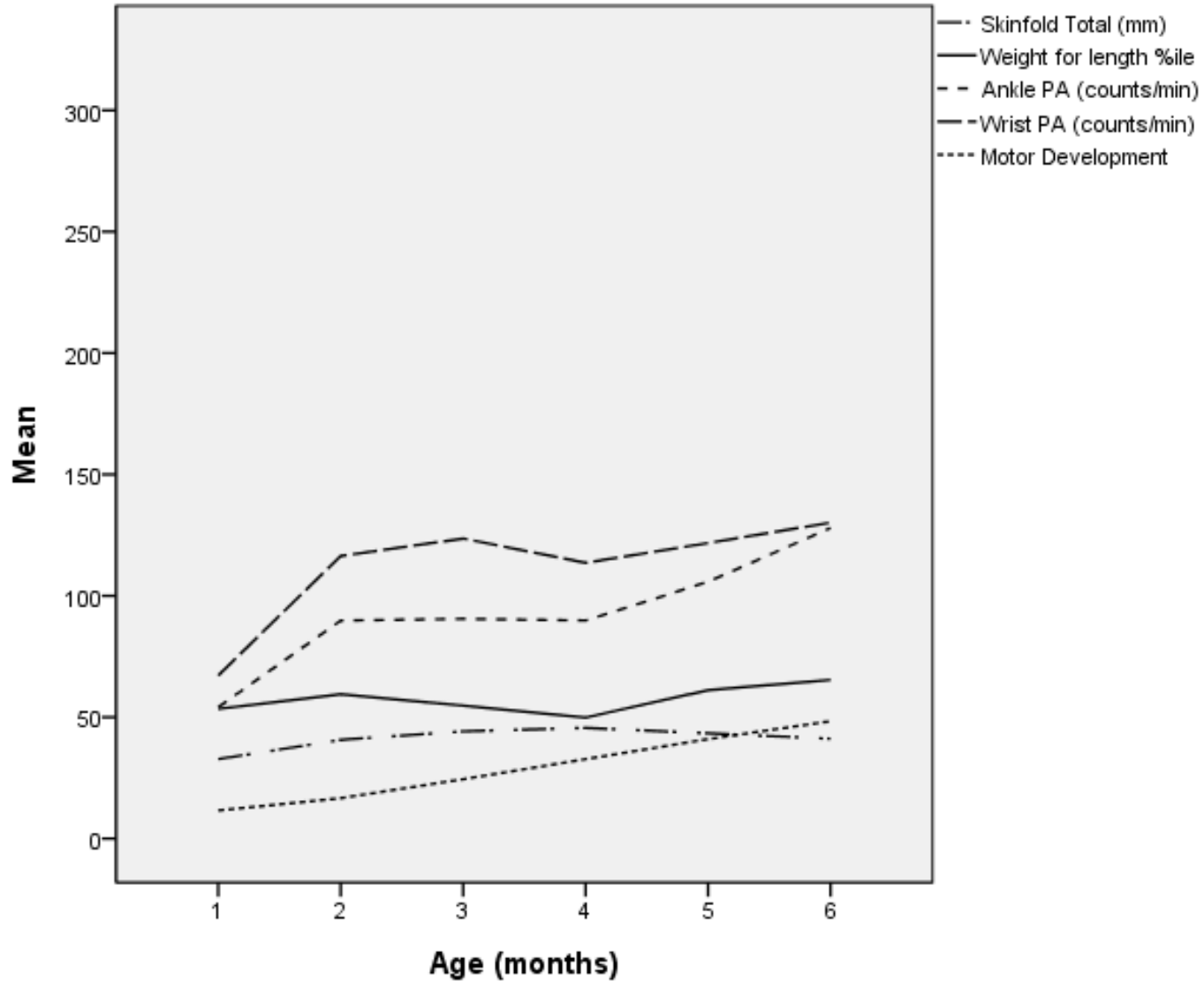
c) Infant positioning device



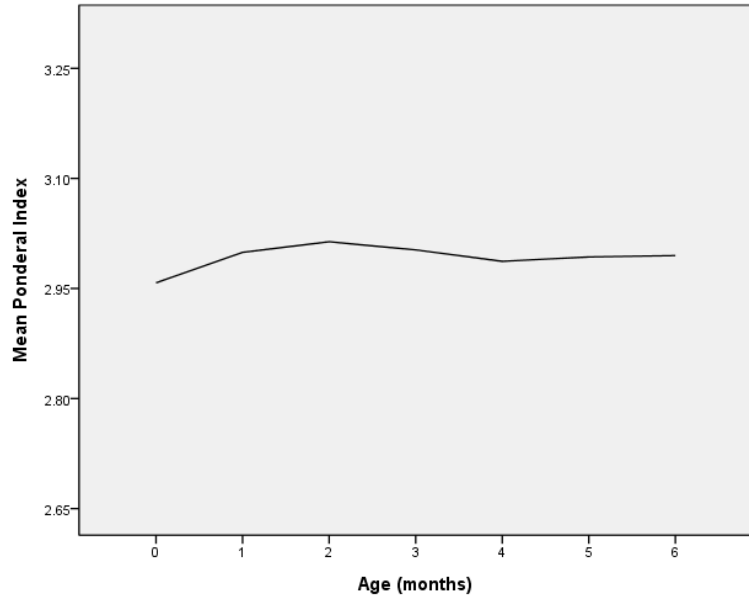
Appendix 2.28 Overlay line graphs of MEAN values of all variables BY age

a) Skinfold total, weight for length percentile, PA at the ankle and wrist, motor development

168



b) Ponderal index



c) Infant positioning device

