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Toddler Gait: Lower Extremity Joint Moments and Powers

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THESIS

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ABSTRACT

Behind every purposeful movement lies a pattern of control and activation. One of the most fundamental movement patterns for humans is that of walking or gait. This study was conducted to further understand gait development of toddlers. This developmental stage was investigated with 13 healthy normal toddlers (11 girls and 2 boys) between the ages of 10 and 24 months who were autonomous walkers of less than a year. All toddlers walked across two force plates (AMTI) touching only with the right foot and were filmed with three (Panasonic) video cameras. Support moments as well as hip, knee and ankle joint moments and powers were calculated for between 6 and 14 steps per toddler. Joint moments and powers were normalized to percent of stride and body mass and were examined across subjects to observe developmental changes over the first year of walking. As well, the toddler joint moments and powers were compared to that of adult slow walking reported by Winter (1991). The data suggests two things: 1) toddler joint moments and joint powers develop over the first year of walking in a distal to proximal fashion and 2) toddler support moments, joint moments and joint powers are different from that of adults.

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PART ONE: EMPIRICAL, THEORETICAL AND METHODOLOGICAL CONSIDERATIONS

CHAPTER I

INTRODUCTION

Behind every purposeful movement there lies a pattern of control and activation. One of the most fundamental movement patterns for humans is that of walking, or gait. Due to the fundamental importance of walking, much time has been devoted to the understanding and analyzing of normal adult gait patterns. Within these gait patterns, four main levels of analysis have been researched and documented. The four levels of gait analysis are temporal patterns, kinematic patterns, kinetic patterns and electromyographic (EMG) patterns. These four levels have been used to analyze normal adult gait, age related changes in gait, and pathological gait patterns (Beck et al., 1981; Cappozzo, 1991; Gage, 1983; Herzog et al., 1989; Inmann et al. 1981; Mechelse, 1985; Murray et al., 1984; Nigg et al., 1994; Oberg et al., 1993a, 1993b; Winter, 1991).

For toddlers, childhood is marked by many significant motor milestones, including the acquisition of walking. When toddlers begin to walk autonomously, the four aforementioned levels of gait patterns can be recorded and analyzed. These gait patterns can be used to determine developmental changes that occur during the acquisition of walking, as well as can be compared to the gait patterns of different weight normalized populations, such as adults and children. Currently there is little research available on the gait kinetics of toddlers who are within their first year of walking. The toddler gait patterns that have been analyzed consist of temporal patterns, kinematic patterns, ground reaction force (GRF) data and electromyography patterns. To better analyze and understand currently unavailable toddler kinetic gait patterns, an overview of available toddler temporal, kinematic, GRF, and EMG patterns will be examined.

Previous research has examined toddler temporal gait patterns (Bril & Brenière 1989, 1991, 1992; Sutherland et al., 1980; Beck et al., 1981; Phillips & Clark, 1985; Clark et al., 1988). It has been shown that over a period of six months of autonomous walking, toddlers increase their speed of walking. Furthermore, the temporal structure of their steps changes to a pattern similar to an adult's after only three months of autonomous walking. Other available toddler data describes that step duration decreases significantly as speed increases (Bril & Brenière, 1991; Sutherland et al., 1980; Beck et al., 1981), and that, even at such a young age, toddlers can vary their speed of walking (Philips & Clark., 1985). Other toddler temporal gait patterns have also been examined for developmental changes, such as timing invariance, step length, step velocity and cadence (Bril & Brenière, 1991, 1992; Clark, et al., 1988). Available toddler data indicates that double support time and step width decrease while the swing phase time, step length, step velocity, and cadence increase sharply over the first three to five months of walking. After this time, these changes level off showing slower developmental change until gait maturity is reached. These changes in phasing percentages and temporal gait structure have also been seen in other studies (Beck et al., 1981; Bril & Brenière, 1989; Sutherland et al., 1980). The rapid changes that occur early on in toddler walking development have been hypothesized to occur due to increases in postural control (Bril & Brenière, 1992). This hypothesis is congruent with the postural data available on the compensatory stepping of toddlers, where it is indicated that toddlers between one and three months of autonomous walking show an increase in their effective stepping response with regards to perturbations (Roncesvalles, et al., 2000).

In addition to toddler temporal gait patterns, kinematic gait patterns have also been examined. Researchers examining these gait patterns have documented joint ranges of motion and joint orientations during the gait cycle (Sutherland et al., 1980; Statham & Murray, 1971; Burnett & Johnson, 1971a, 1971b; Forssberg, 1985). These researchers concluded from their data on joint ranges of motion that as toddlers begins to walk autonomously there is less overall joint range of motion for the lower extremity when compared to adults. They also show that the ranges of motion increase as toddlers mature. These authors have also examined toddler joint orientations, observing striking similarities between research. Some similar conclusions include: 1) At the onset of autonomous walking, the lower extremity remains externally rotated throughout swing, and after the foot is flat during stance it externally rotates (Burnett & Johnson, 1971a; 1971b). 2) As gait matures over the first year of walking, there is less external rotation of the lower extremity (Sutherland, 1980). 3) For the first few months of autonomous walking, toddlers, at foot contact, have their knee in a flexed position and then extend for weight-bearing and remain in extension past midstance (Sutherland et al., 1980; Statham & Murray, 1971). Between three and five months of autonomous walking, knee extension at midstance changes to flexion creating a knee flexion wave (Forssberg, 1985; Sutherland et al., 1980). 4) At the onset of autonomous walking, the ankle is more plantar flexed at foot contact, resulting in a flat foot or toe contact, and there is very little dosiflexion during stance. However, by one year of autonomous walking, there is less plantar flexion and an obvious heel strike (Forsberg, 1985; Statham & Murray, 1971).

5) Reciprocal swinging of the opposite upper limbs is initially absent, but is present after approximately three months of walking (Sutherland et al., 1980).

Very little research has examined toddler kinetic gait patterns. Ground reaction forces (GRF) are one of the only kinetic gait patterns to be examined and reported for toddlers within the first year of walking (Forssberg, 1985; Beck et al., 1981; Bril & Brenière, 1991). Vertical GRFs available for toddlers not only show that toddlers can produce forces greater than their body weight, but they also show a lack in the double peak normally seen in adult walking. Variations in toddler walking speeds have demonstrated a change in the magnitude of the GRF in both the vertical and anterior-posterior directions. GRF have also been utilized to analyze transitions from step to step (Bril & Brenière, 1988). In this study, they utilized the force plate data to propose that toddlers actually "walk while falling", whereas adults "fall while walking". The proposed "walk while falling" was shown to occur in the negative acceleration of toddlers' centers of gravity. The data showed that the center of gravity acceleration for toddlers was always negative at foot-strike and was the reason for the "walk while falling" hypothesis. Should this hypothesis be correct and toddlers actually "walk while falling", then one could predict that toddlers will exhibit some negative support moments around foot-strike during stance phase.

Electromyography EMG patterns have been examined for toddlers (Sutherland et al., 1980; Forssberg, 1985). Toddler EMG patterns show a great deal of co-activation when compared to those of adults. Vastus medialis and tibialis anterior muscle activity gradually decrease with maturation. Tibialis anterior muscle activity also shows no silent periods between bursts. The normal phasic activity of the gastrocnemius muscle is present at two years of age, but shows late swing phase and premature stance phase activity between one and two years of age. Medial and lateral hamstring muscles also show prolonged stance phase activity, but this too decreases with age.

The research on temporal, kinematic, GRF, and EMG patterns indicate that there is development of these patterns produced by toddlers over the first year of walking; therefore, it would be inappropriate to assume toddler gait kinetics do not change over the first year of walking. It is probable that within the first year of autonomous walking, toddler kinetic walking patterns develop from a less organized toddler gait pattern to a more structured adult gait pattern. Without available kinetic gait patterns for toddlers, the propulsive strategies utilized to produce locomotion over this developmental period is still uncertain. Despite "the similarity between the temporal structure of gait in toddlers and adults, insofar as its relation to speed is concerned, [this] may mask the remarkable differences in propulsion strategies" (Bril & Brenière, 1991, p. 243). By further examining toddler gait in the form of gait kinetics over the first year of walking, the specific propulsive strategies in the form of support moments, net joint moments, and joint powers of the hip, knee, and ankle will be documented.

Study objective

The purpose of this study was to contribute to the knowledge of toddler gait kinetics in the form of support moments, net joint moments, and their powers for the hip, knee and ankle over the first year of autonomous walking. This study was exploratory in nature and its main focus was to characterize and describe the abovementioned kinetic gait patterns for toddlers over the first year of walking.

The goals of the present study were:

1) To examine how the support moments, net joint moments and powers for the hip, knee, and ankle develop over the first year of walking, and
2) To determine if toddler support moments, net joint moments, and powers for the hip, knee, and ankle differ from those of adults.

This study contributes to the body of knowledge concerning toddler gait kinetics in the form of support moments, joint moments, and powers for the hip, knee, and ankle. By analyzing toddler kinetics for developmental changes over the first year of walking and comparing these data to adults, this study furthers our understanding of the specific propulsive strategies utilized by toddlers. It was the intent of this research to examine unavailable gait data for toddlers and further the understanding of toddler walking development in the form of net joint moments and powers of the hip, knee, and ankle.

Hypothesis

This study addresses two hypotheses.

1) Toddler support moments, net joint moments, and powers for the hip, knee, and ankle change over the first year of walking, indicating a change in the propulsive strategies used by toddlers over the first year of walking.
2) Kinetic gait development will move towards adult-like patterns within the first year of autonomous walking.

These hypotheses were tested by examining toddler kinetic gait data over the first year of walking, by testing toddlers of different walking experience, and by comparing toddler gait data to available adult kinetic gait data.

Definition of Terms

The following defined terms were used throughout this study.

Autonomous Walking: Walking without external support for a minimum of five steps.

Good Step: A step considered for analysis if the right foot only touches the force plate during the stride and the left foot does not, and if all markers are present in at least two of the three cameras during the trial.

Moment Power: A power produced by a moment of force.

Toddler: Children who are autonomously walking and have walked autonomously for less than one full year.

Delimitations

The assumptions inherent in this study are:

1) The placement of joint surface markers accurately represents the centre of rotation for that joint.
2) The stretchy tights used for the experiment exhibited limited movement while walking.
3) Body segments can be accurately modeled as rigid bodies.

Limitations

Limitation of this study are:

1) The surface markers placed on the stretchy tights had a greater chance for movement possibly creating movement artifacts in the data.
2) This study is a cross-sectional study and may not represent the actual change in gait patterns for one specific child over the first year of walking.

3) The sample size does not accurately represent the population due to the non-homogeneity of the sample.

CHAPTER II

REVIEW OF LITERATURE

General Overview

This study examined the development of toddler kinetic gait patterns in the form of support moments, net joint moments, and joint powers over the first year of autonomous walking, and compared these toddler kinetic gait patterns to those of adults. First, a general review of the four levels of gait patterns for adults and children was conducted. Second, an examination of the different aspects of infant and toddler motor development helped explain how a child gains the ability to walk autonomously. Finally, an in depth review of toddler walking was explored to indicate the levels of gait patterns currently available for toddlers, and how these gait patterns changed over the first year of walking. The developmental changes observed in available toddler gait pattern data were used to propose hypotheses for the specific kinetic gait pattern development. For the purpose of this study, the adult data remained a reference tool to better examine toddler kinetic gait development over the first year of walking.

Gait Patterns

Many scientific publications have been written on gait patterns of healthy adults and children (Beck et al., 1981; Cappozzo, 1991; Herzog et al., 1989; Inmann et al., 1981; Mechelse et al., 1985; Murray et al., 1984; Nigg et al., 1994; Oberg et al. 1993a & 1993b; Winter, 1991). The reason for these numerous investigations was to gain a better understanding of what occurs while individuals are walking. As indicated by Winter (1991), there are four main levels of gait analysis that have been researched and documented. The four levels of analysis are temporal patterns, kinematic patterns, kinetic patterns, and electromyographic patterns.

Temporal Patterns

Temporal walking patterns have been examined by many researchers (Oberg et al., 1993a; Ounpuu, 1994; Winter, 1989, 1991). Temporal pattern analysis is a method of quantifying the general structure of gait, and is the most superficial of the four levels. This level of analysis provides a general background on the outcome of the gait cycle, but does not give any indication to the causes of the motion. Temporal patterns that are frequently reported include the following five measures: 1) cadence; 2) step length; 3) stride rate; 4) velocity; and 5) stance/swing percentages. Winter (1991) recorded these five temporal measures in healthy adults at three different walking speeds and running. He reported that as speed increased so did cadence, stride rate, velocity, and percent swing phase. These temporal changes due to speed were also observed in the temporal reference data published by Oberg, Karsznia, and Oberg (1993a). This data included male and female subjects between 10-79 years of age, as well as examined two different gait speeds. Along with showing that temporal patterns change as a function of speed, the authors also found that temporal patterns change as a function of age. Both speed related and age related changes in temporal gait patterns were also observed for children between the ages of five and fourteen (Ounpuu, 1994), however only cadence and velocity ranges were reported. Because these temporal measures vary as a function of walking speed and sample population, any comparison of measured temporal gait patterns should be conducted with corresponding age and speed related temporal data.

Kinematic Patterns

The second level of gait analysis is that of gait kinematics. This level of analysis provides an understanding of what type of motion is occurring at the level of the joints and segments. Kinematics do not account for the mass of body segments, nor do they explain the underlying mechanism of how movements are produced by either internal or external forces. Kinematic gait patterns that have been examined include relative angles between body segments expressed as joint ranges of motion (ROM), linear and angular velocities, as well as linear and angular accelerations of the joints and body segments (Inmann et al., 1981; Oberg et al., 1993b; Winter, 1987, 1991). Kinematic patterns have also been examined for slow, natural, and fast walking (Murray et al., 1984; Winter, 1991), and for children between five and fourteen years of age (Ounpuu, 1994). Lower extremity joint ROM, velocities, and accelerations are typically reported as changes over the stride in the sagital plane. However, Ounpuu (1994) described these kinematic gait patterns in multiple two-dimensional planes by reporting gait kinematics in the sagital, coronal, and transverse planes. Like the changes in temporal patterns, kinematic patterns have been shown to vary as a function of speed and age. Oberg et al. (1993b) also examined kinematic gait data. From their work, they reported that with speed came an increase in ROM, which was in agreement with previously published kinematic gait data by Inman, Ralston, and Todd (1981) who reported an increase in stride length and hip extension with an increase in gait speed. These findings also stress the importance of matching walking speed and sample population; therefore, a proper analysis of any kinematic data should include reference to age and speed related kinematic data.

Kinetic Patterns

Kinetic gait patterns are the next level of gait pattern analysis. Kinetic gait patterns arise from the combination of gait kinematics and force data. These gait patterns are used to explain body and joint motions with regards to all internal and external forces. Kinetic patterns include ground reaction forces, support moments, net joint moments, and powers produced by the moment of force (moment powers).

Ground Reaction Forces

Ground reaction forces (GRF) are numerically quantified using a force plate. The GRF gives information about the magnitude and direction of the force that an individual creates when in contact with the ground. Herzog, Nigg, Reed, and Olsson (1989), and Winter (1987) have described normal adult GRF profiles in the vertical, medial-lateral, and anterior-posterior directions. These studies have shown that adult GRF patterns contain typical patterns. In the vertical direction, a reproducible "double hump" curve is present during walking. The first hump in the "double hump" is produced by a braking force at foot contact and the second hump is produce by a propulsive force at toe-off. These braking and push-off forces are also characteristic of forces in the anterior-posterior directions. There is a switch from braking to propulsion forces in the anterior-posterior direction that occurs at approximately fifty percent of the stance phase. In the medial-lateral directions, there are more variations of forces, but for adults there remains a distinctive medial force produced for approximately the first fifteen percent of stance, followed by a switch to a lateral force for the remainder of stance. Some researchers have utilized these typical adult GRF profiles to analyze GRF pattern changes due to aging and variations in speed. Nigg, Fisher, and Ronsky (1994) analyzed GRF with respect to age and gender. From their study, they showed that people between the ages of 70 and 82 walk more slowly and exert lower anterior-posterior forces while walking when compared to people between the ages of 60 and 69. Changes in force amplitudes due to walking speeds were also examined by Beck, Andriacchi, Kuo, Fermier, and Galante (1981) and Winter (1991). Both of these studies agree with the data reported by Nigg et al. (1994), that there is a general increase in vertical GRF when gait speed is increased. In addition to the previous finding, Beck et al. (1981) also reported that the medial-lateral force was the least sensitive to walking speed and that, up to age five, vertical GRF normalized to body weight decreased with increasing age and then remained constant. Interestingly, the amplitudes of the force patterns for children change between the ages of one and five years old, but the patterns themselves are reported by Beck et al. (1981) to be similar to that of older children and adults. These data suggest, like temporal and kinematic data, that there are definite changes in GRF amplitudes with regards to speed, but the relative GRF patterns do not change with age.

Support Moments

Support moments are another kinetic gait pattern that have been created to describe gait. Support moments are used to quantify lower extremity support that is present during the stance phase of walking to prevent collapse. Winter (1980) described, and defined the support moments (Ms) as the sum of all the net joint moments of the lower extremity, where an extensor moment is considered a positive value. A support moment is calculated using the equation $Ms=Mk+Mh+Ma$, where Mk is the moment at the knee, Mh is the moment at the hip, and Ma is the moment at the ankle. Therefore, this equation expresses mathematically the combination of the moments at the hip, knee, and ankle. When calculated for stance phase, a person should exhibit a net extensor moment to prevent a collapse or fall. Winter (1980) utilized this equation to describe the overall effect of the moments occurring at the joints of the lower extremity. These support moments have been described for both natural and slow cadences, as well as running and pathological gait. It has been reported that with changes in walking speed, the support moment varies considerably (Winter, 1980). This variation in the support moment is mainly due to the speed related changes that occur in the GRF and gait kinematics.

Net Joint Moments

Net joint moments are another important kinetic gait pattern because they represent the sum of all the moments occurring at a specific joint. Net joint moments take into account moments produced by the body mass, the distal and proximal segmental masses, the soft tissue resistance, externally applied loads, and the complete muscle activity of both the antagonistic and agonistic muscles. The net joint moment is represented as either flexor or extensor and indicates the dominant muscle group, but does not imply that the muscle on the opposite side is inactive. Net joint moments are calculated using inverse dynamics and are typically reported as changes in flexor and extensor moments over a stride (Winter, 1991). Winter (1983, 1989, 1991) examined net joint moments for adults for different cadences of walking. He reported that as cadence increased, so did the magnitude of the moment. Through these examinations, he also reported typical flexor and extensor moments that happen at the hip, knee, and ankle over the stride. The moment at the hip shows an extensor moment at the beginning of weight bearing, which turns to a flexor moment at midstance through to late swing, and then switches back to an extensor moment to slow the thigh flexion and to prepare for foot contact. The knee moment is typically extensor for early stages of stance phase and weight bearing. During midstance there is a slight flexor moment, which is followed by an extensor moment at toe-off. The moment at the ankle sometimes has an initial dorsiflexor moment at foot contact followed by a large increase in the plantarflexor moment approaching toe-off. Following toe-off, the ankle moment drops extremely close to zero until the next foot contact.

Net joint moments have been examined by Ounpuu, (1994) comparing walking and running of adults. This comparison revealed that, similar to GRF patterns, an increase in speed corresponds to an increase in the net joint moments amplitude, but that typical joint moment profiles remain similar. Age effects on joint moments were also looked at by Ounpuu, Gage, and Davis (1991), who quantified the lower extremity joint moments of children between the ages of 5 and 16 in three dimensions. They reported that net joint moment profiles of children at the age of five were not significantly different to those of previously published adult net joint moment patterns. They concluded that, by the age of five, children have developed gait patterns similar to those of adults. Like GRF, joint moments also have distinct changes in amplitude with regards to speed, but there are striking similarities in the joint moment profiles for different speeds and different ages.

Moment Powers

Net joint moments are also used to calculate another kinetic gait pattern characteristic, power. Moment power patterns are the product of a joint's angular velocity and its corresponding joint net moment of force. The equation for a moment power is as follows: $P_j = M_j \omega_j$. In this equation, P_j is the instantaneous power at the joint, M_j is the net joint moment, and ω_j is the angular velocity of the joint. Moment powers quantify the rate of energy generation or absorption at the joint due mainly to the actions of the muscles (Ounpuu, 1994). A moment power is related to the type of contraction, where power production occurs during concentric contraction and where power absorption occurs during eccentric contraction. These moment power patterns can provide even more insight than net joint moments as to how a person produces locomotion. Adult power production patterns have been described for normal walking adults (Robertson & Winter, 1980), for comparing walking and running (Ounpuu, 1994), and for children (Ounpuu et al., 1991). Within a single walking stride for adults, Winter (1991) outlined and explained three power bursts at the hip, four at the knee, and two at the ankle. The power bursts at the hip, knee, and ankle are labeled H1 to H3, K1 to K4, and A1 to A2 respectively in Figure 4. H1 is thought to maintain trunk stability, whereas H2 acts as an absorber of energy as the hip extends while walking, and H3 delivers a power burst to lift the leg and initiate the swing phase. There are four knee bursts, K1 occurs as the knee flexes during swing absorbing power. K2 is the only positive knee power that occurs because the knee extends during mid-stance. K3 is present just before toe-off due to an increase in transnational kinetic energy of the thigh. After toe-off, the K4 power burst works to decrease the angular velocity of the lower leg before heel strike. There are two power bursts at the ankle, A1 occurs to decelerate the lower leg around the ankle and to dorsiflex the foot to gradually lower the ball of the foot to the ground. The A2 power burst is a large plantar flexor burst that happens at the ankle to generate forward motion and toe-off. These power bursts, like GRF, support moments, and net joint moments, have been reported to have amplitude changes that occur as a function of speed (Ounpuu, 1994; Winter 1991). Age effects on moment powers were also looked at by Ounpuu et al. (1991), who quantified the lower extremity moment powers of children between the ages of 5 and 16 years old in three dimensions. They reported that by the age of five children have similar moment powers to those of previously published adult patterns. Like GRF and joint moments, moment power amplitudes increase with speed, but the different power bursts remain the same between these different speeds and remain similar from age five onward.

EMG Patterns

EMG walking patterns have been examined for every major muscle in the lower extremity and are the next level in gait pattern analysis. EMG is used to record muscle activity and indicates when a muscle is contracting during a movement. Therefore, EMG gait analysis helps explain when and how muscles contract with regards to the kinematics and kinetics of gait. Winter (1991, 1987) reported normal gait EMG muscle patterns for 18 lower extremity muscles, as well as for seven related muscles. Muscle activity patterns during walking have also been documented by many other researchers (Inmann et al., 1981; Murray et al., 1984; Ounpuu, 1994; Winter, 1983). For example, Murray, Mollinger, and Gardner (1984) described EMG patterns of slow, free, and fast walking. From this study, the researchers reported the timing patterns of multiple muscle contractions and the duration of the contractions over a stride as well as changes in these EMG patterns with speed. Like other gait patterns, changes in EMG amplitudes and duration of muscular contraction have been reported as a function of speed. Other EMG analysis have compared treadmill walking to over-ground walking (Arsenault et al., 1986), showing that similar EMG profiles exist between treadmill and over-ground walking. These adult EMG patterns have also been used to evaluate elderly and pediatric gait (Baumann, 1991; Gage, 1991; Murray et al., 1984; Nigg et al., 1991; Perry & Hoffer, 1977; Shiavi et al., 1985, 1987; Winter, 1991). Shiavi, McFadyen and Green (1985) examined and presented the EMG patterns of children between the ages of five and eleven years old. The child data revealed that children have similar EMG muscle recruitment patterns when compared to those of normal adults, but there is an increase in the duration of the contractions for children of this age. These researchers also reported differences in the EMG recruitment duration and the amount of co-activation of muscle groups between these age groups. So, as age increased the duration of the contractions and the amount of co-activation of the muscles decreased. Speed related changes were also reported to influence the duration of the EMG recruitment duration. As speed increased, so did the duration of the contractions. From these studies, two conclusions are common. First, as speed increases so does the amplitude and the duration of the EMG signal, and second, the younger the person, the greater the amount of muscle co-activation.

The purpose of describing these previously mentioned studies with regards to the four levels of gait analysis has been to provide a general background on the temporal, kinematic, kinetic, and EMG patterns of adult and child gait. The importance of this gait information is to serve as a reference tool for unstudied populations and to be a method of diagnosis, treatment, and/or evaluation for individuals who exhibit abnormal gait patterns. Having normalized adult gait patterns has allowed for the analysis of unstudied populations. From these adult gait patterns, control mechanisms involving gait have been proposed, child gait development has been reported, and elderly gait changes have been examined (Winter, 1991; Whittle, 1995). Even with this normative database on adult and child gait patterns, and evidence that gait patterns change during childhood, some toddler gait data remains unavailable. Analyzing infant and toddler motor development, as well as examining available toddler gait patterns, will help determine how toddlers develop specific propulsive strategies within their kinetic gait patterns over the first year of walking.

Infant and Toddler Motor Development

A background on infant and toddler motor development is important when trying to determine how toddler gait develops within the first year of walking. Infant and toddler motor development will be described with regards to what transpires during 1) the stages of walking development; 2) infant kicking; 3) the stepping reflex; 4) supported infant stepping; and 5) autonomous toddler walking.

Stages of walking development

Before being able to understand gait development in toddlers, one must first understand the general stages of walking development. Mcgraw (1943) identified seven stages of motor development. These stages are as follows; 1) the stepping reflex, 2) stepping reflex disappearance, 3) stepping reflex reappearance, 4) assisted locomotion, 5) autonomous locomotion with hands in a high guard position, 6) autonomous locomotion with arms down to the side, and 7) autonomous locomotion with the head and the trunk in a more erect position. Each one of these stages provides a general idea of the different motor milestones infants and toddlers go through to attain autonomous walking. Further analyses of some of these stages are to follow, including a review of locomotor changes in infant kicking.

Infant Kicking

To begin understanding the leg movements involved in toddler gait, researchers looked to infant kicking and tried to conceptualize and transfer similarities of infant kicking to normal gait (Jensen et al., 1994; Schneider et al., 1990; Thelen & Fisher, 1983). Because infants voluntarily kick, this was a good place to start analyzing and understanding how infants control and move their lower limbs prior to walking. Some temporal patterns and most kinetic gait patterns cannot be analyzed for infant kicking because their legs are not touching the ground. The main levels of kicking pattern analysis to be examined for infants included kicking kinematics, torques, and EMG patterns. These investigations on infant kicking have been performed mainly in a supine position, but have also included different body orientations while kicking (supine, 45 degree to horizontal and vertical). Schneider, Zernicke, Ulrich, Jensen, and Thelen (1990) reported joint ranges of motion and joint torque along with gravity, muscle, and motion dependent torque for infant kicking in a supine position. From their data, they reported that the hip and knee motions were coupled within the kicking action, and that the ankle remained relatively steady. Because the knee and hip motions were coupled, the net torque at the knee followed that of the hip but in the opposite direction. When the hip would flex, the knee would extend. The net ankle torque was insignificant to the kicking motion. Within the net hip and knee torque, there was a great deal of interaction between the muscle torques and the motion dependent torques, where the motion dependent torques generally dictated the movement directions. Schneider et al. (1990) also discovered that during infant kicking, the hip muscle torque initiates the kicking movement by flexing the hip, but to reverse the motion and cause hip extension, a gravitational torque is used instead of active hip extensor muscle activity. This occurrence was found in most kicks with the exception of "vigorous kicks". These observations are in agreement with those observed by Jensen, Ulrich, Thelen, Schneider, and Zernicke (1994) who quantified infant kicking in a similar manner, but included different body orientations while kicking (supine, 45 degree to horizontal and vertical). From their data, they supported the findings of Schneider et al. (1990), but reported that a further constrained kicking motion occurred as a function of changing body positions. This constraint was due to the change in gravitational torque that was present in the vertical body orientation that increased the resistance to flexion.

Researchers of infant kicking have also utilized EMG to show that stepping and kicking have the same cyclical repetitions and synchrony of muscle activation, which in turn suggests that stepping and kicking are similar movement patterns (Thelen, 1983; Thelen & Fisher, 1983). These similar patterns do not mean that infants can walk, rather that the underlying pattern to produce locomotion is present before infants can walk. Other interesting data that these authors reported were the co-activation of the tibialis anterior and rectus femoris muscles during the flexion phase, and more interestingly, no active extensor EMG and only passive tonic muscle activity maintain the posture of the leg during the extension phase. These EMG results coincide with the torque data available for infant kicking, concluding that flexion occurs due to muscular contraction of the flexor muscles, but extension occurs because of passive means. Infant kicking is a unique activity that provides information on motor development. It shows that at such a young age that leg movements are coordinated and initiated by infants, but their external environment largely shapes the movement. Because gravity and motion dependent torques are limiting factors in determining infant kicking, it is clear that one of the reasons why infants are not able to just get up and walk is due to under-developed extensor muscle strength. As infants continue to develop, there are many factors, such as balance and strength that will affect the initiation of autonomous walking.

Stepping reflex

To examine the idea of coordinated infant motor control similar to that of walking, some researchers looked at the stepping reflex (Thelen et al., 1984; Zelazo, 1983). One major event in the stepping reflex that has been reported is that the reflexive-walking pattern in infants disappears a few months following birth and then returns when they begin to hold themselves up and begin to cruise. It has been shown by Zelazo (1983) that when the stepping reflex is trained it does not disappear. Through examination, Thelen, Fisher, and Ridley (1984) also supported the conclusion that the stepping reflex does not disappear when trained, but their conclusions differ from those offered by Zelazo. Zelazo concluded that the stepping reflex changes at the level of cognition, from a reflex to a cognitively integrated movement. Whereas Thelen et al. concluded that as a product of the training process an infant's muscles remain sufficiently strong to move the increasing weight of the lower limb against gravity. To test this hypothesis, Thelen et al. placed infants whose stepping reflex had disappeared in water to simulate lower gravitational forces on the infants' legs, which allowed the infants' reflexive walking patterns to return. These findings further reinforce the conclusion that the external environment largely shapes movements produced at this age. Another aspect of strength that has been indicated by Thelen et al. is that within the first six months of development extensor strength of infants' lower limbs lag far behind flexor strength, but after six months the extensor muscles are more engaged in movements. Because of this strength imbalance, the stabilization of upright positioning is compromised, which underscores one reason why autonomous walking takes time to develop.

Supported infant stepping

When infants cannot walk autonomously across a force platform, other methods need to be utilized to analyze their gait patterns. Some researchers have collected data by holding infants and gently pulling them over a force plate or holding infants over a treadmill to promote stepping. The purpose of analyzing supported infant stepping was to probe the control mechanisms behind infant stepping as well as to examine the kinematics, kinetics, and EMG patterns of supported infant stepping. One study, by Forssberg (1985), examined supported infant stepping patterns and attempted to reveal the "neural mechanisms" behind the development of autonomous walking by following infants from the time of birth to when the first signs of autonomous walking emerged. From this, Forssberg reported that all the infants had a "flexion bias" at the hip and knee throughout the step, which coincides with previously published data on infant kicking and stepping reflex where infants had underdeveloped extensor muscles. The data also showed that the hip and knee typically flexed together during step initiation, whereas the ankle did not until the end of swing when all three joints extended together. This extension of the ankle and knee at the end of swing also corresponded to extensor muscle activity. Forssberg also reported that infant supported stepping contains much co-activation of the antagonistic muscle groups during a motion. This EMG and movement data obtained by Forssberg for supported infant stepping was shown not to be significantly altered when the toddler began to walk autonomously. Where toddlers were tested one to two weeks after they could walk autonomously, and it was reported that the movement and EMG patterns did not change between supported infant locomotion and the newly established autonomous walkers. It is clear that the activities of infant kicking, supported infant stepping, and the onset of autonomous walking arise from similar movement patterns and are all constrained by the external environment. This indicates that similar neural pathways are used for these different motor patterns and that all three movements are interconnected within the development of autonomous walking.

Yang, Stephens and Vishram (1998a) also studied the infant stepping of children 10 days to 10 months of age, by holding the infants over a treadmill. In this study, the researchers examined three different issues. First, the effect of practice on infant stepping was examined. Second, they examined whether or not EMG patterns were "regular and reproducible". Lastly, they looked at the sensory control of stepping as it related to treadmill speed. From this study, they concluded that: a) with training, infants between one and six months of age, improved greatly the incidence of taking four or more continuous steps on the treadmill; b) infants exhibit an "alternation" between extensor and flexor muscles while stepping and had co-contraction of the tibialis anterior and quadriceps muscles that was not significantly different from adults, but had co-contractions of the tibialis anterior and gastrocneimius muscles that were significantly longer than adults; and c) infants adapted their stepping frequencies to a range of treadmill speeds, but were less consistent at the highest and lowest speeds. Similar improvements in the incidence of stepping have been reported for the stepping reflex when trained (Thelen et al., 1984), as well as the ability to change frequencies of infant kicking (Schneider et al., 1980). The prevalence of co-activation of the muscles during infant stepping has also been observed (Thelen & Fisher, 1983)

Ulrich, Jensen, Thelen, Schneider, and Zernicke (1994) also used a treadmill to examine infant stepping response to compare the kinematics and kinetics of infants and adults walking. From their data, they reported that infants and adults initiate swing and generate movement using torques from their muscles, from gravity, and from motion dependent movement. But, unlike adults, infants generate joint reversals through the influence of gravity rather than contracting actively against a movement to switch directions. The role of gravity in determining movement outcome is not unique to supported infant stepping. Previously, Jensen et al. (1994) reported that during infant kicking, hip joint reversals from flexion to extension were caused by a passive gravitational torque and not by an active extensor muscle torque. Gravity has been shown to play an important role in infant kicking, the stepping reflex, supported infant stepping, and autonomous walking.

Autonomous walking

The influence of gravity, mentioned in the previous sections for infant kicking and supported infant stepping, plays a large role with newly walking toddlers. For newly autonomous walking toddlers, a step is initiated by shifting the center of mass forward, which in turn helps propel the foot and leg forward through the use of gravitational torques. With gravity contributing such a large influence on gait and not muscle torques, toddlers do not utilize active muscle torques to stop the downward movement of their lower limb until after foot contact. Evidence of this inability to stop the downward movement of the body has been examined by Bril and Brenière (1988). In this study, the researchers utilized the force plate data to hypothesize that toddlers actually "walk while falling", whereas adults "fall while walking". The proposed "walk while falling", was shown to exist in the acceleration of toddlers' centers of gravity. The data indicated that the center of gravity acceleration for toddlers is always negative at foot-strike, which coincides with newly walking toddlers' inability to stop the downward movement of their body before foot-strike. To validate this "walk while falling" hypothesis, the support moment could be used to confirm if toddlers are actually "walking while falling". If toddlers are truly "walking while falling" then they should exhibit some negative support moments during the first part of stance phase.

As toddlers attain greater motor milestones and begin to walk autonomously, all four levels of gait patterns can be recorded and analyzed. Gait patterns that have been analyzed for toddlers within their first year of walking include temporal patterns, kinematic patterns, GRF data and EMG patterns.

The available toddler temporal gait patterns (Beck et al., 1981; Bril & Brenière, 1989, 1991, 1992; Clark et al., 1988; Phillips & Clark, 1985; Sutherland et al., 1980) have been shown to develop over the first six months of autonomous walking. Toddlers increase their speed of walking, but have a temporal structure to their steps that is similar to an adult pattern after only three months of autonomous walking. Toddlers have also been seen to decrease their step duration significantly as speed increases (Beck et al., 1981; Bril & Brenière, 1991; Sutherland et al., 1980), as well as vary their speed of walking (Phillips & Clark, 1985). Other changes in timing invariances, step length, step velocity, and cadence have been examined for toddlers within their first year of walking

(Bril & Brenière, 1991; 1992; Clark et al., 1988). Double support time and step width have been shown to decrease while the swing phase time, step length, step velocity, and cadence increase sharply over the first three to five months of autonomous walking. Post five months of AW, developmental changes have been seen to change more slowly until gait maturity is reached (Beck et al., 1981; Bril & Brenière, 1989; Sutherland et al., 1980). Rapid changes that occur early on in toddler walking development have been hypothesized to occur due to increases in postural control (Bril & Brenière, 1992). This hypothesis is congruent with the postural data available on the compensatory stepping of toddlers. It has been reported that around three months of AW, toddlers show more effective stepping responses with regards to perturbations (Roncesvalles et al., 2000).

Kinematic gait patterns have also been examined for toddlers within their first year of walking. Joint ranges of motion and relative joint angles have been reported for the whole gait cycle (Burnett & Johnson, 1971a, 1971b; Forssberg, 1985; Statham & Murray, 1971; Sutherland et al., 1980). It has been concluded from these kinematic studies that when a toddler begins AW, the overall joint range of motion for the lower extremity is less than that of adults, but it has been reported that as these toddlers develop their ranges of motion increase. Some common conclusions have been made with regards to toddlers joint kinematics: 1) At the onset of autonomous walking, the lower extremity remains externally rotated throughout swing, and after the foot is flat during stance, it externally rotates. 2) As gait develops over the first year of walking, there is less external rotation of the lower extremity. 3) For the first few months of autonomous walking, toddlers, at foot contact, have their knee in a flexed position and then extend for weight-bearing and remain in extension past midstance. Between three and five months of autonomous walking, the extension at midstance changes to flexion creating a knee flexion wave. 4) At the onset of autonomous walking, the ankle is more plantar-flexed at foot contact, resulting in a flat foot or toe contact, and there is very little dosiflexion during stance. However, by one year of autonomous walking, there is less plantar flexion and an obvious heel strike. 5) Reciprocal swinging of the opposite upper limbs is initially absent, but is present after approximately three months of walking. All of these observations indicate that toddler gait kinematics develop over the first year of walking and are likely due to a combination of experience and maturation.

As for kinetic gait patterns only GRF have been examined and reported for toddlers over the first year of walking (Beck et al., 1980; Bril & Brenière, 1991; Forssberg, 1985). It has been reported that toddlers can generate vertical GRF larger than their own body mass, but do not exhibit the typical adult-like "double peak" profile in their vertical GRF. Like adults, toddler variations in walking speeds change the magnitude of the GRF in both the vertical and anterior-posterior directions.

Toddler EMG patterns have also been examined and show a great deal of co-activation when compared to that of adults (Forssberg, 1985; Sutherland et al., 1980). From the EMG collected on toddlers, the vastus medialis and tibialis anterior activity gradually decreased with maturation, normal gastrocnemius activity was present at two years of age with late swing phase and premature stance phase activity between one and two years of age, and medial and lateral hamstrings showed prolonged stance phase activity that decreased with age.

With previous research indicating a developmental change in temporal, kinematic, GRF, and EMG patterns over the first year of walking, it would be inappropriate to assume that toddler gait kinetics do not develop over the first year of walking. Should other gait patterns develop from a less organized toddler gait patterns to more structured adult-like patterns over the first year of walking then so should toddler gait kinetics. Also, without kinetic gait patterns for toddlers, the propulsive strategies utilized by toddlers to produce locomotion over the first year of walking is still unclear. Despite "the similarity between the temporal structure of gait in toddlers and adults, insofar as its relation to speed is concerned, [this] may mask the remarkable differences in propulsion strategies" (Bril & Brenière, 1991, p.243). By further examining toddler gait in the form of gait kinetics over the first year of walking, the specific propulsive strategies in the form of net joint moments and joint powers of the hip, knee, and ankle have been be documented.

Summary

The four gait patterns, temporal, kinematic, kinetic, and EMG, have been examined for a normal adult population. In many cases these normal adult patterns are used as a tool to determine age related changes in gait or to examine gait changes with respect to pathological disorders.

Currently, there has been some research done on the temporal, kinematic, GRF and EMG gait patterns of toddlers within their first year of autonomous walking, but there has been no work done on the kinetic gait patterns of toddlers. From previous works that have been conducted, it has been concluded that, "toddlers exhibit step organization [that] is remarkably similar to that of the mature walkers" (Clark & Philips, 1987, p.430) as early as three months of age. Despite this similarity, it has been noted that these similarities might not be representative of "differences in propulsive strategies" (Bril & Brenière, 1991, p.243). Due to the fact that toddler propulsive strategies in the form of support moments, net joint moments and joint power are currently unavailable for toddlers, it remains unknown how these kinetic gait patterns develop over the first year of walking. This kinetic gait data is a large piece of the developmental puzzle, which needs to be examined and was examined in this study.

CHAPTER III

METHODOLOGY

Participants

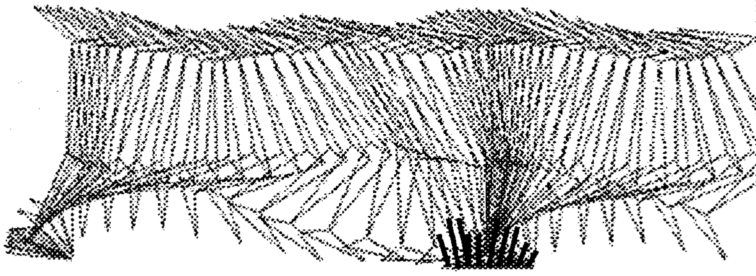
A convenience sample of thirteen toddlers (11 girls and 2 boys) participated in this study. The toddlers were between the ages of 10 and 24 months and were autonomous walkers of less than a year. The toddlers had no history of any musculoskeletal or neurological impairment and were in good health prior to participation as identified by the parents or guardian.

Experimental equipment

Two force plates (AMTI) sampled at 240 Hz were used to record the ground reaction forces during each walking trial. Walking trials were filmed with three (Panasonic) video cameras. A control grid, 1m by 1m by 1m, with 19 control points and one fixed point were used for calibration. A light synchronizer was used to synchronize video and force data. Eight reflective markers were used to identify segments and joints. The markers were placed on top of dark tights on the right side of the body over the anterior superior illiac spine (ASIS), the sacrum, the greater trochanter, the lateral femoral condyle, the tibial tuberosity, the lateral malleolus of the fibula, the heel and the fifth metatarsal head.

Body segment parameters (BSP) were collected using a soft retractable anthropometer. The lengths of each toddler's thigh, leg and foot segments were measured between body landmarks. Anthropometric measurements also included the girth of the subject's thigh and leg measured mid-segment, the width of the foot at its widest spot, and the child's height and weight. These measurements were used to obtain each toddler's lower limb segmental centers of mass, segmental mass fractions and segmental moment of inertia for children of this age (Schneider & Zernicke, 1992). These values were used in the model created for each subject to calculate joint moments and powers.

Figure 1. (right) Marker placement on one toddler walking across a force pate with a foreground fixed point seen on the floor. (under) Digitized segments and force data are overlaid for the trial.



The Ariel Performance Analysis System (APAS) was used to collect analog force platform data as well as to grab, digitize and transform the video data. Biomech Motion Analysis Software (Robertson, 2002) was used to process the force and video data, to obtain segmental kinematics, to calculate inverse dynamics of the joints of the lower extremity, and to calculate the support moment for each step.

Procedure

One testing session of approximately one hour was required of each toddler. Toddlers had a parent or guardian present during the testing. The testing took place in the

Motor Control Lab at the University of Ottawa. Prior to any testing the parent or guardian read and signed a consent form (see Appendix D for the consent forms given ethics approval from the University of Ottawa in accordance with the Tri-Council Statement).

The toddler was changed into a dark blue stretch suit and was given time to become accustomed to the laboratory setting while the researcher described the parent's role in the session and the goal of the testing. After informing the parent, the toddler's sex, age in months, birth date and number of months of autonomous walking were recorded from information reported from the parent or guardian. Anthropometric measurements were recorded and reflective surface markers were placed on the body. The toddler was placed on the walkway behind the force plates where he/she was required to take a few steps before the force plates and one or two steps on each of the force plates (AMTI).

The parent or guardian stood or walked either in front or behind their toddler to encourage the toddler to walk across the force plates. Every attempt was made to obtain up to 15 good steps. A good step was considered acceptable if the toddler had only the whole right foot on the force plate for the duration of foot-strike (FS) to toe-off (TO) and the toddler was unsupported by an adult for the total duration of the step. For each toddler the session ended when 15 good steps were obtained, or if the toddler became fatigued and unwilling to further participate.

Data Reduction

Up to 15 good steps were included for data reduction for each toddler and were further reduced following the testing session. The final number of good steps utilized for data analysis was between six and fourteen. A step was not considered for analysis if at any time a surface marker was not visible in two of the three cameras, if at any time a part of the right foot was not touching the force plate as seen in the video, or if the force data showed that the toddler's right foot touched both force plates during stance phase. Other criteria for further reducing the number of good steps for analysis were if the toddler was running or if the toddler was purposefully toe walking.

Data

Seven temporal parameters and three kinetic patterns of gait were analyzed. First, the temporal gait parameters, cadence was calculated for each step and averaged over the number of trials obtained for each toddler. The toddler cadence data was used to determine the speed of normalized adult data that would be used for the kinetic gait pattern comparison. The six other temporal measures included stride length as a percent of height, stride velocity, stride rate, stride time, and the percentages of time in stance and double support for comparison with previously published toddler temporal gait data.

The first kinetic gait pattern to be analyzed was each toddlers' support moments. Support moments were calculated using the net joint moments at the hip, knee and ankle. The support moments and their corresponding net joint moments were normalized to body mass and percent of stance starting with the foot-strike (FS) of the right foot and ending with toe-off (TO) of the same foot. The hip, knee, and ankle net joint moments where calculated using inverse dynamics and the support moments were calculated by summing these net joint moments, with extension being positive, using the equation $M_s = M_k + M_a + M_h$ (Winter, 1980).

Where: M_s = the support moment,

M_k = the net knee moment,

M_a = the net ankle moment, and

M_h = the net hip moment.

The support moments were analyzed among toddlers, with different walking experience, for developmental changes in the support moments over the first year of autonomous walking and compared to corresponding cadence-related adult data.

The net joint moments at the hip, knee, and ankle were the second gait patterns to be analyzed. These net joint moments were normalized to body mass and to percent of stance starting with the foot-strike (FS) of the right foot and ending with the toe-off (TO) for the same foot at 100% of the stance. The net joint moments were also analyzed between toddlers with different walking experience for developmental changes that occurred in the net joint moments over the first year of autonomous walking. Net joint moment analysis included a comparison with corresponding cadence-related adult data.

The last kinetic gait patterns to be analyzed were the powers produced by the moments of force at the hip, knee, and ankle. These moment powers were normalized to body mass and to percent of stride starting with the first TO of the right foot and ending with the second TO for the same foot at 100% of the stride. Moment powers were computed from the product of a joint's angular velocity and its corresponding joint moment of force using the equation: $P_j = M_j \omega_j$

Where: P_j = the instantaneous power at the joint,

M_j = the net moment of force at the joint, and

ω_j = the joint angular velocity.

Toddler moment powers at the hip, knee, and ankle were also analyzed among toddlers with different walking experience for developmental changes that occurred in these moment powers over the first year of autonomous walking. Moment power analysis also included a comparison with corresponding cadence-related adult data.

Pearson product moment correlation coefficients ranges and averages were obtained by comparing the net joint moments and moment powers of each individual toddler step to that of mean adult slow walking net joint moments and moment powers. The range and mean of the correlation coefficients were calculated for each toddler's hip, knee, and ankle net joint moments and moment powers. Mean correlation coefficients were obtained by adding individual toddler step correlation values and dividing by the number of analyzed steps for that toddler (between 6 and 14).

PART TWO: RESULTS OF THE STUDY

CHAPTER IV

TODDLER GAIT: LOWER EXTREMITY JOINT MOMENTS AND POWERS

Introduction

Childhood is marked by many significant motor milestones, including the acquisition of walking. Due to the importance of gait for everyday locomotion, a multitude of scientific publications have been devoted to the understanding and analysis of adult and child gait patterns (Beck et al., 1981; Cappozzo, 1991; Herzog et al., 1989; Inmann et al. 1981; Mechelse et al., 1985; Murray et al, 1984; Nigg et al., 1994; Oberg et al. 1993a, 1993b; Winter, 1991). These numerous investigations helped explain how the neurological and musculoskelatal systems combine to produce walking. To date, four main hierarchical levels of gait analysis have been studied and documented. The four levels of gait analysis are temporal patterns, kinematic patterns, kinetic patterns and electromyographic (EMG) patterns. Each level of gait analysis provides a different level of understanding towards what is happening while walking.

Temporal pattern analysis is a method of quantifying the general structure of gait, and is the most superficial of the four levels. This level of analysis provides a general background on the outcome of the gait cycle, but does not give any indication to the causes of the motion. Temporal patterns frequently reported include the following five measures: cadence, step length, stride rate, velocity, and stance/swing percentages. These measures have been indicated to vary as a function of walking speed and sample population (Oberg et al., 1993a; Ounpuu, 1994; Winter, 1989, 1991).

The second level of gait analysis is that of gait kinematics. This level of analysis provides an understanding of the type of motion occurring at the level of the joints and segments. Kinematics, however does not take into account the masses of body segments, nor does it explain the underlying mechanism of how each movement is produced.

Kinematic gait patterns that have been examined include both linear and angular velocities, as well as linear and angular acceleration of the joints and body segments. Other gait kinematics investigated are relative angles between body segments and joint ranges of motion (Inmann et al., 1981; Oberg et al., 1993b; Winter, 1987, 1991). Further, kinematic patterns have been examined for slow, self-selected, and fast walking in adults (Murray et al., 1984).

Kinetic gait patterns, the next level of gait pattern analysis, are calculated from the combination of gait kinematics and force data. These gait patterns are used to explain body and joint motion with regards to all internal and external forces. Kinetic patterns include ground reaction forces, support moments, net joint moments of force, and powers produced by the moment of force (moment power). Each kinetic gait pattern provides different details about what is happening while walking. For example, ground reaction forces are numerically quantified using a force plate and provide information about the magnitude and direction of the force an individual uses to contact the ground. Normal adult and speed-related changes in GRF profiles have been described in the literature (Herzog et al., 1989; Nigg et al., 1994; Ounpuu, 1994). Support moments are used to quantify lower extremity support that is present during the stance phase of walking to prevent collapse. Winter (1980) defined a support moment as the sum of all the net joint moments of the lower extremity, where an extensor moment was considered a positive value. The support moment serves to keep the body from collapsing during the stance phase of walking. Winter also described support moments for adults at different speeds of walking and for running.

Net joint moments are another important kinetic gait parameter because they represent the sum of all the moments occurring at a specific joint. When calculated, net joint moments take into account moments produced by the body masses, soft tissue resistance, externally applied loads, and the complete muscle activity of both the antagonistic and agonistic muscles groups. The net joint moment is represented as either a flexor or extensor moment and indicates the dominant muscle group, but does not imply that the muscle on the opposite side is inactive. Net joint moments have been used to compare both walking and running, to analyze different cadences of walking, and to assess pathological gait in adults (Mechelse et al., 1985; Ounpuu, 1994; Winter, 1991).

Net joint moments are also used to calculate another kinetic gait pattern, power. Moment powers are the product of a joint's angular velocity and its corresponding net moment of force. Moment powers quantify the rate of energy generation or absorption at the joint due mainly to the actions of the muscles. These energy patterns can provide even more insight than net joint moments on how a person produces locomotion. Moment powers have been used to examine walking (Robertson & Winter, 1980) and to compare walking and running (Ounpuu, 1994).

The final level of gait analysis, electromyography (EMG), has been examined for every major muscle in the lower extremity. EMG is used to record muscle activity and indicates when a muscle is contracting during a movement. Therefore, EMG gait analysis helps explain when and how the muscles are contracting throughout the gait cycle. EMG activity during normal gait (Inmann et al., 1981; Murray et al., 1984; Ounpuu, 1994; Winter, 1983; 1991), slow, natural, and fast walking (Murray et al., 1984), and treadmill versus over ground walking (Arsenault et al., 1986) has been documented.

Toddler Gait Patterns

When toddlers begin to walk autonomously, the four levels of gait pattern analysis can be conducted. Toddler gait patterns can be used to determine developmental changes that occur during the acquisition of walking as well as compared to gait patterns of different populations such as adults and children. Before kinetic gait patterns can be calculated, accurate body segment parameters (BSP) must be used to take into account the different segmental mass distributions of children of this age. This is due to the fact that toddlers have very different mass distributions to that of adults and even young children and therefore these different mass distributions affect inverse dynamics calculations. Proper toddler BSP's have been created for children of this age group by Schneider and Zernicke (1992) and were used in this study as part of the inverse dynamics calculations of the net joint moments and moment powers.

There is little research available on toddler gait patterns within the first year of walking. Published reports are limited to temporal patterns, kinematic patterns, GRF data and EMG patterns (Beck et al., 1981; Bril & Brenière, 1989, 1991, 1992; Clark et al., 1988; Phillips & Clark, 1985; Sutherland et al., 1980). Over the first six months of autonomous walking, toddlers increase their speed of walking, but the temporal structure of their steps mimics the adult pattern after only three months of autonomous walking (Bril & Brenière, 1989). Step duration decreases significantly as speed increases (Beck et al., 1981; Bril & Brenière, 1991; Sutherland et al., 1980), and over the first six months of autonomous walking, toddlers increase the range of their walking speeds (Clark et al., 1988; Bril & Brenière, 1989). Double support time and step width decrease while the swing phase time, step length, step velocity and cadence increase sharply over the first three to five months of walking (Bril & Brenière, 1991, 1992; Clark et al., 1988). After this time, these changes level off, showing slower developmental change until gait maturity is reached. These changes in phasing percentages and temporal gait structure have also been seen in other studies (Beck et al., 1981; Bril & Brenière, 1989; Sutherland, 1980). The rapid changes that occur early on in toddler walking development have been hypothesized to occur in conjunction with increases in postural control (Bril & Brenière, 1992). This hypothesis is congruent with the postural data available on the compensatory stepping of toddlers, where it is indicated that toddlers between one and three months of autonomous walking show an increase in their effective stepping response with regards to perturbations (Roncesvalles et al., 2000).

In addition to toddler temporal gait patterns, kinematic gait patterns have also been examined (Burnett & Johnson, 1971a, 1971b; Forssberg, 1985; Statham & Murray, 1971; Sutherland et al., 1980). When a toddler begins to walk autonomously, the overall joint range of motion of the lower extremity is less than that of adults. These ranges of motion increase as toddlers mature (Burnett & Johnson, 1971a, 1971b). At the onset of autonomous walking, the lower extremity remains externally rotated throughout swing, and after the foot is flat during stance it externally rotates. As gait matures over the first year of walking, there is less external rotation of the lower extremity (Sutherland et al., 1980). For the first few months of autonomous walking, toddlers, at foot contact, have their knee in a flexed position and then extend for weight-bearing and remain in extension past midstance (Statham & Murray, 1971; Sutherland et al., 1980). Between three and five months of autonomous walking, the extension at midstance changes to flexion creating a knee flexion wave (Forssberg, 1985; Sutherland et al., 1980). At the onset of autonomous walking, the ankle is more plantar flexed at foot contact, resulting in a flat foot or toe contact, and there is very little dosiflexion during stance. However, by one year of autonomous walking, there is less plantar flexion and an obvious heel strike is evident (Forsberg, 1985; Statham & Murray, 1971). Reciprocal swinging of the opposite upper limbs is initially absent, but is present after approximately three months of walking (Sutherland et al., 1980). These kinematic observations indicate that toddler gait develops within the first year of walking and is different to those kinematic patterns observed in adults.

Ground reaction forces are one of the only kinetic gait patterns to be examined and reported for toddlers within the first year of walking (Beck et al., 1981; Bril & Brenière, 1991; Forssberg, 1985). Vertical GRF available for toddlers not only show that they can produce forces greater than their body weight, but they also show a lack in the double peak normally seen in adult walking. Variations in toddler walking speeds have also shown a change in the magnitude of the GRF in both the vertical and anterior-posterior directions. GRF have also been utilized to analyze transitions from step to step (Bril & Brenière, 1988). In that study, they utilized the force plate data to indicate that toddlers actually “walk while falling”, whereas adults “fall while walking”. The proposed “walk while falling”, was explained by the acceleration of toddlers’ centers of gravity. The data indicated that the center of gravity acceleration for toddlers is always negative at foot-strike, whereas adult’s center of gravity acceleration was always positive.

EMG patterns have also been examined for toddlers between one and three years of age (Forssberg, 1985; Sutherland et al., 1980). Toddler EMG patterns show a great deal of co-activation when compared to that of adults. Vastus medialis and tibialis anterior activity gradually decreases with maturation. The normal phasic activity of the gastrocnemius is present at two years of age, but the gastrocnemius shows late swing phase and premature stance phase activity between one and two years of age. Medial and lateral hamstrings also show prolonged stance phase activity, but this too decreases with age.

Without available kinetic gait patterns for toddlers, the propulsive strategies utilized to produce locomotion over this developmental period is still unsure. Despite "the similarity between the temporal structure of gait in toddlers and adults, insofar as its relation to speed is concerned, [this] may mask the remarkable differences in propulsion strategies" (Bril & Brenière, 1991, p.243). By further examining toddler gait in the form of gait kinetics over the first year of walking, the specific propulsive strategies in the form of net joint moments and joint powers of the hip, knee, and ankle will be documented. Moreover, it is possible that toddler kinetic gait patterns develop from a less organized toddler gait to a more structured adult gait pattern.

Without available kinetic gait data for toddlers over the first year of walking and the need to understand the propulsive strategies utilized by toddlers, this study was undertaken for three reasons. First, this study was exploratory in nature and characterized support moments, net joint moments and the moment power gait patterns for toddlers within the first year of walking. Second, this study determined propulsive strategies toddlers' use and how these strategies develop over the first year of autonomous walking. Third, this study also looked to ascertain if toddler and adult kinetic gait pattern differ. To research these three aspects of toddler gait development we examined how the support moments, net joint moments and joint powers for the hip, knee, and ankle develop over the first year of walking. Second, we compared toddler support moments, net joint moments, and joint powers for the hip, knee, and ankle to those of adults. By doing both these things we attempted to further our understanding of how toddler kinetic gait patterns develop over the first year of walking.

Material and Methods

Participants

A convenient sample of thirteen toddlers (11 girls and 2 boys) participated in this study. The toddlers were between the ages of 10 and 24 months and were autonomous walkers of less than a year (Table 1 for other characteristics). The toddlers had no history of any musculoskeletal or neurological impairment and were in good health prior to participation as recorded by the parent. In general, as the age of the toddlers increased, the number of months autonomous walking also analyzed increased.

Table 1. Subject Characteristics

Sub #	Months Walking	Age (months)	Age (months) walking onset	Sex	Weight (kg)	Height (cm)	# Steps Analyzed
10	1	12	11	F	11.7	84	12
2	2	15	13	F	8.1	73	11
4	3	17	14	M	11	79.5	9
8	3	14	11	F	12	83	14
6	4	14	10	F	10.3	73.5	7
12	4	18	14	F	11.1	78	11
13	4	17	13	F	14.2	86	12
7	5	16	12	F	10.4	74.5	8
11	5	18	13	F	10.9	78.5	12
3	7	21	14	F	9.2	84	9
9	9	21	11	F	12.6	83	6
14	11	23	11	F	12.4	84	10
5	12	22	10	M	11.7	85	6

Subjects ordered by number of months of autonomous walking (AW)

Experimental equipment

Two force plates (AMTI) sampled at 240 Hz. Sensitivity levels of Fx and Fy were set at 0.75 μV/[V*N] with a standard deviation of 0.17 μV, and the sensitivity of Fz set at 0.19 μV/[V*N] with a standard deviation of 0.04 μV. These force plates were used to record the ground reaction forces during each walking trial. Walking trials were filmed with three (Panasonic) video cameras. A calibration frame ($1m^3$), with 19 control points and one fixed point were used for calibration. A light synchronizer was used to synchronize video and force data. Eight reflective markers were used to identify segments and joints. The markers were placed on top of dark tights on the right side of the body over the anterior superior illiac spine, the sacrum, the greater trochanter, the lateral femoral condyle, the tibial tuberosity, the lateral malleolus of the fibula, the heel and the fifth metatarsal head.

Table 2. Segment Parameters (cm)

	Thigh		Shank		Foot	
Sub #*	Length	Girth	Length	Girth	Length	Width
10	17	26	16.8	21	6.1	5.8
2	14.8	24.2	13.7	18.1	6.2	4.2
4	15.2	24.5	13.9	20.5	6.5	5.5
8	17	30.5	16.5	22	6.5	6
6	14	28	15	21.5	6.1	5
12	14.5	31	14	21.5	5.5	5
13	17.5	30.3	17	22.9	7	6.1
7	14.5	20.1	14.2	19.7	6.1	5.3
11	14	27.5	13.5	20	6.2	5.5
3	14.5	23.9	15	20	6.1	5.2
9	16	31.5	14.8	23	6.5	6
14	18.5	30.1	15.5	23	7.2	6.5
5	16.2	24.3	16	20	6.4	5.6

*Subjects ordered by number of months of AW (see Table 1)

Body segment parameters (BSP) were collected using a soft retractable anthropometer. The lengths of each toddler's thigh, leg and foot segments were measured between body landmarks. Anthropometric measurements also included the girth of the subject's thigh and leg measured mid-segment, the width of the foot at its widest spot, their height and weight (Table 2). These measurements were used to obtain each toddler's lower limb segmental centers of mass, segmental mass fractions and segmental moments of inertia for children of this age (Schneider & Zernicke, 1992). These values were used in the model created for each subject and used to calculate joint moments and powers.

The Ariel Performance Analysis System (APAS) was used to collect analog force platform data, as well as to grab, digitize and transform the video data. Biomech Motion Analysis Software (Robertson, 2002) was used to process the force and video data for three purposes: 1) to calculate the temporal parameters of each step for each toddler; 2) to obtain segmental kinematics; and 3) to combine the kinematic and force plate data to calculate kinetic gait patterns. The kinetic gait patterns analyzed included support moments, net joint moments, and moment powers using inverse dynamics.

Procedure

One experimental session, of approximately one hour was required of each toddler. Toddlers had a parent or guardian present during the experimental procedure, which took place in the Motor Control Laboratory at the University of Ottawa. Prior to participation the parent or guardian read and signed a consent form that was approved in accordance with the Tri-Council Statement from the University of Ottawa.

The toddler was changed into a dark blue stretch suit and was given time to become accustomed to the laboratory setting while the researcher described the parent's role in the session and the goal of the experiment. The toddler's sex, age in months, birth date and number of months autonomously walking were then recorded. Anthropometric measures used to determine body segment parameters (BSP) appear in Table 2.

The segment lengths of the toddlers studied differed up to 24%. Similar differences in morphology are seen during periods of growth like adolescence. Further studies to determine the influence of large ranges in body morphology on toddler gait may help distinguish differences between initial gait acquisition in toddlers and gait adaptations due to growth spurts.

Once the toddlers had been changed, measured and surface markers placed on their legs, the toddlers were placed on a walkway with two embedded force plates such that they were required to take a few steps before the force plates and one or two steps on each of the force plates (AMTI).

The parent or guardian stood or walked either in front or behind their toddler to encourage the toddler to walk across the force plates. Every attempt was made to obtain up to 15 good steps. A good step was considered acceptable if the toddler had only the whole right foot on the force plate for the duration of foot-strike (FS) to toe-off (TO) and the toddler was unsupported for the total duration of the step. For each toddler, the session ended when 15 good steps were obtained or if the toddler became fatigued or unwilling to further participate.

Data Reduction

Steps were considered for analysis if all surface markers were visible in two of the three cameras, if the right foot was touching one force plate from the period of foot-strike to toe-off, and if the toddler was not running or toe walking.

Six temporal parameters and three kinetic gait patterns were obtained. First, the temporal gait parameter, cadence, was calculated and used to determine the speed of normalized adult data that would be used for the kinetic gait pattern comparison. Additional temporal data included stride length, stride velocity, stride time, and the percentages of stance and double support for comparison with previously published toddler and child temporal gait data.

The net hip, knee, and ankle moments were the first kinetic gait pattern calculated using standard inverse dynamics (Winter, 1991). The support moment was then computed by summing these net joint moments, where an extensor moment was considered positive. Data were normalized to body mass and percent of stance starting with the foot-strike (FS) of the right foot and ending with toe-off (TO) of the same foot.

The support moments and net joint moments at the hip, knee, and ankle were compared between toddlers with different walking experience for developmental changes that occurred over the first year of autonomous walking. Data were also compared with corresponding cadence-related adult data.

Powers produced by the moment of force at the hip, knee, and ankle were normalized to body mass and to percent of stride starting with the first TO of the right foot and ending with the second TO for the same foot at 100% of the stride. Moment powers were computed from the product of joint angular velocity and the corresponding joint moment of force.

Data Analysis

Pearson product moment correlation coefficients (PPMCC) were used to identify similarities in curve profiles between toddler and adult moment and power patterns.

PPMCC were obtained by comparing the net joint moments and moment powers of each individual toddler step to that of mean adult slow walking net joint moments and moment powers. The range and mean of the correlation coefficients were calculated for each toddler's hip, knee, and ankle net joint moments and moment powers. Mean correlation coefficients were obtained by adding individual toddler step correlation values and dividing by the number of analyzed steps for that toddler (between 6 and 14).

Results

Gait Characteristics

Individual toddler temporal gait characteristics are presented in Table 3. Also presented are cadence and percent stance values for adult natural and slow walking (data from Winter, 1991). Cadence was selected as the variable for determining the appropriate adult data for comparison because it relates to both speed and how many steps a child was taking a minute. It was important to have a close comparison related to speed of walking progression because of changes that can be seen in gait patterns due to speed and number of steps taken per minute. A stem-and-leaf analysis (Green et al., 1997) was used to identify extreme values in the toddler cadence data. Toddler walking cadences ranged from 40.28 to 97.32 and were closest to those of slow rather than natural walking adults. Gait cadence for subject 3, 158 steps/min, was identified as an outlier and this toddler was excluded from further analysis. Although individual toddler cadences were significantly different from the mean adult slow walking cadence, $p < .003$ two-tailed one sample t-test, we are limited to data sets that are currently available in the literature. Therefore, this slow walking adult data is the best published data set, which is available and suitable for comparison with toddler data due to the similarity in acquisition and analysis of the kinetic data sets.

Table 3. Temporal Gait Characteristics

Sub #*	Stride length as % of height Mean (sd)	Stride Velocity (m/s) Mean (sd)	Cadence Mean (sd)	% Stance Mean (sd)	% Double Support Mean (sd)	Stride Time (s) Mean (sd)
10	0.40 (0.06)	0.34 (0.08)	40.28 (9.29)	68.32 (0.04)	38.55 (0.06)	1.03 (0.15)
2	0.46 (0.07)	0.45 (0.10)	53.45 (12.36)	65.17 (0.06)	32.77 (0.08)	0.78 (0.13)
4	0.54 (0.08)	0.69 (0.18)	82.54 (21.82)	62.95 (0.02)	33.70 (0.05)	0.65 (0.10)
8	0.47 (0.14)	0.51 (0.15)	60.79 (18.51)	65.54 (0.05)	33.49 (0.04)	0.78 (0.06)
6	0.40 (0.09)	0.34 (0.03)	40.56 (4.07)	70.48 (0.05)	39.70 (0.09)	0.87 (0.13)
12	0.48 (0.07)	0.54 (0.08)	64.86 (9.03)	69.07 (0.04)	39.39 (0.03)	0.70 (0.10)
13	0.47 (0.14)	0.50 (0.18)	60.08 (21.51)	67.02 (0.06)	38.41 (0.05)	0.84 (0.13)
7	0.56 (0.09)	0.74 (0.19)	88.93 (22.71)	63.87 (0.04)	35.27 (0.08)	0.58 (0.09)
11	0.43 (0.09)	0.51 (0.11)	61.23 (12.96)	69.91 (0.05)	46.89 (0.21)	0.67 (0.03)
3	0.69 (0.06)	1.32 (0.11)	158.40 (13.45)	49.96 (0.04)	19.70 (0.07)	0.44 (0.03)
9	0.53 (0.04)	0.55 (0.06)	65.83 (6.97)	64.45 (0.04)	34.25 (0.03)	0.81 (0.06)
14	0.51 (0.06)	0.57 (0.12)	68.55 (14.83)	66.09 (0.05)	32.68 (0.05)	0.76 (0.11)
5	0.68 (0.08)	0.81 (0.22)	97.32 (25.87)	64.74 (0.03)	34.48 (0.07)	0.74 (0.12)
Adult Slow[a]			84.7 (10.4)	63.5 (1.9)		
Adult Natural[a]			105 (7.7)	63.3 (1.0)		

[a] Adult walking data obtained from Winter 1991

*Subjects ordered by number of months of AW (see Table 1)

Support Moments

Support moments, normalized to body weight, for six toddlers and adult slow and natural cadences are presented in Figure 2. These six toddlers were chosen in order to represent the full year of AW. The normalized amplitudes of the toddler support moments are approximately one half that of the adult. There was a marked increase in the normalized support moment amplitudes by four and five months of AW with no further increases by nine and eleven months of AW. Despite these increases in the support moment amplitudes by eleven months, the maximum normalized amplitudes of the

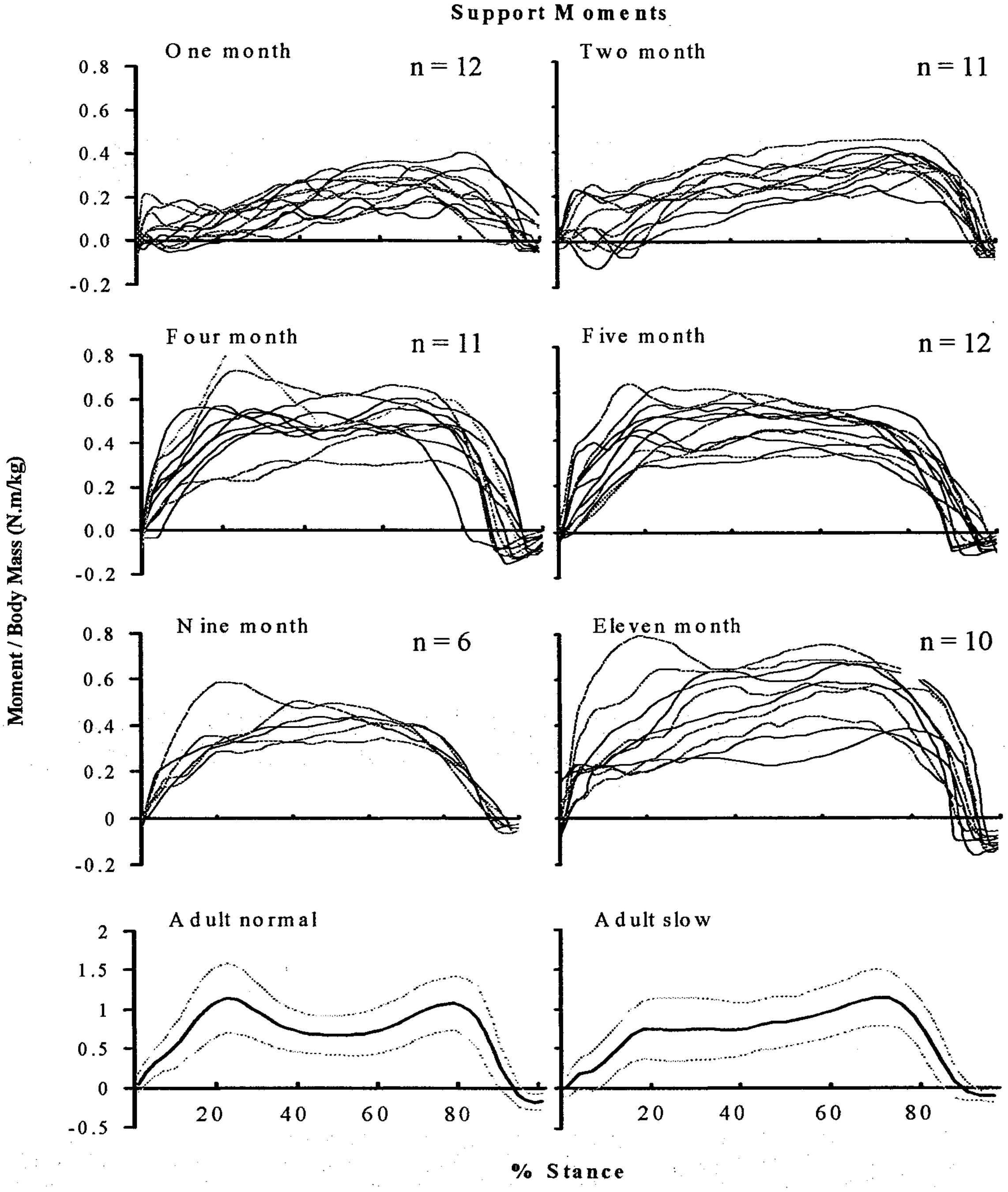


Figure 2. Support moment curves of individual steps for a one, two, four, five, nine and eleven month autonomous walker are plotted. Number of steps plotted indicated on graph. Also plotted are adult (mean +/-sd; data from Winter, 1980) support moment curves for both natural and slow walking cadences. All data are normalized to percent of stance and to body mass. Note the different scaling for the adult support moments.

toddlers' support moments are still significantly different from that of adult support moments ($p < .001$, two-tailed).

The first 20% of stance for both the one and two month AW showed negative support moments in 7/12 trials and 6/11 trials, respectively. This decreased in the four and five month AW with 1/10 trials and 2/12 trials with negative support moments within the first 20% of stance. The support moments for the nine and eleven month AW showed no negative values during the first 20% of stance.

Net Joint and Support Moments

Average net joint moments and standard deviations for the ankle, knee, and hip along with corresponding support moments for three toddlers (one, five and eleven month AW) and adult slow walking are presented in Figure 3.

Like the support moments, the amplitudes of the net hip, knee, and ankle joint moments remain approximately half that of the adult slow walking data, even in the eleventh month of AW. The maximum amplitudes of the toddlers' net joint moments were significantly less than that of adult slow walking maximum values for each of the joints, hip ($p < .001$), knee ($p < .001$), and ankle ($p < .001$).

The pattern of net joint flexor and extensor moments approached that of the adult pattern over the first year of AW and was characterized by a sequential development beginning with the ankle, proceeding to the knee and then the hip. This development is represented in the net joint moment graphs and in the Pearson product moment correlation coefficients. A 1, 5, and 11 month AW were selected to represent early, mid, and late periods of walking within the first year of AW. The range and (mean) Pearson product moment correlation coefficients between the net ankle moment for the 1, 5, and

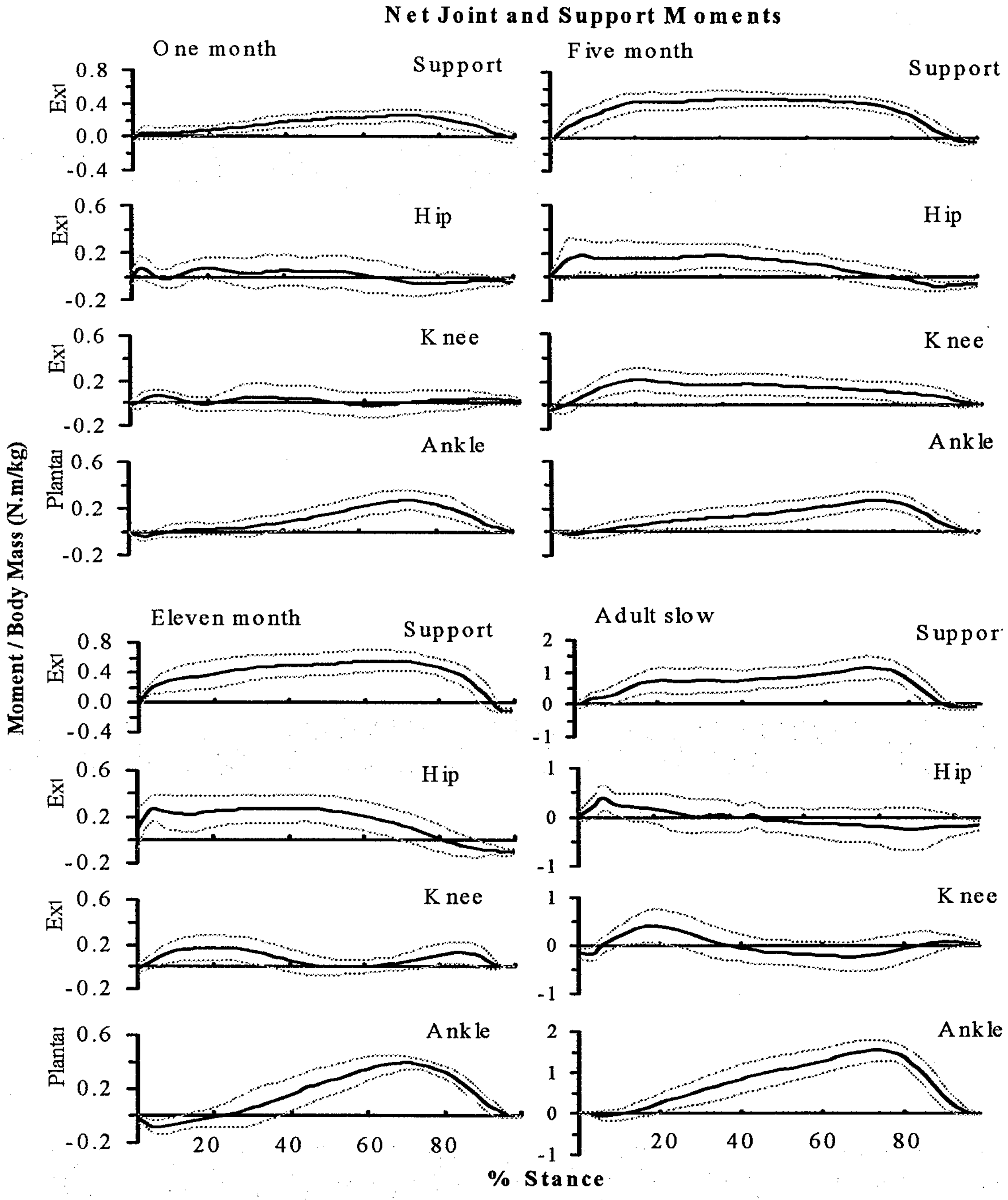


Figure 3. Support, hip, knee, and ankle moments (mean +/-sd) for three toddlers (1, 5 and 11 months autonomous walkers) and adult slow walking (mean +/-sd; data from Winter, 1980) are plotted. All moments were normalized to body mass and percent of stance. Extensor moments are plotted as positive values and flexor moments plotted as negative values. Note the different scaling on the adult slow graphs.

11 month autonomous walkers and the mean adult slow walking data are relatively consistent, ranging from 0.78 to 0.95 (0.87), 0.63 to 0.98 (0.86), and 0.78 to 0.98 (0.89), respectively. The range and (mean) Pearson product moment correlation coefficients between the net knee moment for the 1, 5, and 11 month autonomous walkers and the mean adult slow walking data tends to increase with development, ranging from -0.35 to 0.36 (0.04), -0.36 to 0.47 (0.18), and 0.1 to 0.84 (0.49), respectively. The range and (mean) Pearson product moment correlation coefficients between the net hip moment for the 1, 5 and 11 month autonomous walkers and the mean adult slow walking data was highly variable, ranging from -0.47 to 0.74 (0.29), -0.03 to 0.85 (0.61), and 0.09 to 0.84 (0.43), respectively.

Moment Powers

Average ankle, knee and hip powers, produced by the moments of force, for three toddlers (one, five and eleven month AW) and adult slow walking are presented in Figure 4. The patterns of power produced by the moments of force at the ankle, knee, and hip approach that of the adult slow walking pattern over the first year of autonomous walking. The data suggest a sequential development beginning with the ankle, followed by the knee and then the hip. This suggested development from distal to proximal is represented by the change in the power graphs (Figure 4) and in the Pearson product moment correlation coefficients for the 1, 5, and 11 month AW. Again this is in contrast to the proximal to distal development expressed by Statham and Murray (1971). The range and (mean) Pearson product moment correlation coefficient between the powers at the ankle, knee and hip for the 1 month autonomous walker and the mean adult slow walking data are: 0.37 to 0.87 (0.49), -0.35 to 0.36 (0.18), and -0.16 to 0.56 (0.25). The range and (mean) Pearson product moment correlation coefficient between the powers at the ankle, knee and hip for the 5 month autonomous walker and the mean adult slow walking data are: 0.57 to 0.93 (0.78), -0.24 to 0.44 (0.19), and 0.05 to 0.75 (0.49). The range and (mean) Pearson product moment correlation coefficient between the powers at the ankle, knee and hip for the 11 month autonomous walker and the mean adult slow walking data are: 0.18 to 0.88 (0.65), -0.016 to 0.55 (0.31), and 0.12 to 0.64 (0.45).

The one month AW showed little power generation or absorption at the hip and knee, but the ankle showed a definite concentric A2 power generation by the ankle plantarflexors in the final 20% of stride approaching toe-off (TO). The power production pattern by the ankle develops slightly as seen in the five and eleven month AW with a smoother A2 peak and an increasingly evident eccentric A1 power burst. Despite the differences between the three toddler and the adult ankle power amplitudes, the pattern of power production that occurred at the ankle at one month of AW remained relatively consistent over the first year of AW.

At one month of AW there was little power generation or absorption occurring at the knee, with increased knee power absorption by the fifth month of AW. Compared to the one month AW, the five month AW shows a marked increase in the K1, K3 and K4 power bursts. The increase in the K1 power burst showed that the five month AW was resisting flexion at the knee at the beginning of the stance by eccentrically activating the extensors. The K3 power burst was quite apparent by the fifth month of AW and was present as a hip and ankle are flexing towards push-off. The K4 power burst that served to decrease the angular velocity of the knee in preparation of foot-strike was also evident by the fifth month of AW. By eleven months of AW the transition between power bursts

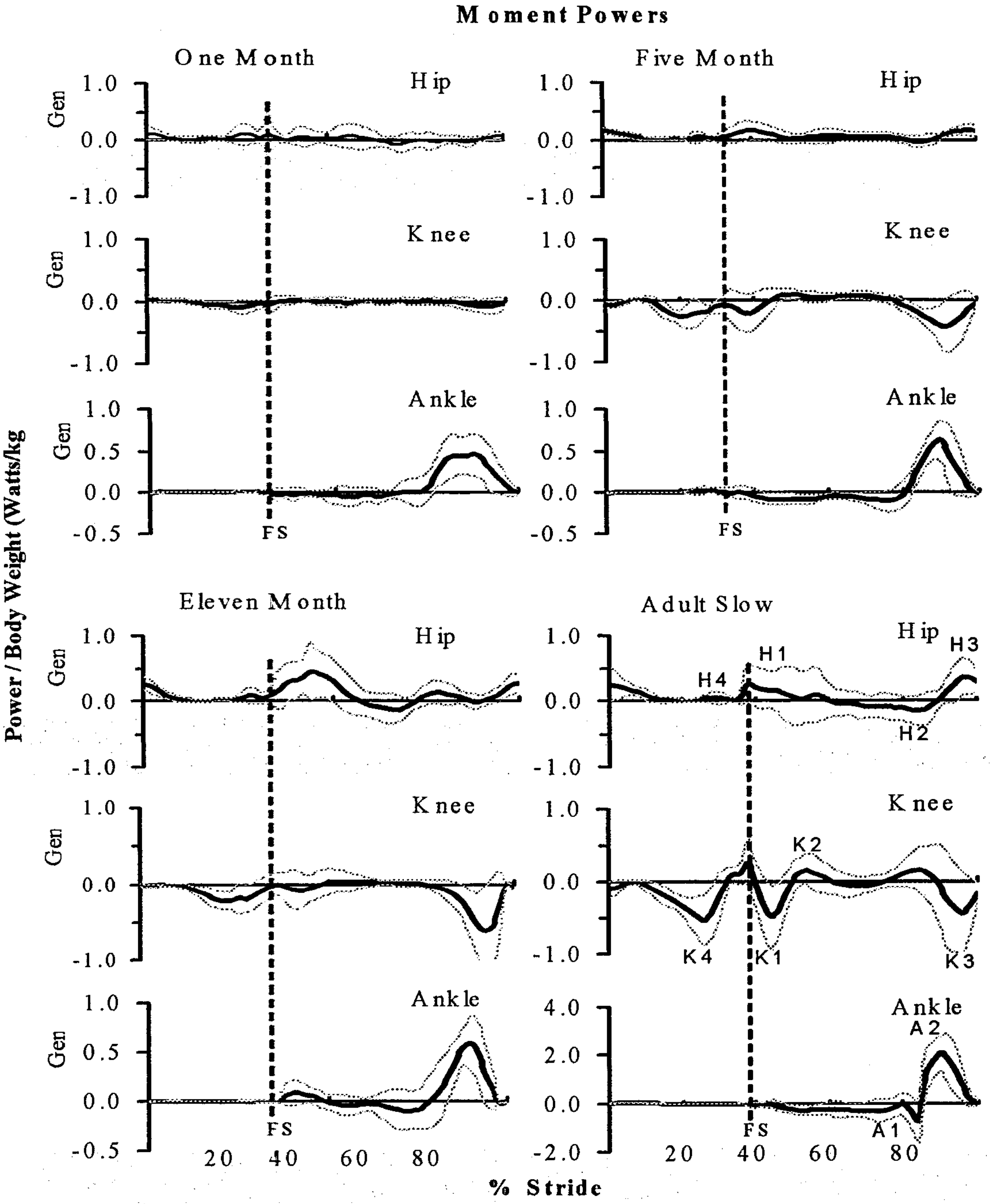


Figure 4. Hip, knee, and ankle moment powers (mean +/-sd) for three toddlers (1, 5 and 11 month autonomous walkers) and adult slow walking (mean +/-sd; data from Winter 1991). All moment powers were normalized to body mass and percent of stride. Note the different scaling of the adult slow ankle moment powers. Positive values represent power generation and negative values represent power absorption.

at the knee were still very similar to that of the five month AW, the K2 power burst was still not present, and all power bursts continued to have smaller amplitudes to those of adults.

The H1 and H3 hip power bursts, at foot-strike and toe-off, respectively, are small but evident by five months of AW with increased amplitudes by eleven months of AW. The H2 and H4 power bursts are not apparent in the fifth month of AW, but the H4 power burst is present in the eleven month AW. These data suggest a development of joint powers in a distal to proximal fashion.

Discussion

The current experiment was an exploratory study conducted 1) to characterize the development of toddler kinetic gait patterns over the first year of AW, and 2) to compare toddler lower limb joint kinetics to that of adults. The discussion will focus on temporal and kinetic gait patterns across toddlers with varying months of AW.

Temporal Patterns

The temporal gait patterns recorded for the toddlers in the current study are comparable to previously reported data. Toddler gait cadences ranged from 40.3 to 97.3 steps/min, spanning the mean of adult slow walking of 84.7 steps/min. Stride length values ranged from 40% to 69% of subject's height, which was slightly lower than the average of 70% published by Beck et al. (1981) for children between one and two years old. The stride time of the toddlers in the current study ranged from 0.58 sec to 1.03 sec. This was similar to Beck et al. (1981) whose subjects' stride times ranged from 0.57 to 1.19s. Statham and Murray (1971) also published percent stance values for toddlers that ranged from 50% to 71% with an average of 62%. These values were similar to those obtained from the toddlers in our study whose percent stance values ranged from 63% to 70% with an average of 63.5%. Bril and Brenière (1991) reported that double support periods for toddlers within the first two years of AW decreased from an average of 38% at onset of autonomous walking to 28% by five months of walking. No such decrease was seen in our data, but we only examined a cross-section of toddlers with different levels of experience over the first year of walking. The double support periods obtained from these toddlers ranged from 32% to 46% and were in accordance with the percent double support average values of 36% obtained by Sutherland et al. (1980) for toddlers between one and two years old. Walking speed of the toddlers in this study ranged from 0.34 m/s in the least experienced walker to 0.81 m/s in the most experienced walker. This range in walking speeds was also observed by Bril and Brenière (1989) who obtained values of 0.2 m/s to 1.1 m/s for toddlers within their first 200 days of AW.

Kinetic Patterns

Current available gait patterns for toddlers within their first year of walking include temporal, kinematic, GRF, and EMG gait data. However, data on toddler support moments, net joint moments, and moment powers over the first year of walking is not available.

Support Moments

It has been hypothesized that at the onset of AW, children actually "walk while falling" (Bril & Brenière, 1988). This hypothesis was based on the examination of the acceleration of toddlers' centers of gravity. The researchers indicated that the center of gravity acceleration for toddlers was always negative at foot-strike, whereas adult's center of gravity acceleration was always positive. Should toddlers actually "walk while falling", then this could also be reflected in a negative support moment during the first part of stance phase. From our analysis, we see that the one and two month AW, show negative support moments occurring within the first 20% of stance. These negative support moments occur in 7/12 trials and 6/11 trials for the one and two month AW, respectively decreasing to 1/10 trials and 2/12 trials for the four and five month AW, respectively. This indicates that by four and five months of AW toddlers are not "walking while falling" as much. By nine and eleven months of AW there were no negative support moments showing that falls utilized to produce forward locomotion were now being anticipated at foot-strike. These results strengthen the hypothesis proposed by Bril and Brenière (1988), who indicated that toddlers actually "walk in falling" while adults "fall in walking". From their data they show that the acceleration of the centre of gravity is negative upon foot-strike for toddlers and then the acceleration increases to a positive value during stance. The support moment data from the one and two month AW show that toddlers at this point are "walking while falling", but the fall is actually controlled because after the first 20% of stance the support moments return to a positive value until time for toe-off. These negative acceleration values have also been shown by Bril and Brenière (1988) to decrease after a few months of AW. This is congruent with our data and supports the hypothesis that by the end of the fourth or fifth month of AW, toddlers exhibit a limited "walk while falling", which then disappears by nine to eleven months of AW. This development in the support moments over the first year of AW leads us to the same conclusion as Bril and Brenière (1988). At one and two months of AW the toddlers are unable to resist collapse of their supporting leg as evidenced by the negative support moment. Winter (1995) and Winter et al. (1990) proposed that the hip has the sole role of dynamic postural control during walking. When looking at the toddler data, the postural stability afforded by hip control, as indicated by Winter (1995) and Winter et al. (1990), that should be present to maintain balance and support during gait progression only begins to appear as toddlers gain experience at AW. The concept of acquiring postural control over the first year of walking has also been shown by (Bril & Brenière,1988; Roncesvalles et al., 2000) and with regards to this data is considered to affect toddler's support moments, net joint moments, and moment powers produced by the lower limb. The resulting data showed development of these kinetic patterns in a distal to proximal fashion with increasing AW experience, thus lending to the idea that as toddlers gain experience walking they are able to acquire greater balance control at the hip thereby limiting postural instability and further developing propulsion strategies at the knee and hip while walking. The distal to proximal development in these kinetic data only became apparent upon graphical representation, which lead to the discussion of Bernstein's (1967) theory in the following sections.

Net Joint Moments

Net joint moments at the hip, knee, and ankle were compared to adult slow walking net joint moments obtained by Winter (1991). The graphs show that the amplitudes of all the moments created by these toddlers are approximately half those of adults and have maximum values that are significantly different. The net joint moments also show a pattern of development over the first year of walking that occurs in a distal to proximal fashion. As seen in figure 3, the one month AW toddler has a similar flexor and extensor ankle moment shaped curve to that of an adult. This net ankle moment pattern remains similar over the first year of walking, but the amplitudes of these moment curves are substantially smaller. Despite the similar shape in ankle moments displayed by these toddlers, the one month AW has minimal net moments at the knee and hip. The five month AW begins to produce a greater net moments at the knee and hip. By eleven months the net knee moment begins to develop into a more adult-like extensor-flexor-extensor pattern, but continues to have an inconsistent flexor moment that spans less of the stance phase than adults. The net hip moment pattern did not change between five and eleven months of AW and remained least developed over this first year of autonomous walking with a net extensor joint moment for over 75% of the stance period.

The increase in net knee and hip moments over the first year of AW could be due to a number of reasons. Forssberg (1985) reported that the muscles controlling the knee and hip of newly AW toddlers showed a great deal of co-activation during the gait cycle indicating that the toddlers were using both agonistic and antagonistic muscles to control the walking movement. By using both sets of muscles, this suggests that toddlers are attempting to deal with increased postural requirements of locomotion along with increased complexity of the skill. In turn, both agonistic and antagonistic muscles that cross the hip and knee joint at an early stage of AW are being involved in postural requirements and not locomotion which could be the cause of the diminished amount of moments at these joints and in turn the increases in these moments over the first year of AW.

It has also been reported (Roncesvelles et al., 2000) that toddlers with less than three months of AW show less postural stability and a lack of an adequate stepping response to perturbations, but toddlers greater than three months show an effective stepping response. Brenière and Bril (1998) also suggested that toddlers between three and six months of AW are first learning to control their balance and from then on progressively refine their walking patterns. Our observations indicate that there is minimal net joint moment produced at the knee and hip joint in the one month AW, which would result in limited contribution of these joints to propulsion, which is reflected in the lack of postural control. Therefore, as toddlers acquire greater control over their net joint moments and achieve greater limb strength due to general development, this would result in better postural control and regulation. Because it has been reported that postural response and control increases over the first year of walking, this would explain why the knee and hip net joint moments become more developed by five months of AW and the knee continues to develop by eleven months. The acquisition of greater postural stability and strength allows the toddler to now attempt different methods of propulsion.

The increased development of the knee and hip moments by five months and subsequent knee development by eleven months are also quite variable. This variability is anticipated, as toddlers try different methods of net joint moment production in order to refine further this skill. According to Bernstein (1967) walking development would follow a specific path to maturity where the toddler would initially reduce the degrees of freedom by coupling the segments together to decrease the complexity of the movement, then would release the degrees of freedom and explore different movement options, leading to a mature pattern. Thus, it can be argued that through the constraint of the hip and knee moments, toddlers are reducing their degrees of freedom at the onset of AW and are slowly releasing them over the first year of walking to explore different movement patterns. This exploration is seen in the increased inclusion of the hip and knee moments over the first year of AW, but even by the end of the fist year of AW net joint moments have not matured completely.

Joint Powers

The net joint moments and moment powers data suggest development in a similar distal to proximal fashion over the first year of walking. The main difference between the toddler ankle power patterns and that of adults is the amplitudes of the powers produced. Again the knee and the hip at one month of AW show a very minimal power production, which again could be attributed to the co-contraction of the hip and knee muscles as indicated by Forssberg (1985), or due to the lack of postural control as proposed by Bril and Brenière (1992) and Brenière and Bril (1998), but it is more likely that the decrease in power production is due to the diminished net joint moments at the hip and knee of newly AW toddlers. These diminished net joint moments and moment powers are more likely to be cause of the lack of postural control than vice versa. Like the net joint moments, the joint powers of the five month AW begin to exhibit adult-like K1 to K4 knee power patterns with a much diminished K2 and an extremely slight H1 and H3 power burst at the hip during foot contact and toe-off. The major difference between the eleven and the five month AW is that the hip begins to create adult-like amplitudes of the H1 to H3 power bursts. These data suggest the toddlers are able to create more adult-like methods of propulsion by the eleventh month of AW, which is paralleled with increased postural control being reported by other researchers (Brenière & Bril, 1998; Bril & Brenière, 1992; Roncesvelles et al., 2000). The toddler power production patterns even at the eleventh month of AW are still quite variable, indicating that these toddlers are continuing to refine their movement. By being present, the H1 power burst shows that toddlers by the fifth month of AW are starting to maintain trunk stability (Winter, 1991). The presence of the H3 power burst demonstrates that toddlers are lifting their leg while trying to initiate swing phase (Ounpuu, 1994). There is an increase in the H1 and H3 power burst amplitudes between 5 and 11 months of AW, which shows that the toddlers develop a greater ability to produce power at the hip within this time. This indicates that these toddlers are testing different methods of propulsion and further attempting to refine their gait patterns.

The transitions in both the net joint moments and joint powers to develop in a distal to proximal fashion as indicated by our data is somewhat contradictory to evidence reported on the development of the cerebral cortex, cerebellum, and corticospinal tract. These regions of the brain and spinal cord are known to be least developed with regards to control of the lower limbs of this age and affect the distal joints more than the proximal ones. It has been reported using kinematic walking patterns of toddlers, namely ranges of motion and flexion/extension patterns, that there is a "lack of refinement" in their lower extremity that is more pronounced distally than proximally, which in turn suggests a proximal to distal joint development (Statham & Murray, 1971). Despite these contradictions, kinematic patterns can not tell what propulsive strategies are being used or how these kinetic patterns develop over the first year of walking. We hypothesize that the development from distal to proximal of the net joint moments and moment powers occurs as the toddler gets stronger and attains better control over their ability to produce larger amounts of propulsion at the knee and hip. Toddlers increased propulsive control at the hip and knee in turn results in better postural regulation and can be explained using Bernstein's (1967) work.

Bernstein's (1967) work suggests that these toddlers have a degrees of freedom problem where they have a great deal of extraneous variables that they must control to produce locomotion. Therefore, toddlers limit the amount of extraneous variables by limiting the amount of propulsion produced by hip and knee, which in turn causes minimal net joint moments and moment powers at the beginning of AW. If Bernstein's theory is correct for all skills, including walking, then we should first observe toddlers reducing the number of degrees of freedom available by tightly linking their segments and making their hip and knee a little stiffer. Subsequently, these toddlers would then release these degrees of freedom and begin to practice different methods of gait pattern production. This is seen in the development of a more adult-like net knee moment and knee power by the fifth month of AW and increased net hip moment and powers by the eleventh month of AW. As part of the last stage indicated by Bernstein, these toddlers would begin to select the most proficient movement pattern. The selection stage for these toddlers was not quite finished as indicated by our data which shows the large amount of variation in their net joint moment and joint power curves by eleven months of AW. Other researchers support this idea by indicating that gait patterns do not develop into a stable adult pattern until about five years of age (Beck et al., 1981; Ounpuu et al., 1991; Sutherland et al., 1980). According to these data, these toddlers are developing adult-like kinetic gait patterns in a distal to proximal fashion.

Summary

Toddlers, over the first year of walking, exhibit a negative support moment within the first few months of AW, which is decreased by four to five months of AW, and subsequently disappears by nine months of AW. Toddler net joint moments and moment powers at the hip, knee, and ankle display a developmental progression from distal to proximal.

Acknowledgments

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PART THREE: CONCLUSIONS AND RECOMMENDATIONS

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

This study examined the support moment, net joint moments, and the moment powers of the lower extremity for toddlers over the first year of walking. The data suggest that there is development of increasingly mature patterns in the net joint moments and the moment powers occurring in a distal to proximal fashion. Future research needs to be conducted in this area to confirm these findings. Specifically, a study including more toddlers at each level of AW as well as an extended developmental period would allow for a more in depth look at all the stages of walking development.

PART FOUR: CONTRIBUTION OF COLLABORATORS

CHAPTER VI

STATEMENT OF CONTRIBUTION OF COLLABORATORS

The research for this thesis and article was performed by Stefan Potoczny under guidance and supervision of both Dr. Heidi Sveistrup and Dr. D. Gordon E. Robertson. The research question and hypothesis formation were selected by Stefan Potoczny. The data collection and processing were done by Stefan Potoczny. The data was analyzed collectively by Stefan Potoczny, Dr. Heidi Sveistrup and Dr. D. Gordon E. Robertson. Finally, this thesis and corresponding article were also written by Stefan Potoczny, but the content of both were edited by both Dr. Heidi Sveistrup and Dr. D. Gordon E. Robertson.

PART FIVE: REFERENCES AND APPENDICES

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Appendix A

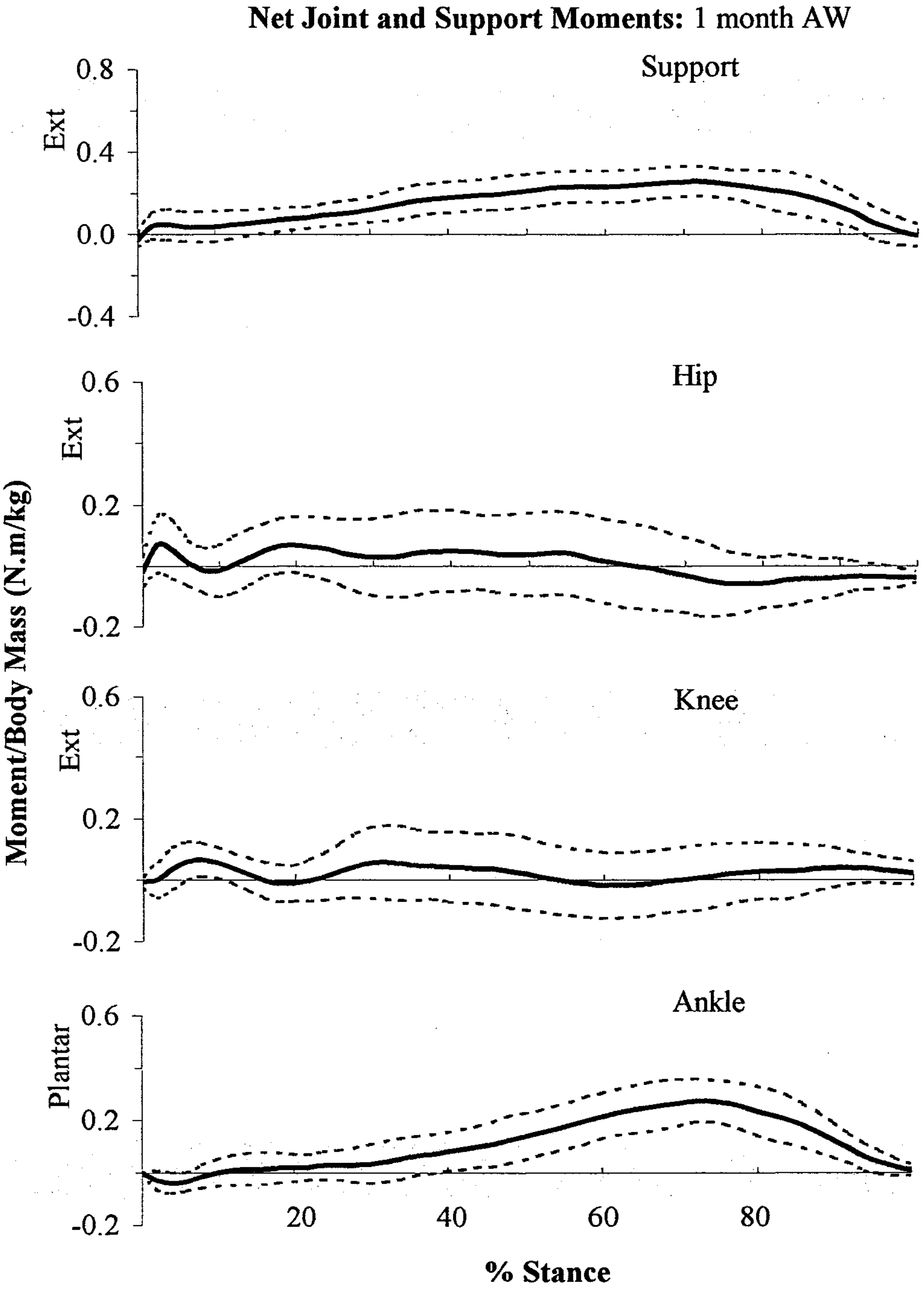


Figure 3a. Mean (+/- sd) support, hip, knee, and ankle net joint moments for subject 10. All moments are normalized to percent of stance and body mass. The range (mean) of the Pearson product moment correlation coefficients between the hip, knee, and ankle net joint moments and comparative adult data are: -0.47 to 0.74 (0.29), -0.35 to 0.36 (0.04) and 0.78 to 0.95 (0.87) respectively.

Net Joint and Support Moments: 2 month AW

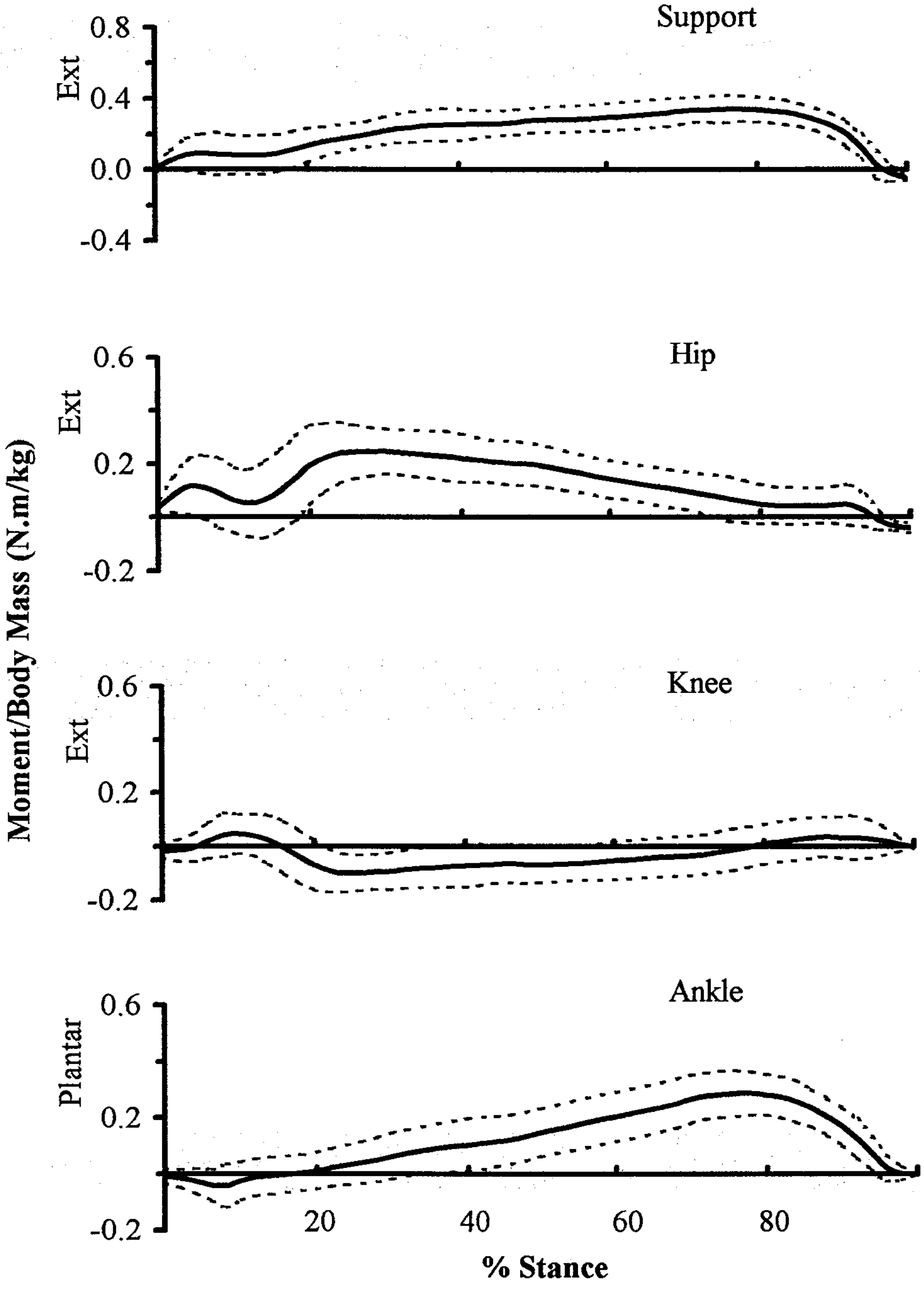


Figure 3b. Mean (+/- sd) support, hip, knee, and ankle net joint moments for subject 2. All moments are normalized to percent of stance and body mass. The range (mean) of the Pearson product moment correlation coefficients between the hip, knee, and ankle net joint moments and comparative adult data are: -0.01 to 0.68 (0.28), -0.42 to 0.29 (-0.16) and 0.70 to 0.98 (0.85) respectively.

Net Joint and Support Moments: 3 month AW

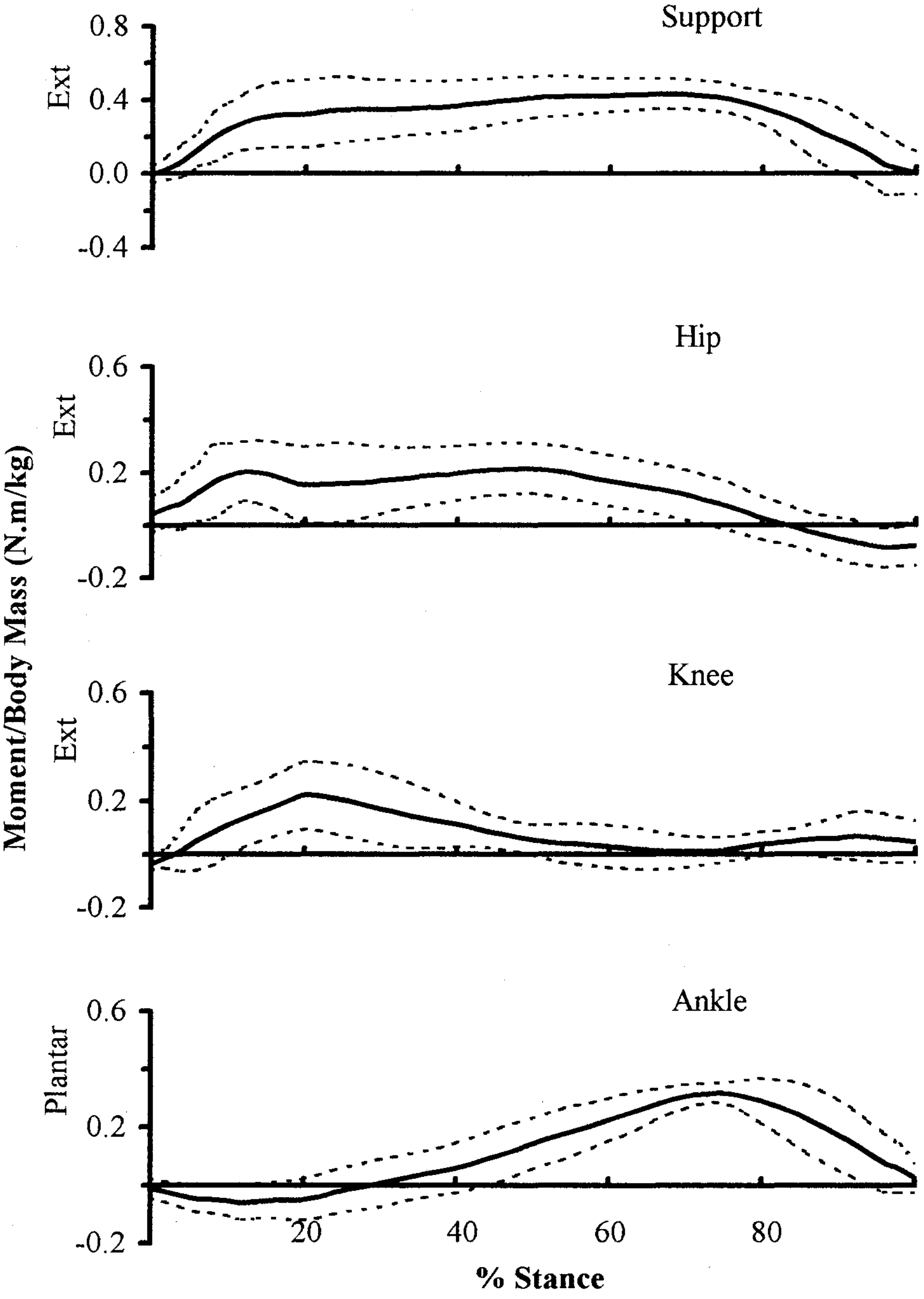


Figure 3c. Mean (+/- sd) support, hip, knee, and ankle net joint moments for subject 4. All moments are normalized to percent of stance and body mass.

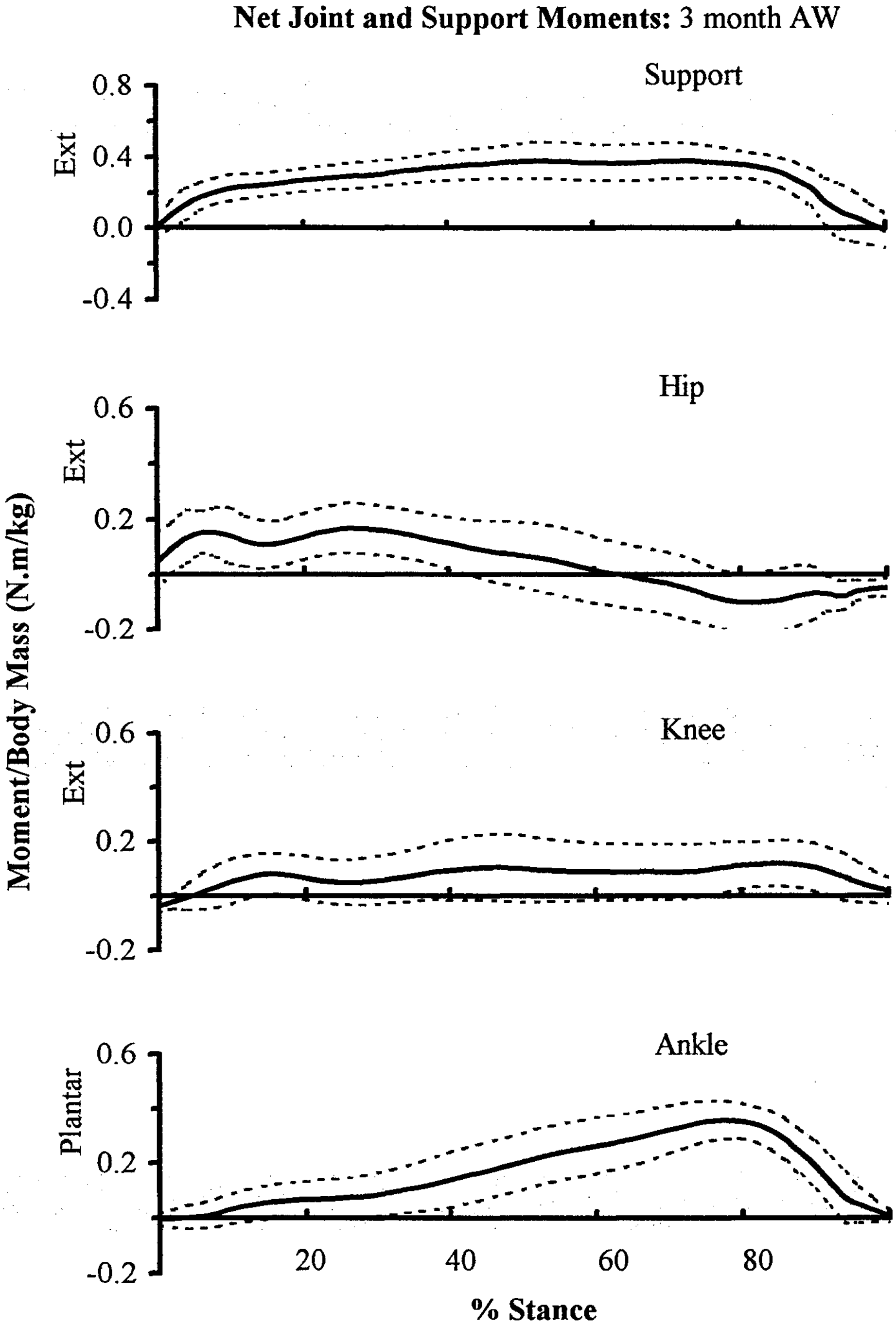


Figure 3d. Mean (+/- sd) support, hip, knee, and ankle net joint moments for subject 8. All moments are normalized to percent of stance and body mass. The range (mean) of the Pearson product moment correlation coefficients between the hip, knee, and ankle net joint moments and comparative adult data are: -0.60 to -0.09 (-0.31), -0.77 to 0.24 (-0.44) and 0.80 to 0.97 (0.90) respectively.

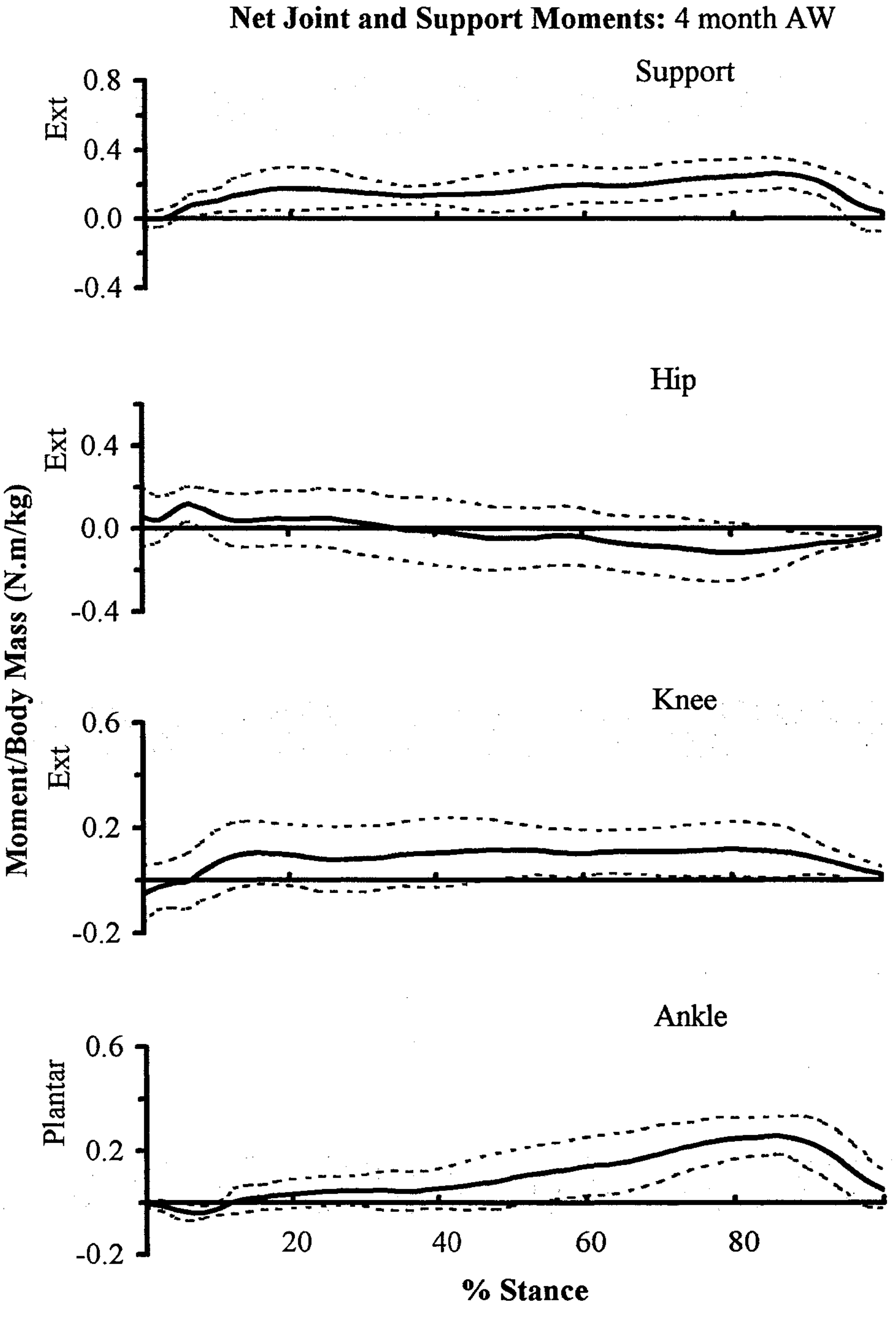


Figure 3e. Mean (+/- sd) support, hip, knee, and ankle net joint moments for subject 6. All moments are normalized to percent of stance and body mass. The range (mean) of the Pearson product moment correlation coefficients between the hip, knee, and ankle net joint moments and comparative adult data are: 0.15 to 0.86 (0.53), -0.32 to 0.50 (0.08) and 0.60 to 0.97 (0.79) respectively.

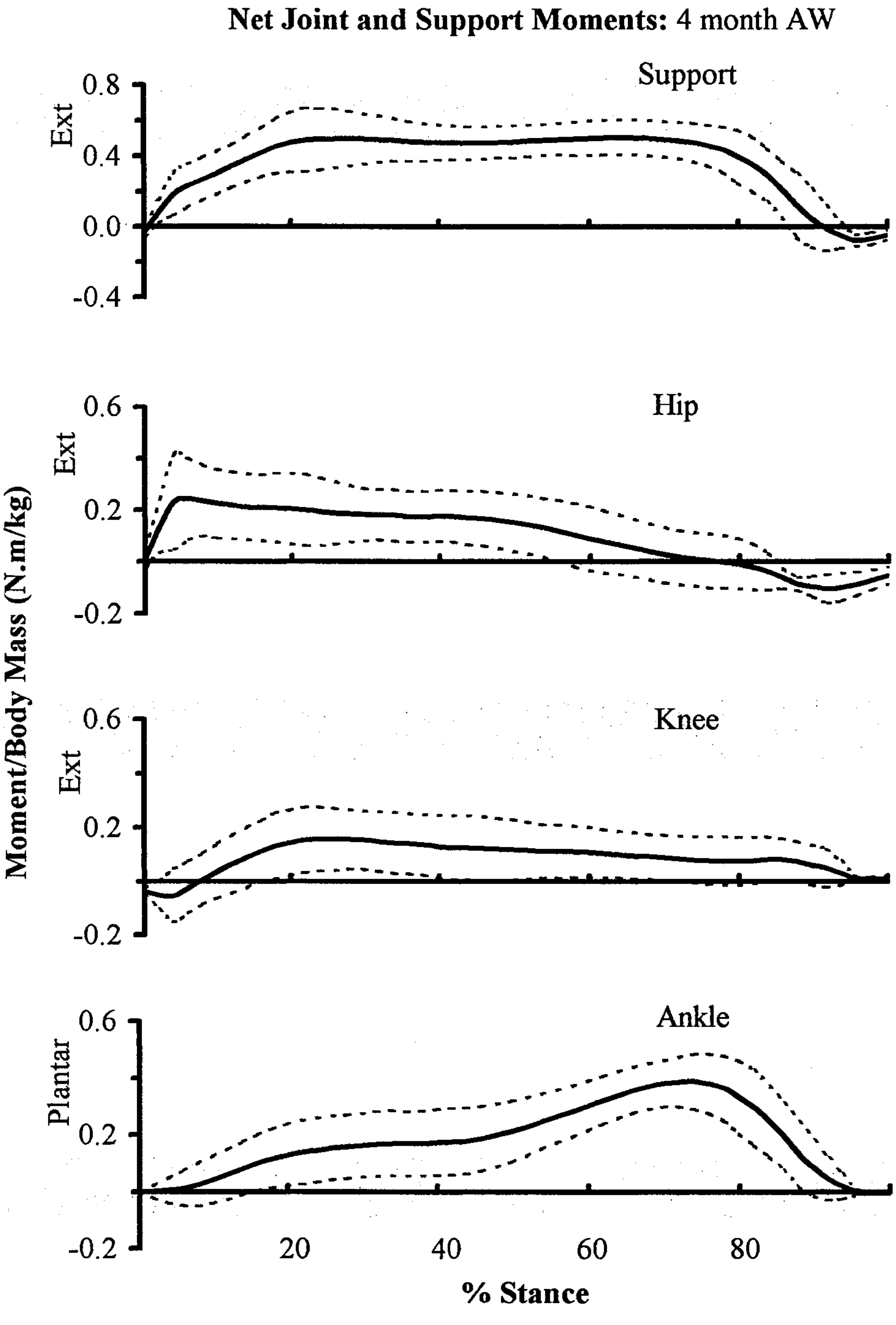


Figure 3f. Mean (+/- sd) support, hip, knee, and ankle net joint moments for subject 12. All moments are normalized to percent of stance and body mass. The range (mean) of the Pearson product moment correlation coefficients between the hip, knee, and ankle net joint moments and comparative adult data are: 0.38 to 0.82 (0.65), -0.19 to 0.69 (0.30) and 0.38 to 0.96 (0.79) respectively.

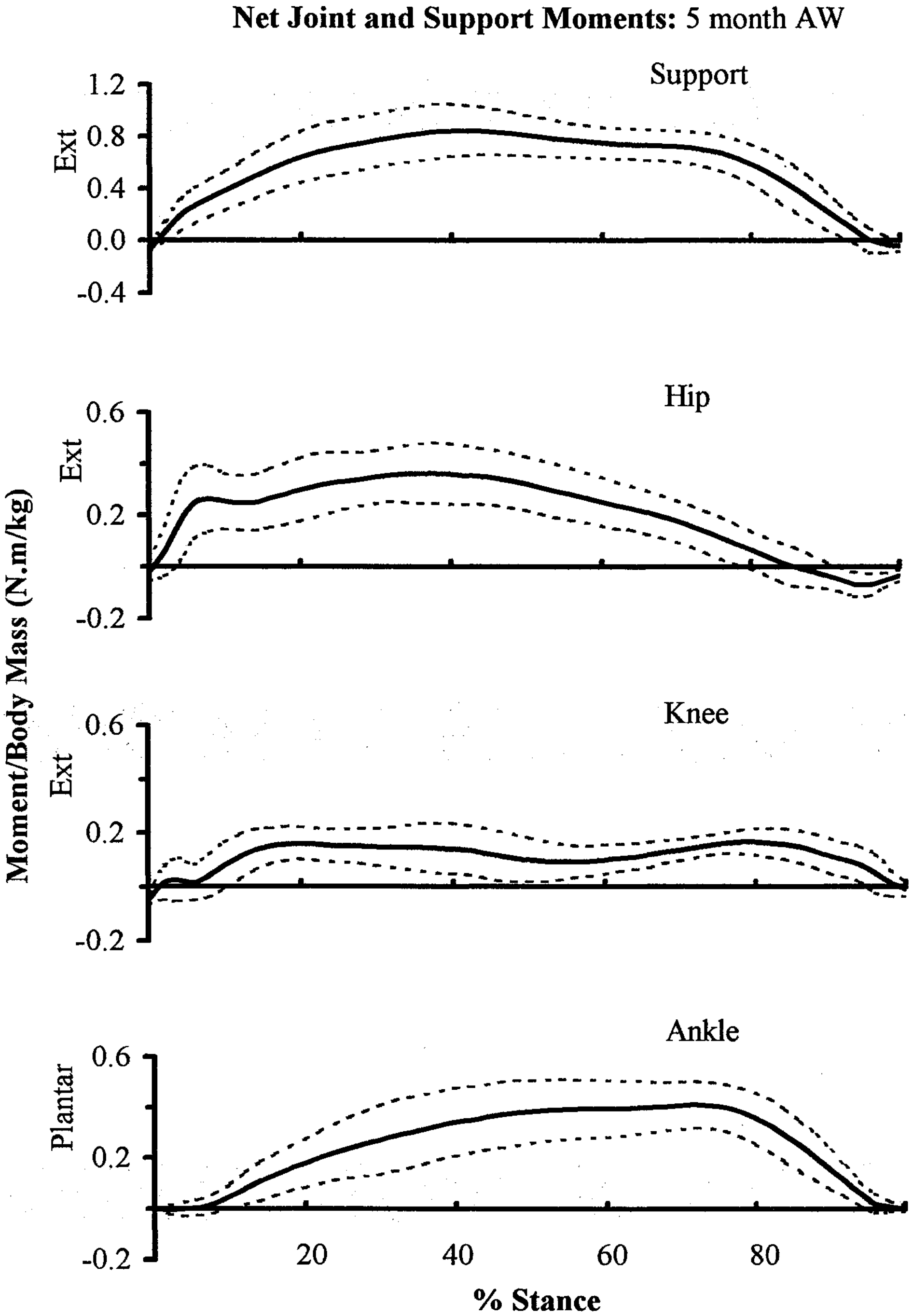
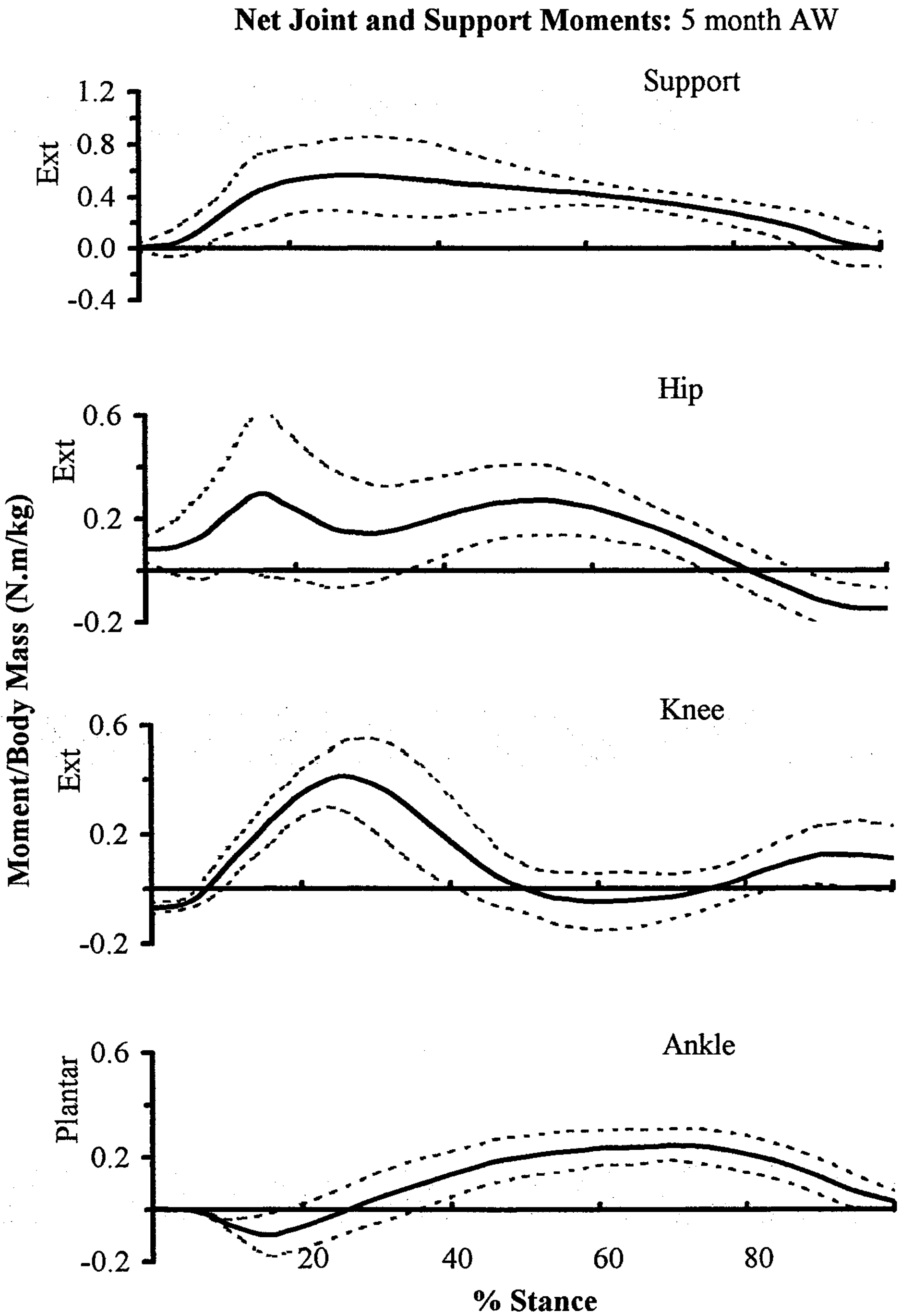


Figure 3g. Mean (+/- sd) support, hip, knee, and ankle net joint moments for subject 13. All moments are normalized to percent of stance and body mass. The range (mean) of the Pearson product moment correlation coefficients between the hip, knee, and ankle net joint moments and comparative adult data are: 0.08 to 0.81 (0.42), -0.11 to 0.45 (0.16) and 0.56 to 0.98 (0.82) respectively. Note the different scaling on the support moment y-axis.


Net Joint and Support Moments: 5 month AW

Support

Hip

Knee

Ankle

Figure 3h. Mean (+/- sd) support, hip, knee, and ankle net joint moments for subject 7. All moments are normalized to percent of stance and body mass. The range (mean) of the Pearson product moment correlation coefficients between the hip, knee, and ankle net joint moments and comparative adult data are: 0.28 to 0.56 (0.37), 0.08 to 0.93 (0.62) and 0.62 to 0.98 (0.87) respectively. Note: 1) The different scaling on the support moment y-axis.

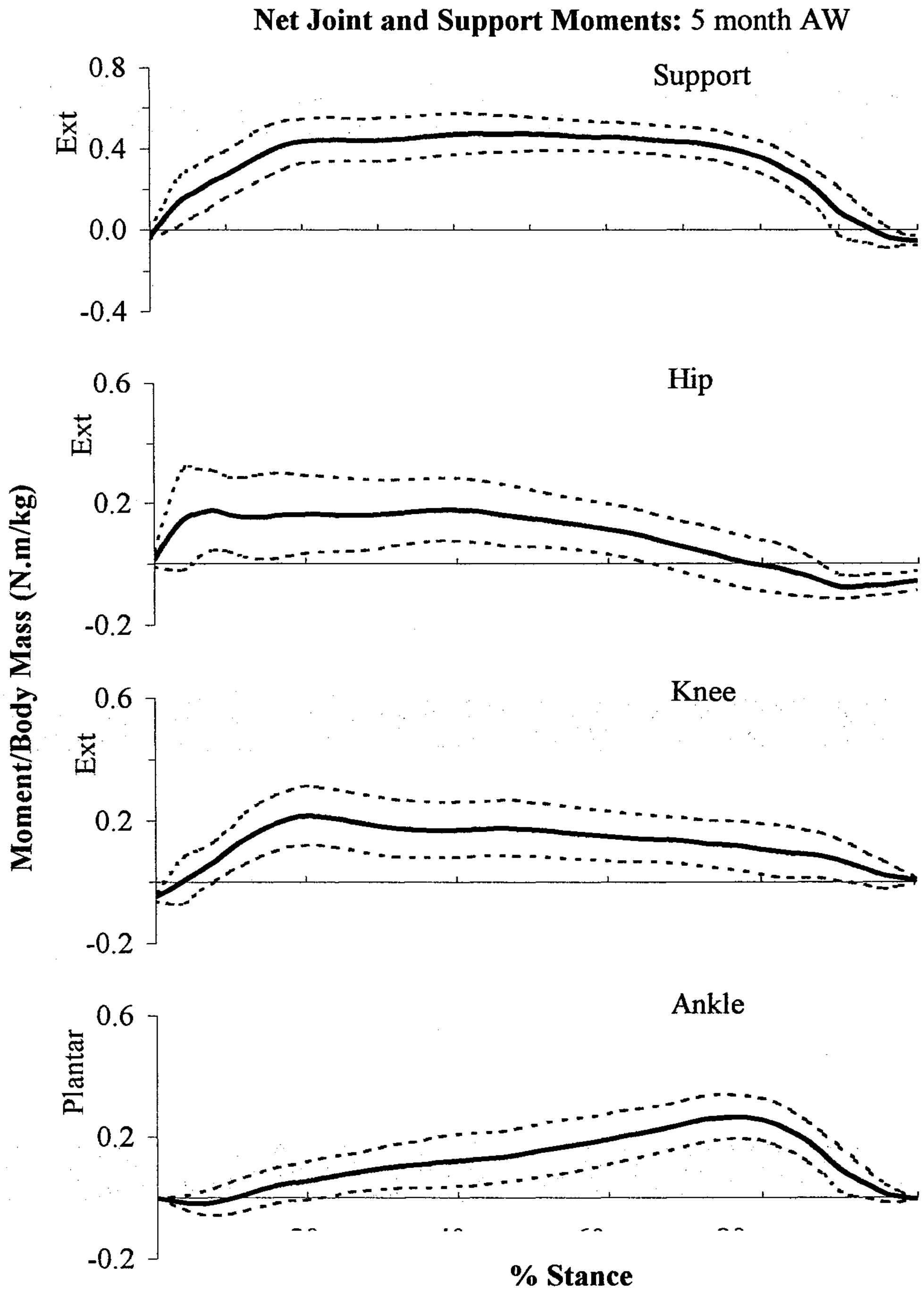


Figure 3i. Mean (+/- sd) support, hip, knee, and ankle net joint moments for subject 11. All moments are normalized to percent of stance and body mass. The range (mean) of the Pearson product moment correlation coefficients between the hip, knee, and ankle net joint moments and comparative adult data are: -0.04 to 0.85 (0.61), -0.36 to 0.47 (0.18) and 0.63 to 0.99 (0.86) respectively.

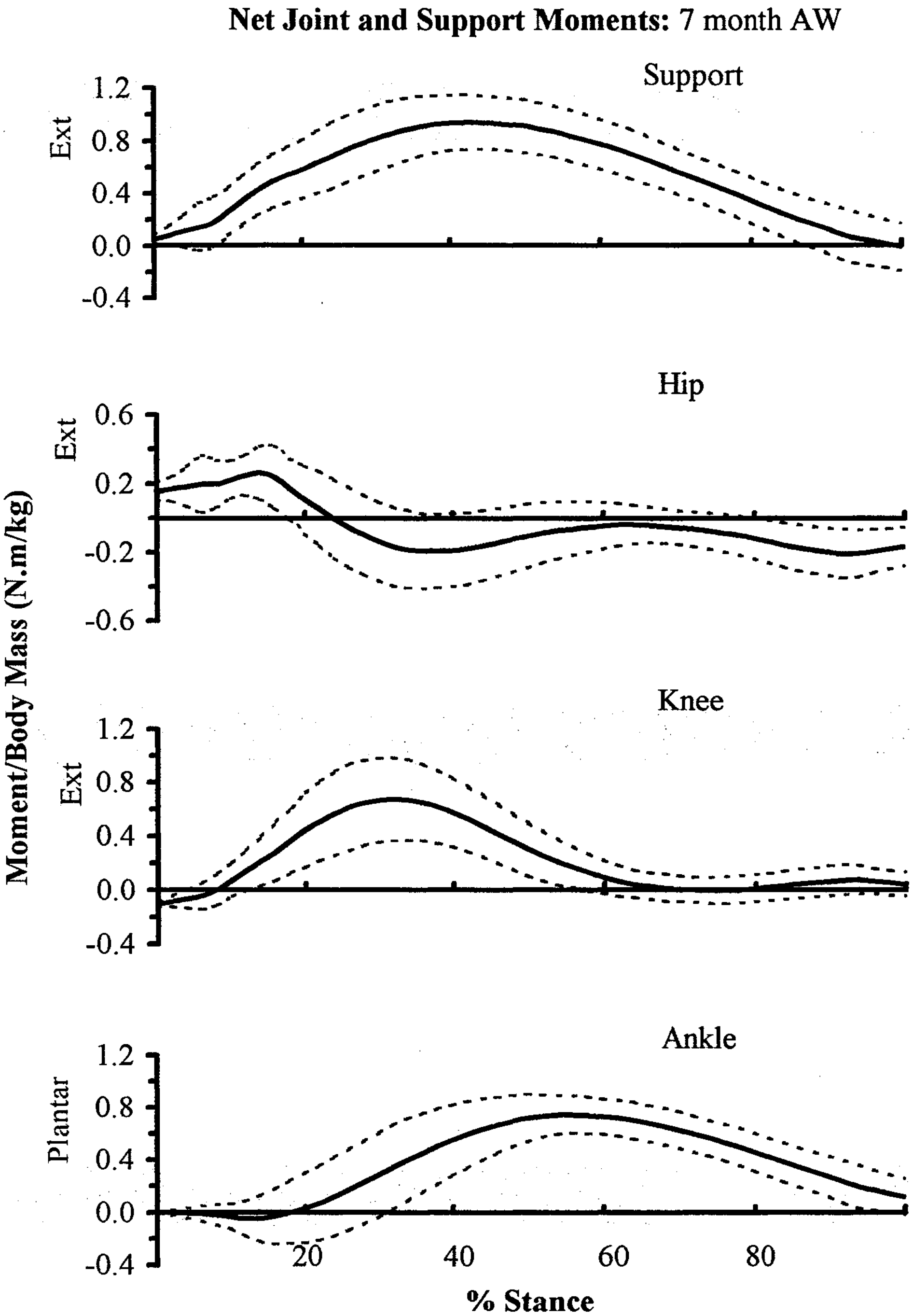


Figure 3j. Mean (+/- sd) support, hip, knee, and ankle net joint moments for subject 3. All moments are normalized to percent of stance and body mass. The range (mean) of the Pearson product moment correlation coefficients between the hip, knee, and ankle net joint moments and comparative adult data are: -0.09 to 0.86 (0.54), -0.28 to 0.273 (0.11) and 0.56 to 0.92 (0.78) respectively. Note: Subject 3's trials were all running trials

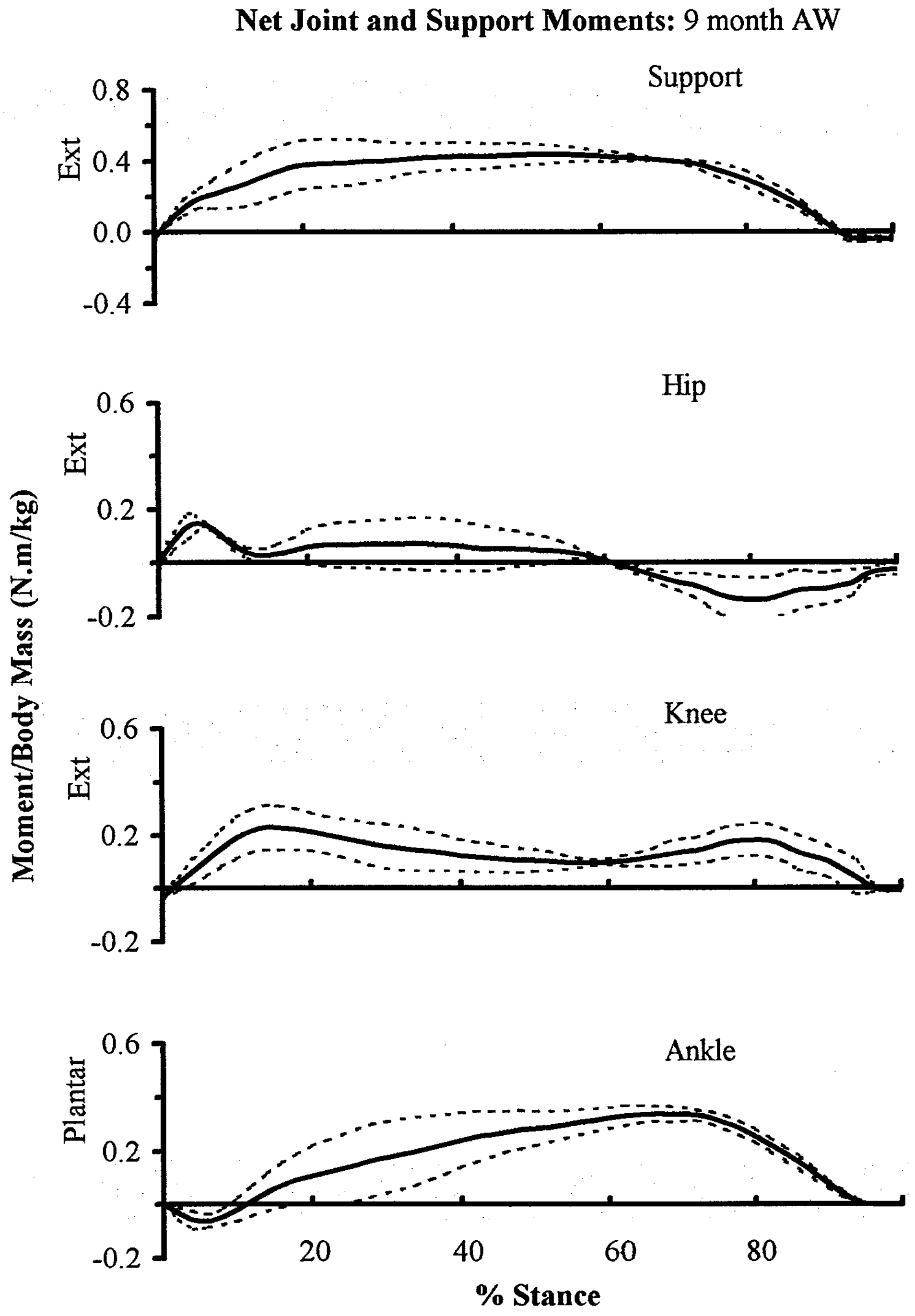


Figure 3k. Mean (+/- sd) support, hip, knee, and ankle net joint moments for subject 9. All moments are normalized to percent of stance and body mass. The range (mean) of the Pearson product moment correlation coefficients between the hip, knee, and ankle net joint moments and comparative adult data are: 0.58 to 0.81 (0.71), -0.25 to 0.48 (0.26) and 0.77 to 0.93 (0.86) respectively. Note these trials are all toe walking trials.

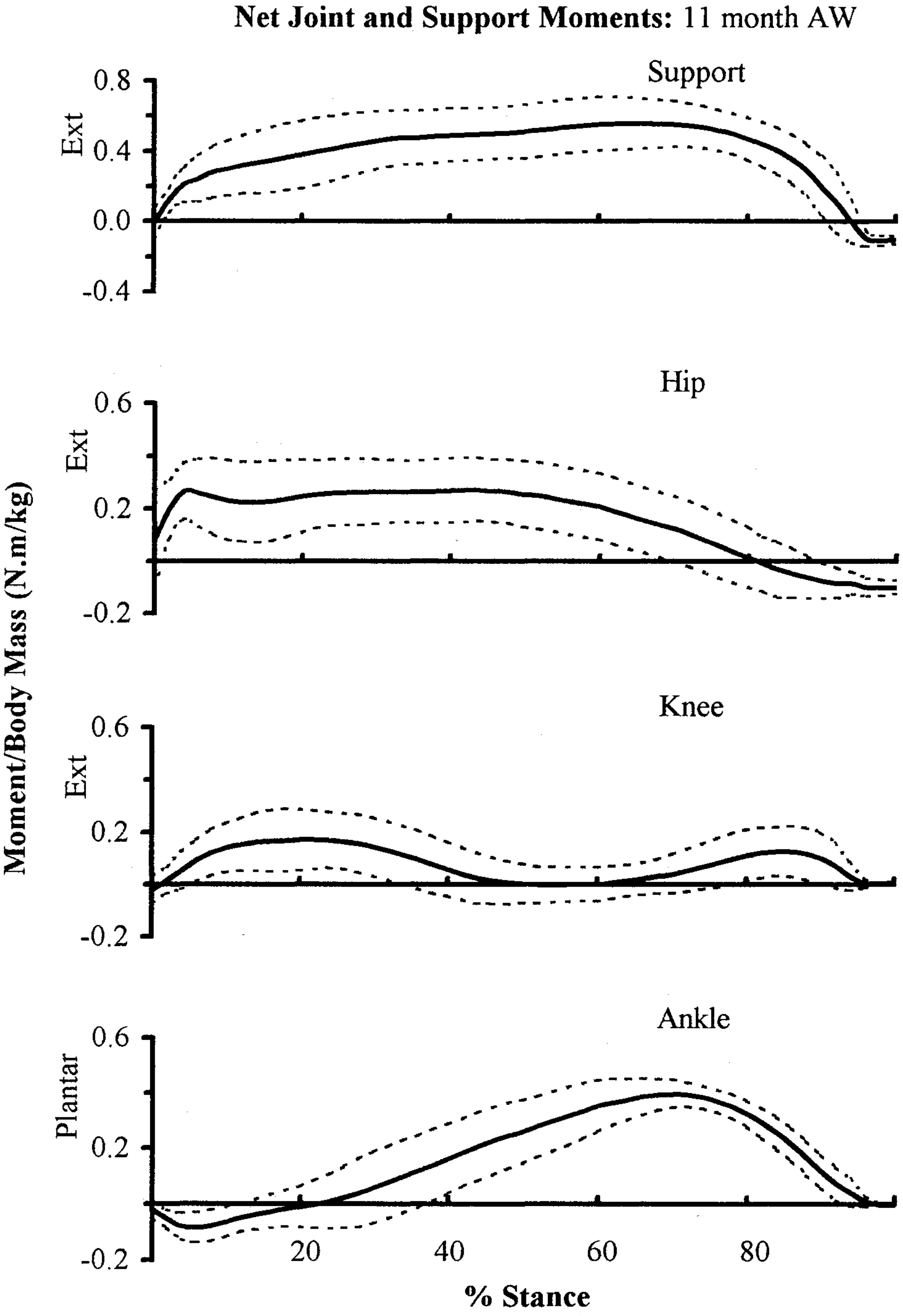


Figure 3l. Mean (+/- sd) support, hip, knee, and ankle net joint moments for subject 14. All moments are normalized to percent of stance and body mass. The range (mean) of the Pearson product moment correlation coefficients between the hip, knee, and ankle net joint moments and comparative adult data are: 0.09 to 0.84 (0.43), 0.11 to 0.84 (0.50) and 0.79 to 0.98 (0.89) respectively.

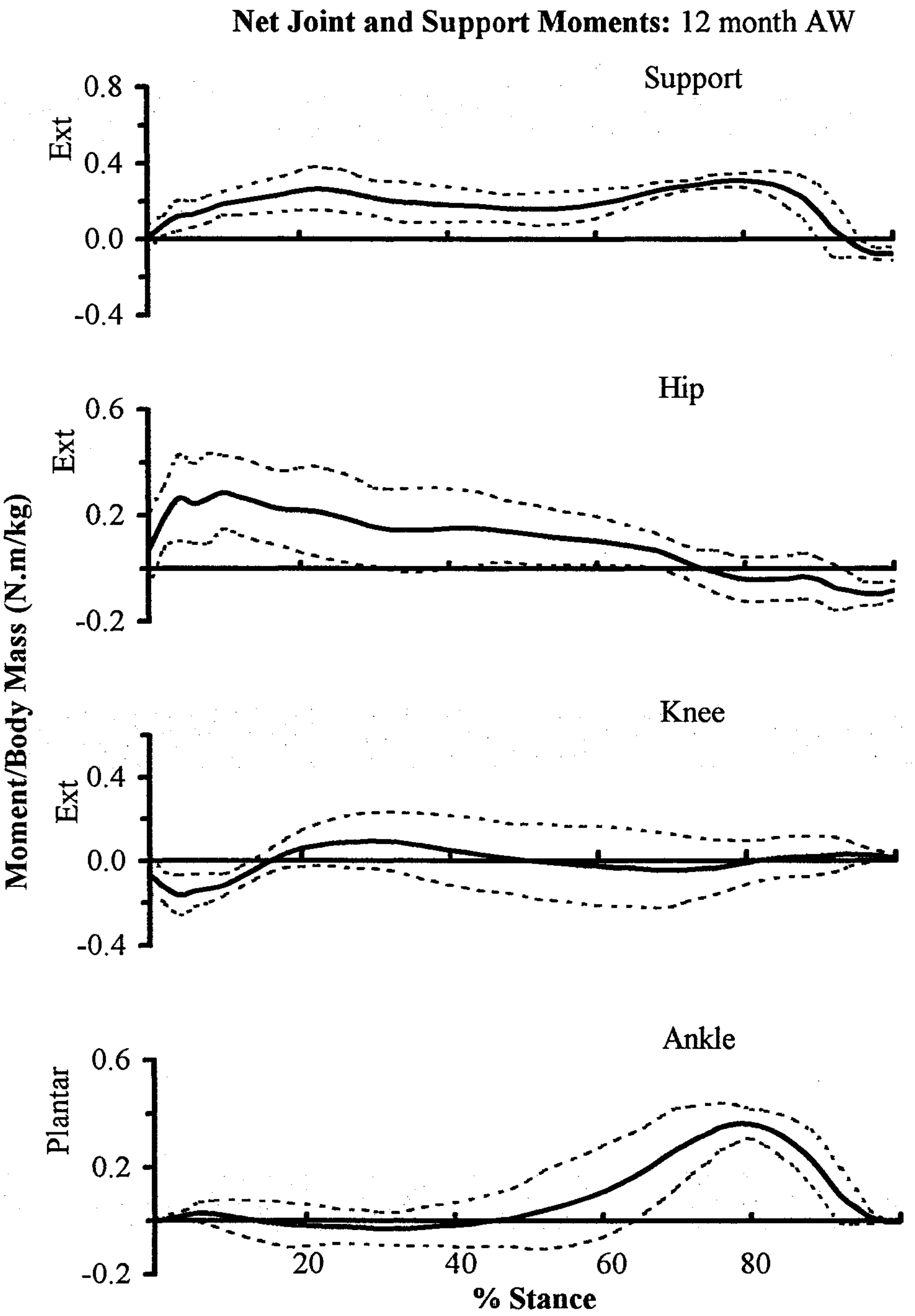


Figure 3m. Mean (+/- sd) support, hip, knee, and ankle net joint moments for subject 5. All moments are normalized to percent of stance and body mass. The range (mean) of the Pearson product moment correlation coefficients between the hip, knee, and ankle net joint moments and comparative adult data are: -0.31 to 0.12 (-0.14), -0.27 to 0.45 (-0.09) and 0.65 to 0.86 (0.74) respectively. Note the different scaling on the knee moment y-axis.

Appendix B

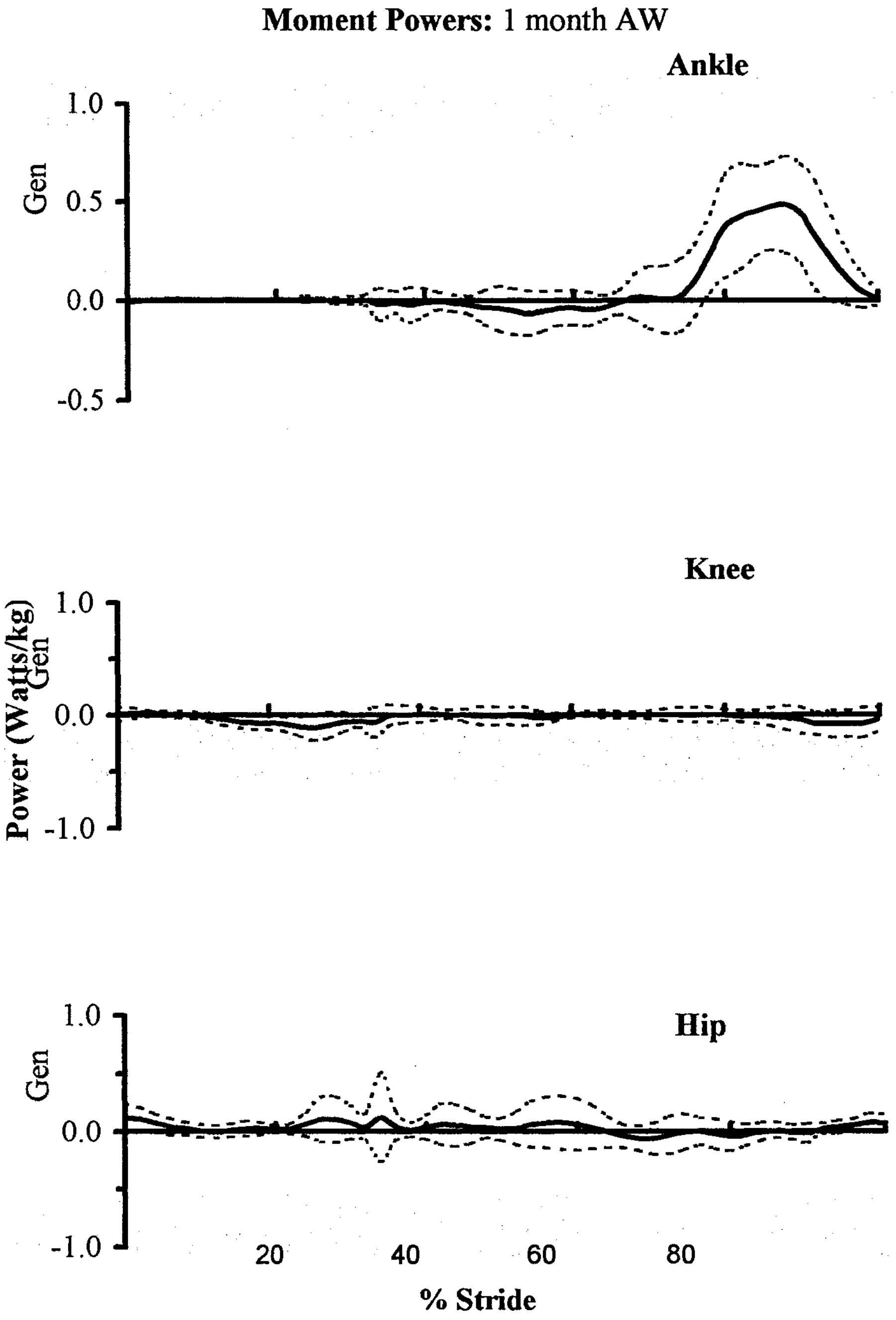
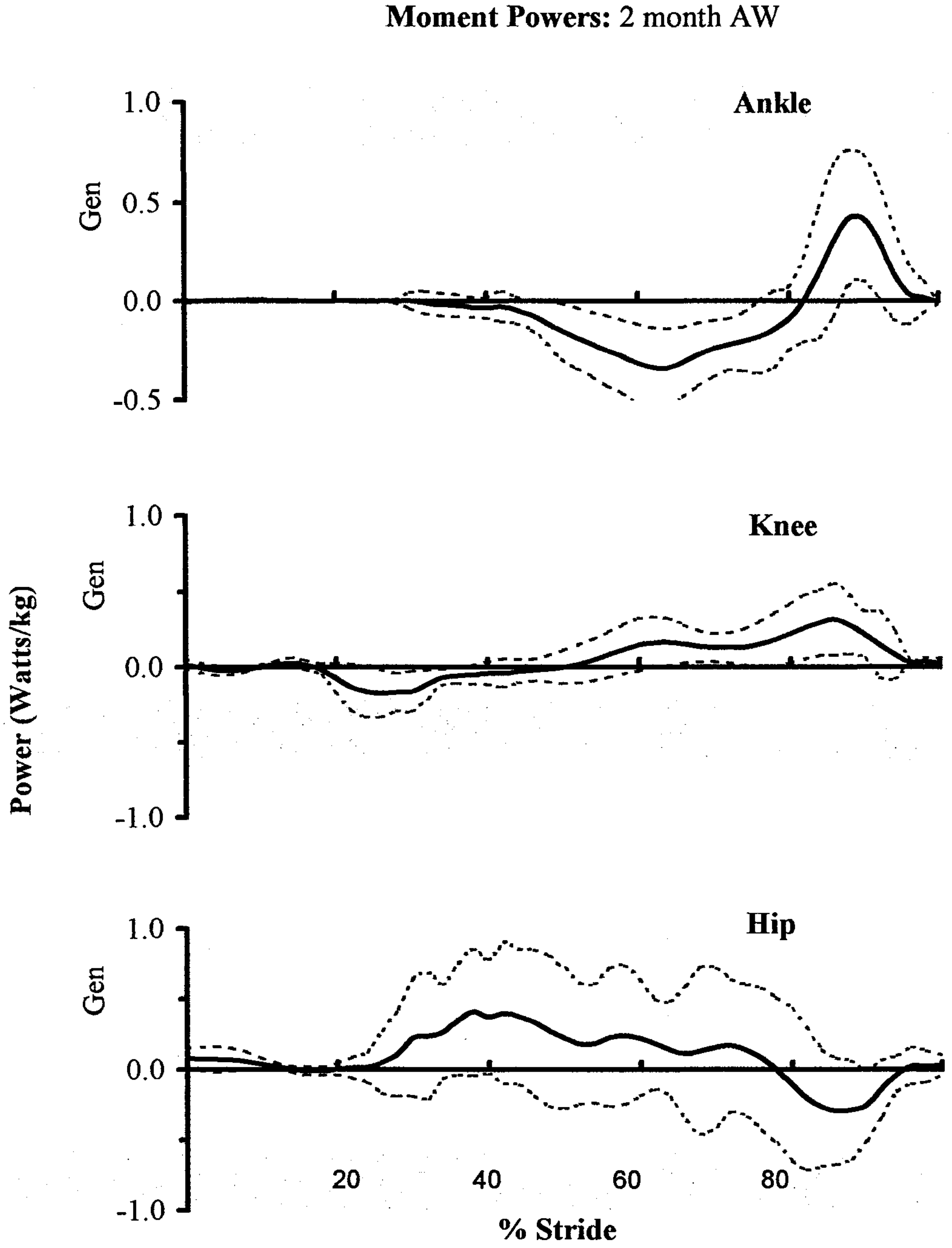


Figure 4a. Mean (+/- sd) hip, knee, and ankle moment powers for subject 10. All powers are normalized to percent of stride and body mass. The range (averages) of the Pearson product moment correlation coefficients between the hip, knee, and ankle powers and comparative adult data are: -0.16 to 0.56 (0.25), -0.35 to 0.36 (0.37) and 0.37 to 0.86 (0.49) respectively.



Moment Powers: 2 month AW

Figure 4b. Mean (+/- sd) hip, knee, and ankle moment powers for subject 2. All powers are normalized to percent of stride and body mass. The range (averages) of the Pearson product moment correlation coefficients between the hip, knee, and ankle powers and comparative adult data are: -0.44 to 0.53 (0.10), 0.11 to 0.58 (0.38) and 0.35 to 0.89 (0.61) respectively.

Moment Powers: 3 month AW

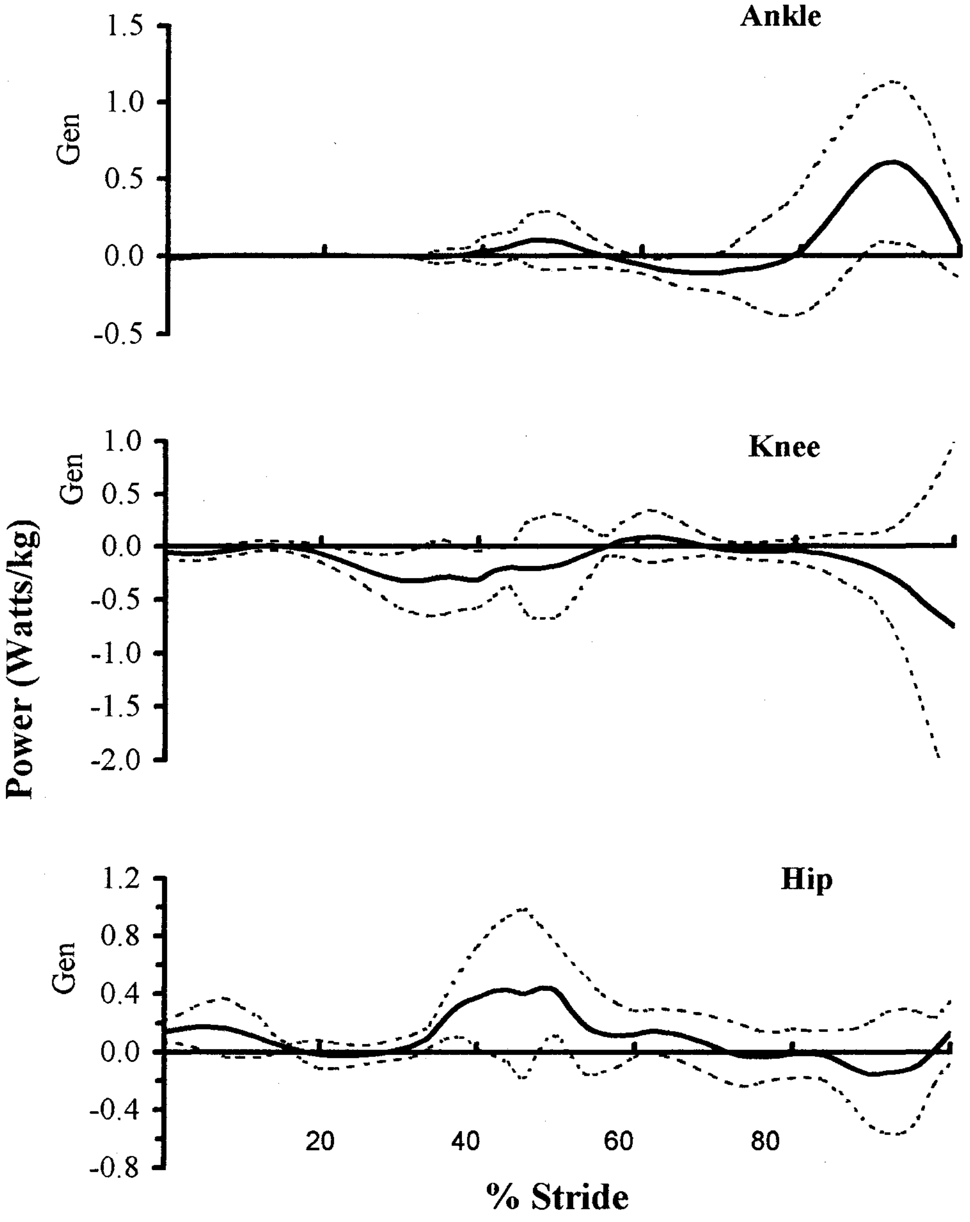


Figure 4c. Mean (+/- sd) hip, knee, and ankle moment powers for subject 4. All powers are normalized to percent of stride and body mass.

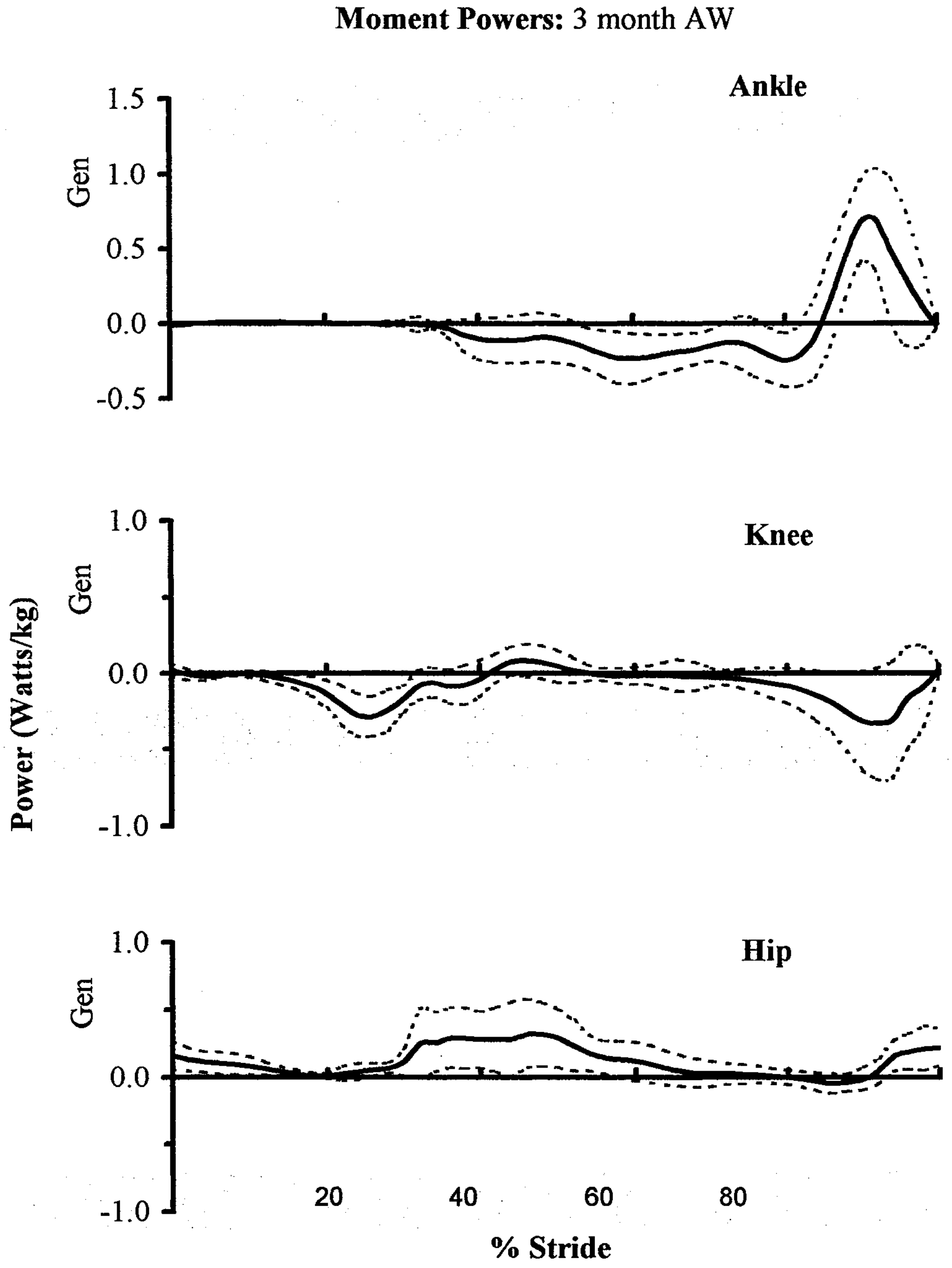


Figure 4d. Mean (+/- sd) hip, knee, and ankle moment powers for subject 8. All powers are normalized to percent of stride and body mass. The range (averages) of the Pearson product moment correlation coefficients between the hip, knee, and ankle powers and comparative adult data are: -0.04 to 0.82 (0.47), -0.05 to 0.54 (0.21) and 0.42 to 0.90 (0.76) respectively.

Moment Powers: 4 month AW

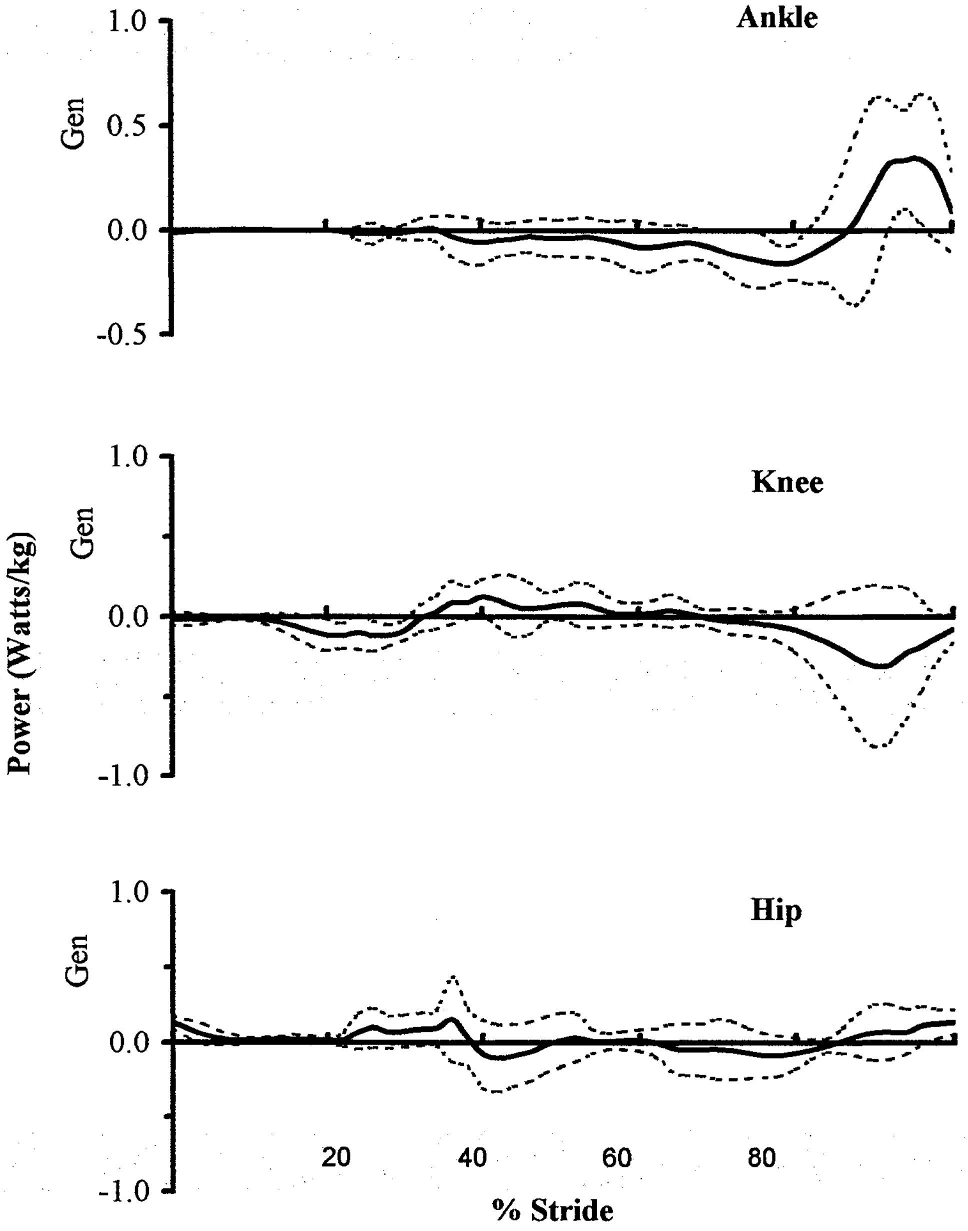


Figure 4e. Mean (+/- sd) hip, knee, and ankle moment powers for subject 6. All powers are normalized to percent of stride and body mass. The range (averages) of the Pearson product moment correlation coefficients between the hip, knee, and ankle powers and comparative adult data are: -0.005 to 0.55 (0.29), -0.02 to 0.58 (0.31) and -0.23 to 0.89 (0.49) respectively.

Moment Powers: 4 month AW

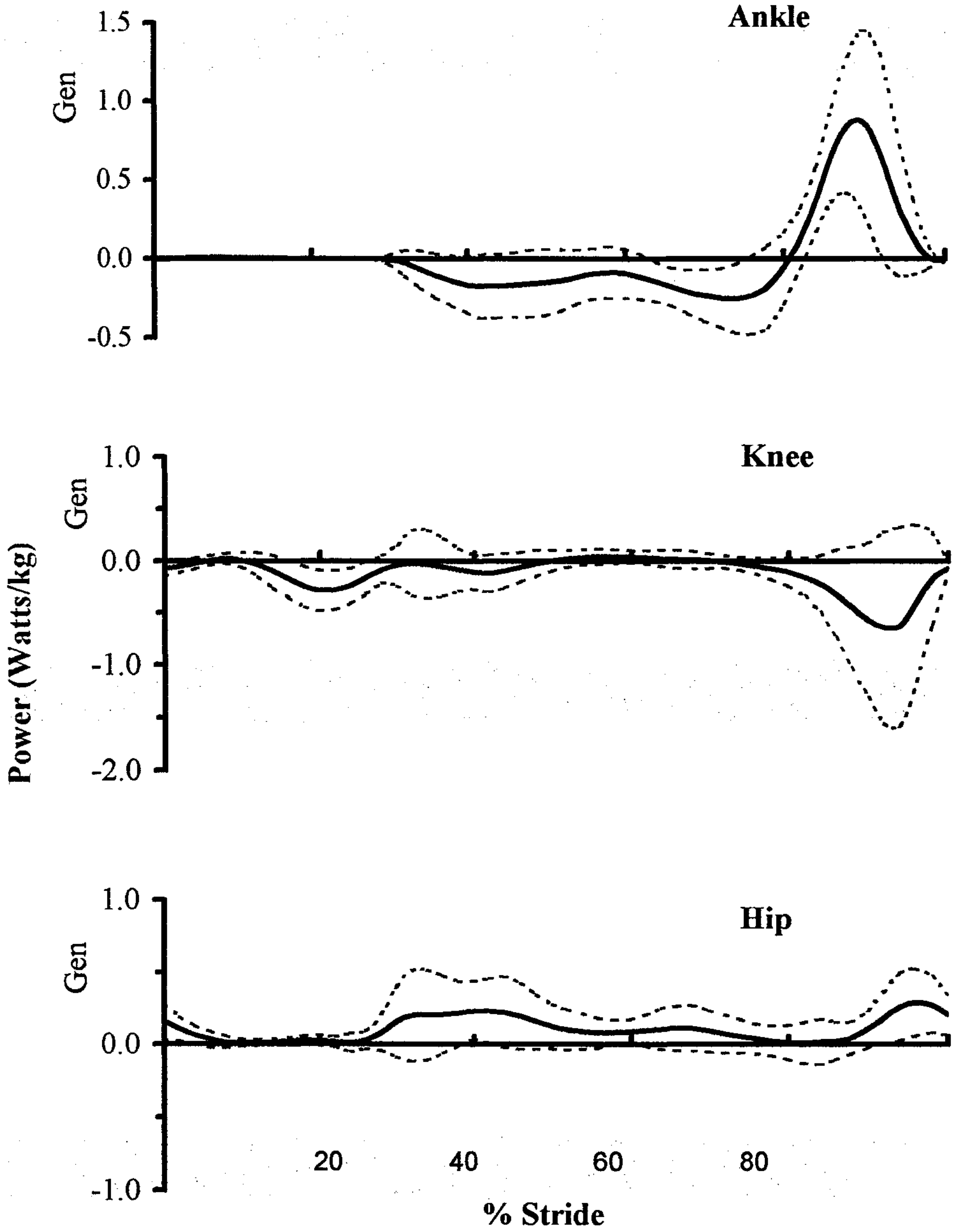


Figure 4f. Mean (+/- sd) hip, knee, and ankle moment powers for subject 12. All powers are normalized to percent of stride and body mass. The range (averages) of the Pearson product moment correlation coefficients between the hip, knee, and ankle powers and comparative adult data are: -0.02 to 0.70 (0.42), -0.27 to 0.54 (0.25) and 0.24 to 0.94 (0.69) respectively.

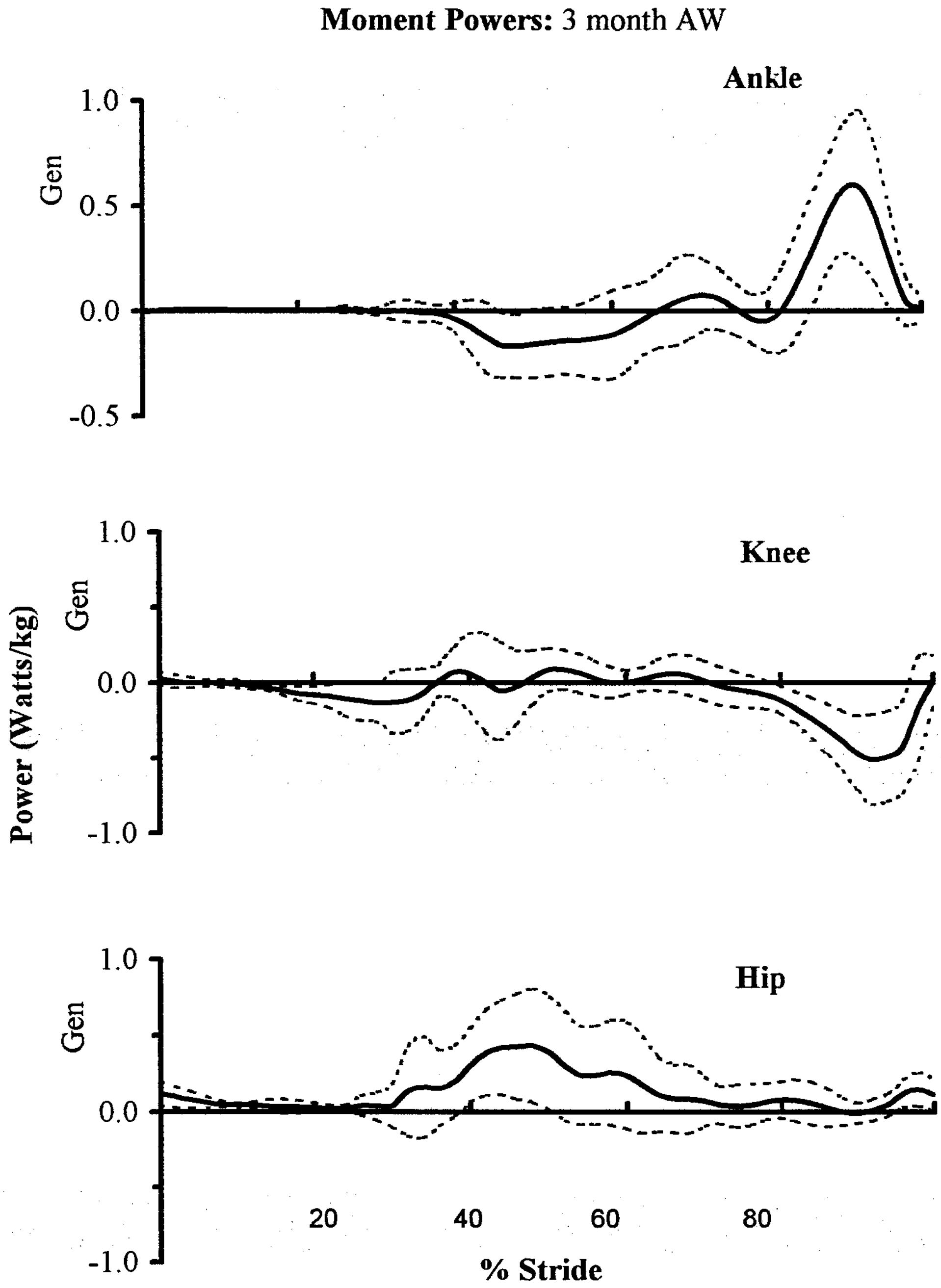
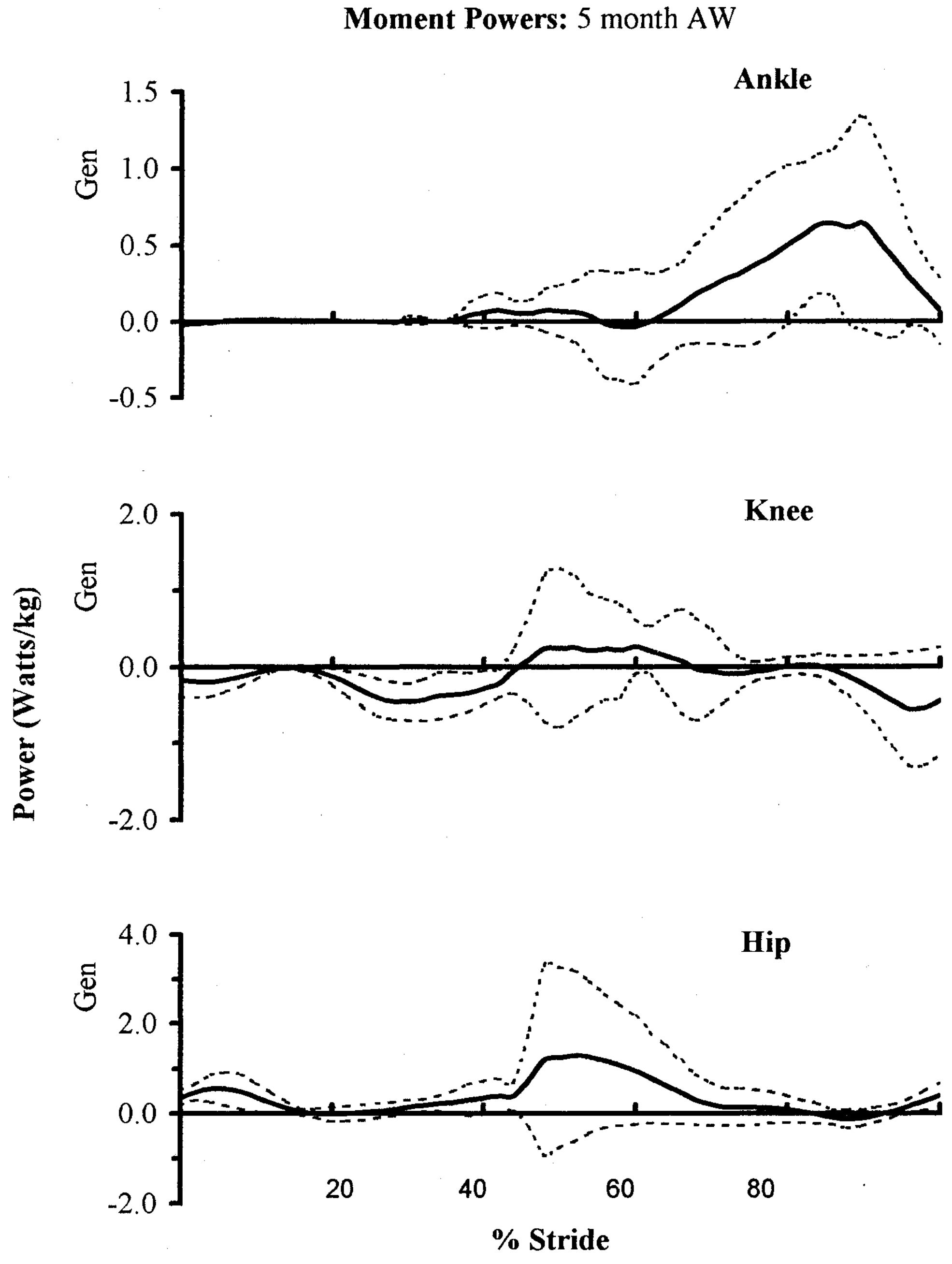


Figure 4g. Mean (+/- sd) hip, knee, and ankle moment powers for subject 13. All powers are normalized to percent of stride and body mass. The range (averages) of the Pearson product moment correlation coefficients between the hip, knee, and ankle powers and comparative adult data are: -0.18 to 0.62 (0.24), -0.09 to 0.56 (0.22) and 0.18 to 0.92 (0.66) respectively.



Moment Powers: 5 month AW

Ankle

Knee

Hip

Figure 4h. Mean (+/- sd) hip, knee, and ankle moment powers for subject 7. All powers are normalized to percent of stride and body mass. The range (averages) of the Pearson product moment correlation coefficients between the hip, knee, and ankle powers and comparative adult data are: -0.001 to 0.63 (0.23), -0.12 to 0.44 (0.21) and -0.13 to 0.71 (0.41) respectively.

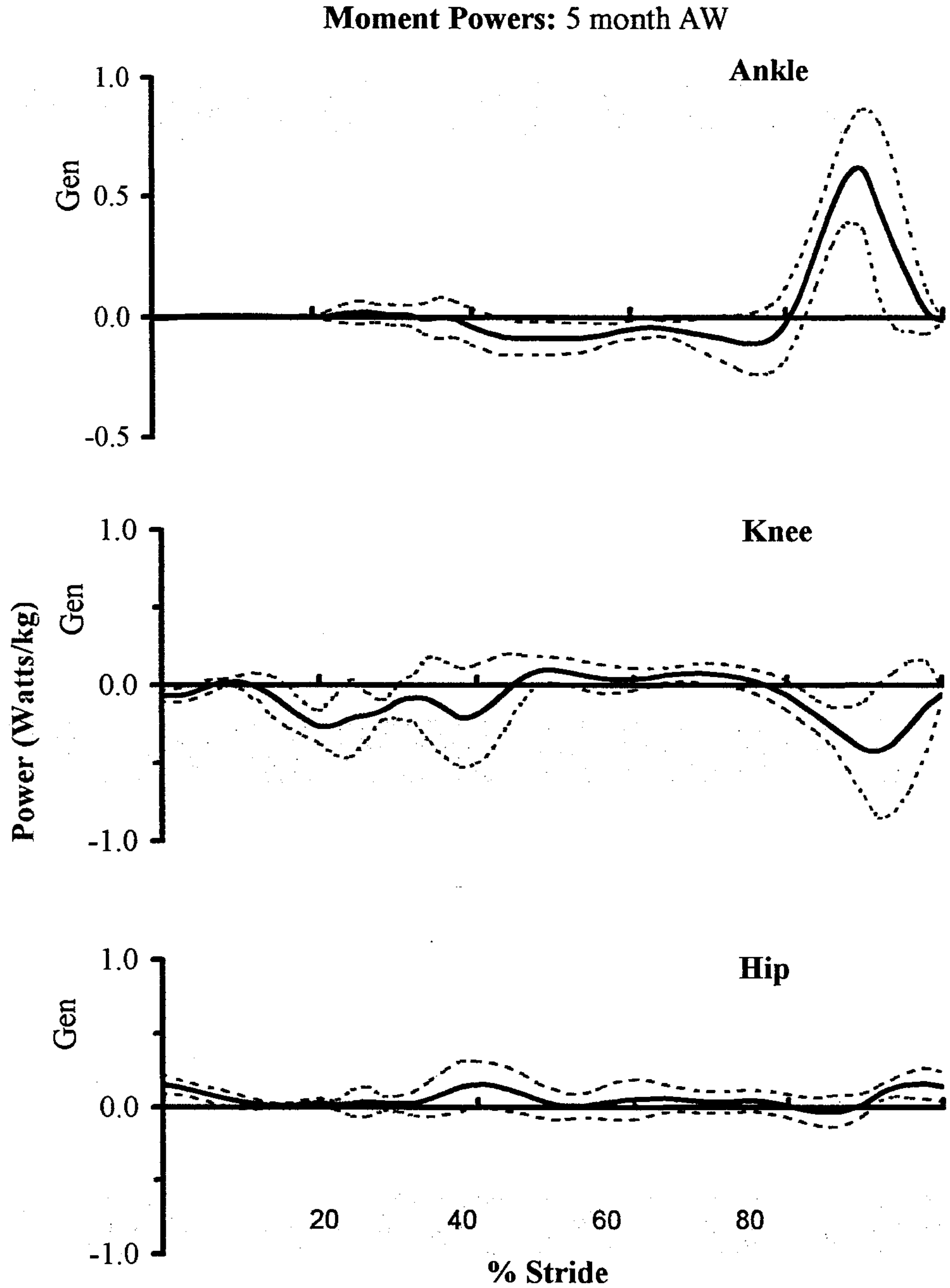


Figure 4i. Mean (+/- sd) hip, knee, and ankle moment powers for subject 11. All powers are normalized to percent of stride and body mass. The range (averages) of the Pearson product moment correlation coefficients between the hip, knee, and ankle powers and comparative adult data are: 0.05 to 0.74 (0.50), -0.23 to 0.43 (0.19) and 0.58 to 0.93 (0.78) respectively.

Moment Powers: 7 month AW

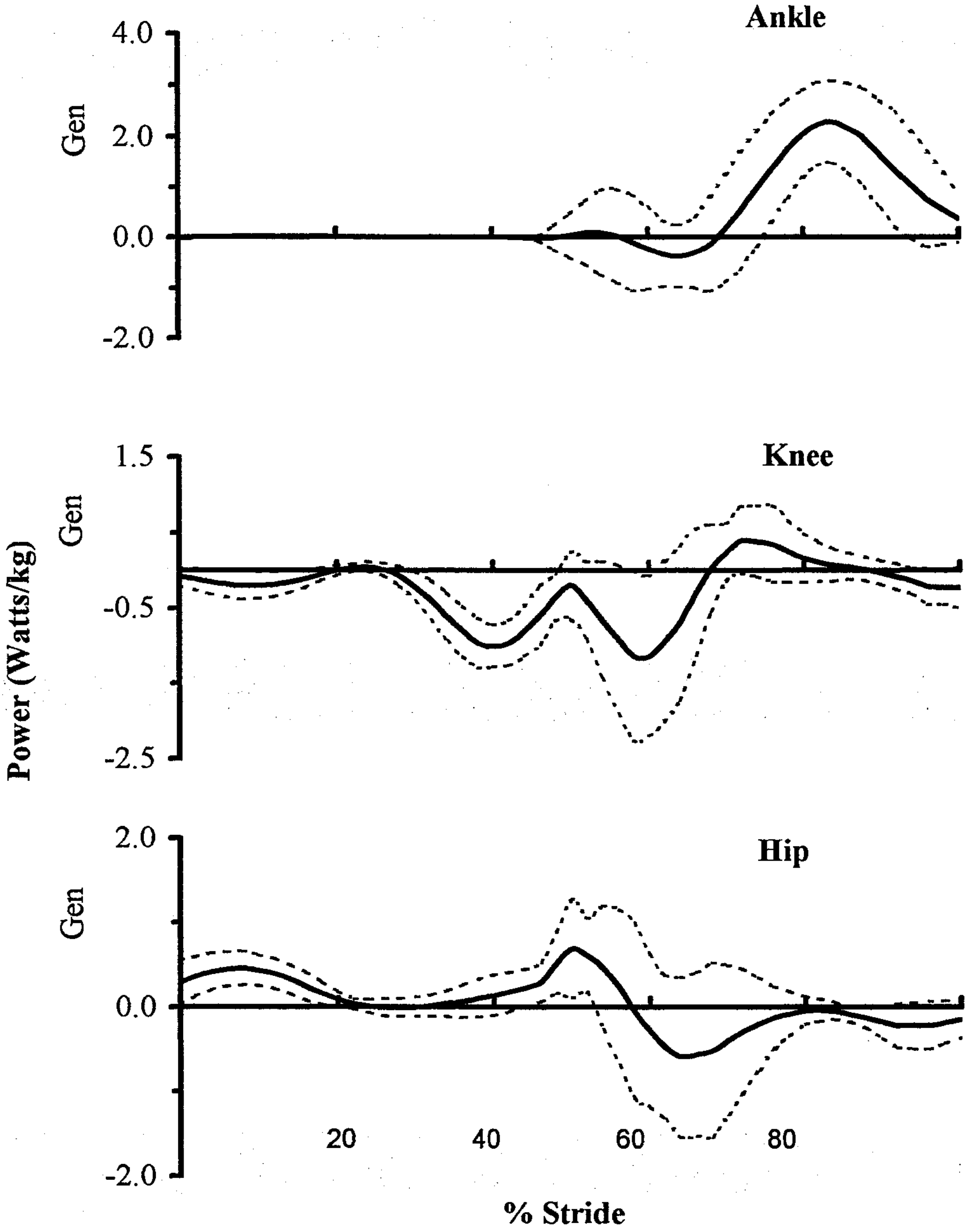


Figure 4j. Mean (+/- sd) hip, knee, and ankle moment powers for subject 3. All powers are normalized to percent of stride and body mass. The range (averages) of the Pearson product moment correlation coefficients between the hip, knee, and ankle powers and comparative adult data are: -0.21 to 0.49 (0.19), -0.39 to 0.09 (-0.09) and -0.04 to 0.74 (0.35) respectively. Note these powers were generated from running trials.

Moment Powers: 9 month AW

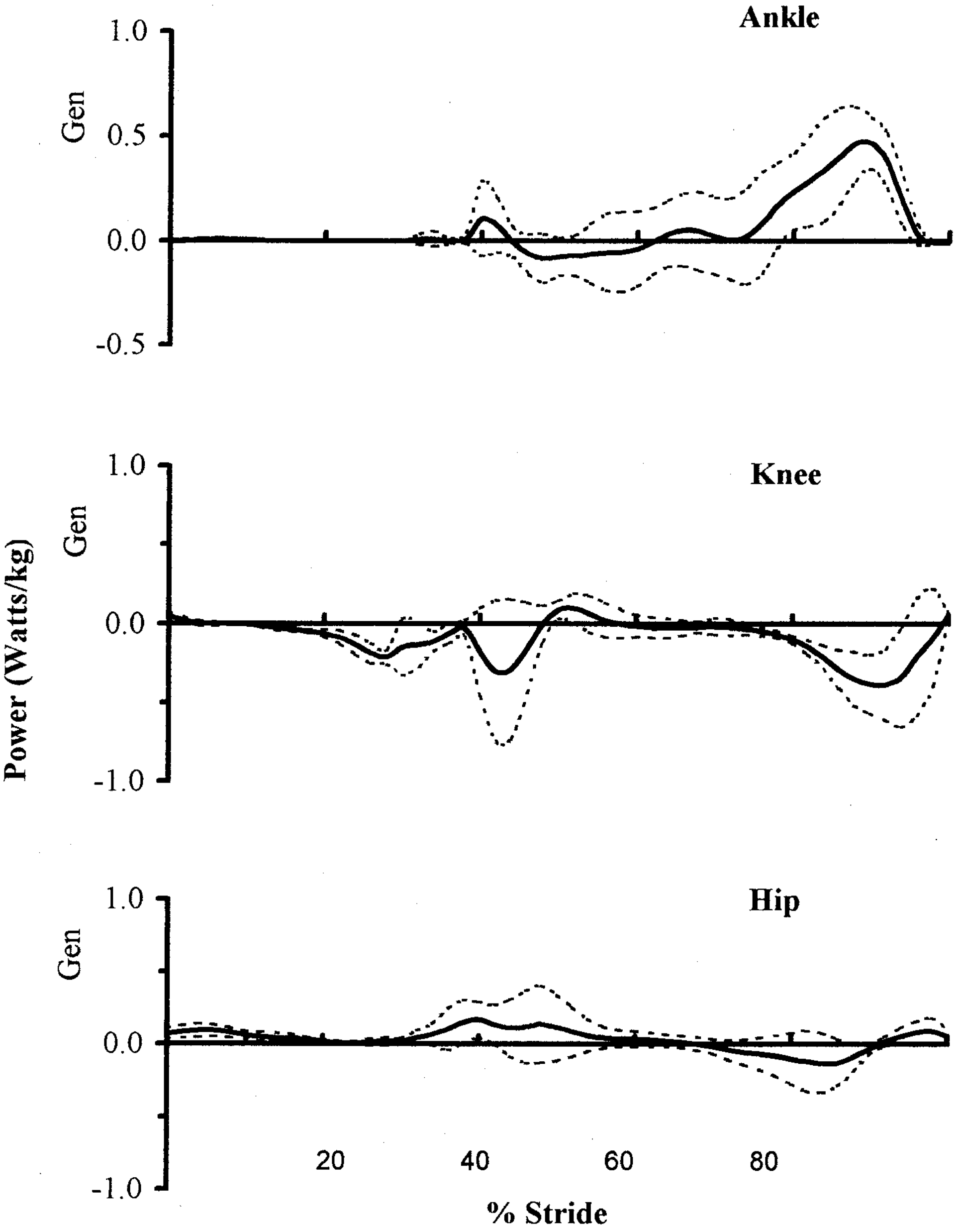


Figure 4k. Mean (+/- sd) hip, knee, and ankle moment powers for subject 9. All powers are normalized to percent of stride and body mass. The range (averages) of the Pearson product moment correlation coefficients between the hip, knee, and ankle powers and comparative adult data are: 0.34 to 0.75 (0.53), 0.09 to 0.56 (0.20) and 0.37 to 0.84 (0.61) respectively. Note these trials are all toe walking trials.

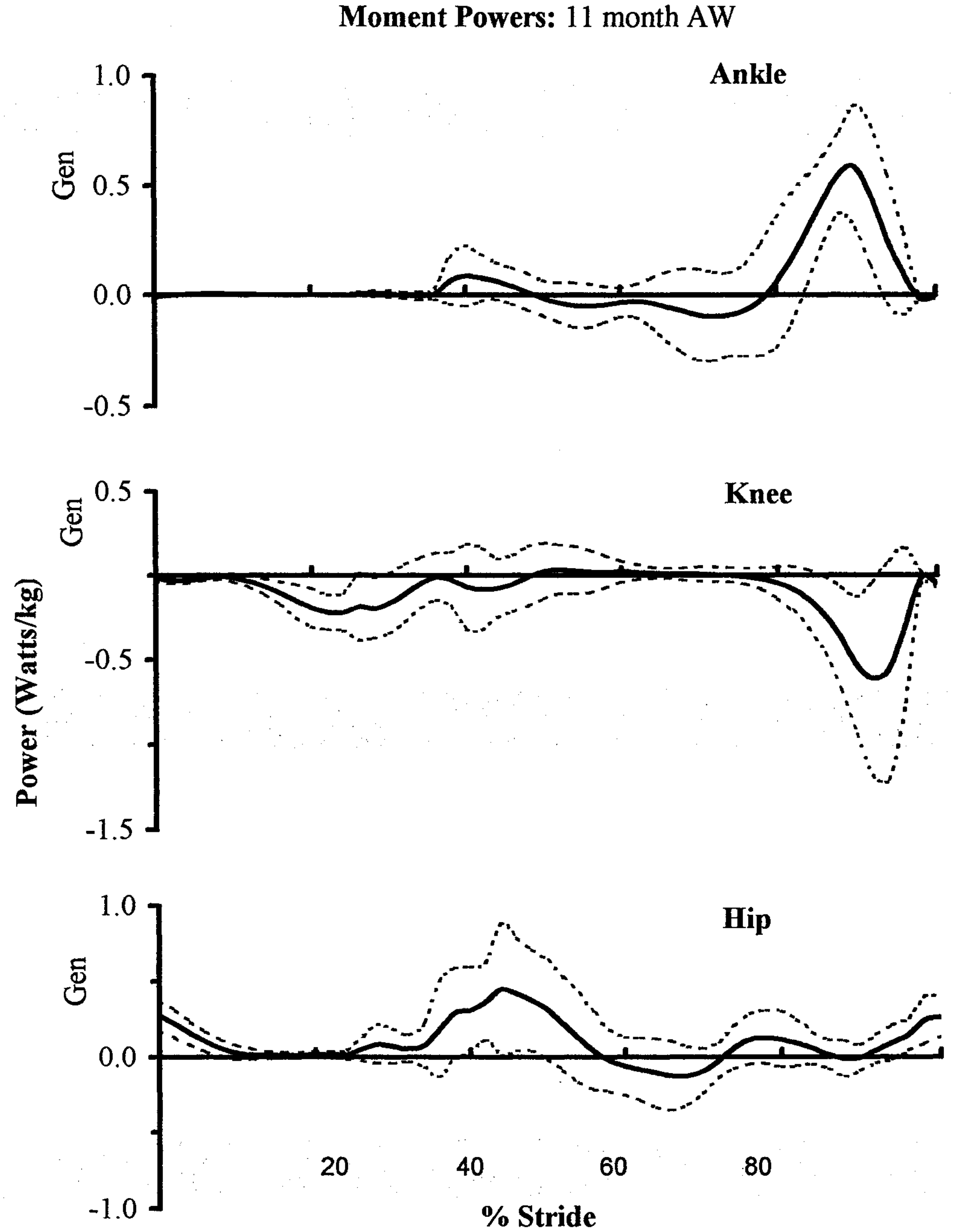


Figure 4l. Mean (+/- sd) hip, knee, and ankle moment powers for subject 14. All powers are normalized to percent of stride and body mass. The range (averages) of the Pearson product moment correlation coefficients between the hip, knee, and ankle powers and comparative adult data are: 0.13 to 0.64 (0.45), -0.01 to 0.55 (0.31) and 0.18 to 0.88 (0.65) respectively.

Moment Powers: 12 month AW

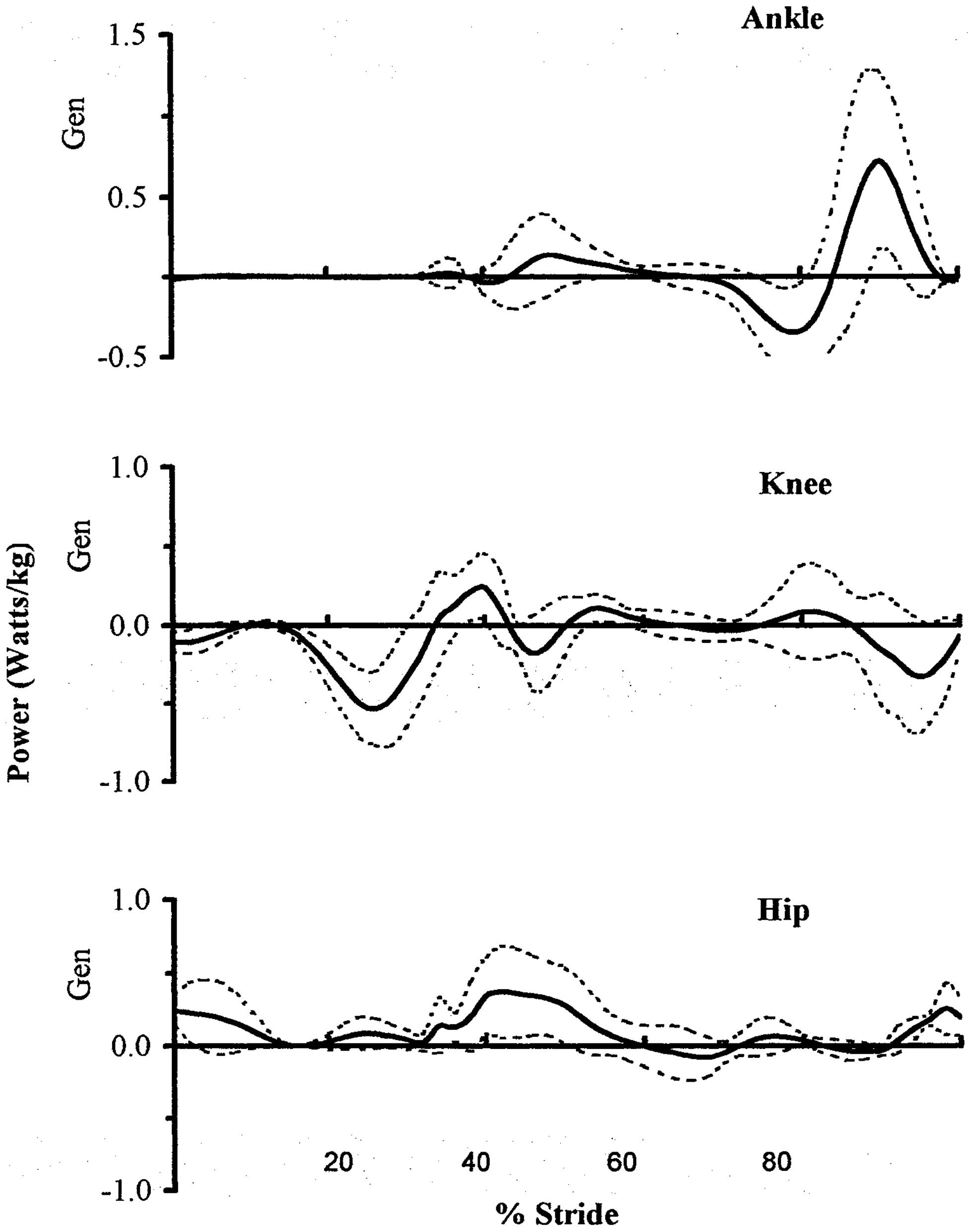


Figure 4m. Mean (+/- sd) hip, knee, and ankle moment powers for subject 5. All powers are normalized to percent of stride and body mass. The range (averages) of the Pearson product moment correlation coefficients between the hip, knee, and ankle powers and comparative adult data are: 0.25 to 0.71 (0.55), 0.52 to 0.64 (0.60) and 0.21 to 0.85 (0.56) respectively.

Appendix C

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Appendix D

Toddler Gait : Lower Extremity Joint Moments and Powers

LETTER OF INFORMED CONSENT

Name of researchers:	Stefan Potoczny B.Sc., Dr. Heidi Sveistrup, and Dr. D.G.E. Robertson
Institution, Faculty, Department:	University of Ottawa, Faculty of Health Sciences, School of Human Kinetics and School of Rehabilitation Sciences
Telephone number:	562-5800 ext. 4246 or 562-5800 ext. 8085
E-mail address:	spotoczny@hotmail.com, hsveist@uottawa.ca dger@uottawa.ca

I,________________, am interested in having my toddler,__________________, participate in the research conducted by Stefan Potoczny, a Masters student in the School of Human Kinetics, Faculty of Health Sciences at the University of Ottawa, under the supervision of Professor's Sveistrup and Robertson of the School of Rehabilitation Sciences and School of Human Kinetics, Faculty of Health Sciences at the University of Ottawa. The purpose of this study is to compare toddler walking to adult walking. I understand that this research will be used as fulfillment of a master's thesis.

My participation will consist of attending one session lasting approximately one hour at the Rodger Guidon campus at the University of Ottawa. In the session I will be required to be present at all times with my toddler to ensure his/her comfort. While my toddler is having the EMG electrodes placed on the skin, being changed into the tights, having markers placed on his/her legs, and having measurements taken of his/her legs and body, I will have to be present and involved in all these processes. I will also have to walk behind my toddler or be in front of my as they are doing the walking trials to encourage them to walk across the force plate. The electrodes that are placed on my toddler will go into a box carried by the researcher or his assistant and will be kept out of reach of the toddler by carrying the box behind the toddler. I will also be asked if my toddler has been given a clean bill of health from my Doctor, to ensure my toddler is in good health prior to testing.

My toddler's participation will consist of attending the same session, which is approximately one hour long. In the session, my toddler will be required to be changed into a different set of clothing that will be provided by the researcher.

My toddler will have disks taped on top of muscles on the front and back of their thighs and calves. The disks are designed to measure and listen to his or her muscle activity, similar to that of a telephone. My toddler will be required to have reflective markers placed on top of the provided tights. These markers will be placed to indicate four joints and four other body points on the lower body. Along with these markers, my toddler will have his/her weight, height, thigh, lower leg and foot measured prior to the walking trials. During the walking trials my toddler will be prompted to walk along a walkway and over two force platforms.

The session has been scheduled at mine and my toddler's convenience.

Session Date and time :____

I understand that before any of the trials in the testing session, both my toddler and I will be given time to become comfortable with the laboratory area and the people. Testing will not begin until my toddler and I are ready. My toddler's height, weight and age will also be recorded to aid in the analysis of the data. I understand that the data collected will be used only for research purposes and that both mine and my toddler's anonymity will be respected by the experimenter because both our names will not be recorded within the data. In fact, we will be assigned an anonymous identification code which will be used throughout the investigation. All results and data pertaining to this study will be kept in a secure area to ensure confidentiality. At no time will my toddler's individual results be made available to anyone outside the researchers. The thesis will be written in such a way as to conceal the identity of all participants.

I understand that since this activity deals with my toddler walking with discs taped over his or her muscles that there is a low risk of discomfort due to the tape or the discs touching the skin. I understand that prior studies have been done over a five year period with over fifty toddlers using this same equipment with no adverse effects. There is also a low risk to my toddler due to falls on the walkway. Since this is a study on normal toddler walking I understand that the risk is no greater than that incurred when the toddler is walking at home or on any level surface with no obstacles. There is also a low level of discomfort associated with dimming of the overhead lights in the room. To ensure my toddler's comfort while the lights are dimmed, I will be walking behind or in front of my toddler to encourage him or her across the force plates. There will be camera lights on while the overhead room lights are dimmed. I have received assurances that I can notify the researcher when I believe that my toddler feels any discomfort, and that testing will end if my toddler feels or exhibits signs of any discomfort. I understand that there is a small risk of skin irritation due to the removal of the tape holding the discs placed on the skin. I am aware that the tape used is skin tape made specifically to be put on skin, that it

is similar to that found on a band-aid and that it will come off from my toddler`s skin with ease and without hurting him or her.
I understand that by participating in this research, my toddler and I are helping to identify how toddlers walk compared to adults. Our participation will help create a set of normative data with respect to toddler gait patterns.

I understand that this testing will specifically used for data collection and will not be used for assessment purposes.

I am free to withdraw myself and my toddler from the project at any time, before or during any testing conditions and have the freedom to refuse to allow my toddler to participate in any one of the testing conditions.

Any information requests or complaints about the ethical conduct of the project may be addressed to Lise Frigault (Protocol Officer for Ethics in Research):Room 302, Tabaret Hall,

University of Ottawa 550 Cumberland, Ottawa, ON
Phone: 562-5800 ext.1787
E-mail: lfrigaul@uottawa.ca

There are two copies of the consent form, one of which I may keep.

If I have any questions about the conduct of the research project, I may contact the researcher or his supervisor at the numbers provided at the top of the page.

Researcher's signature:______________________ Date:______________

Parent/Guardian's signature:_________________ Date:_____________

Toddler Gait : Lower Extremity Joint Moments and Powers

EDUCATIONAL DATA USE FORM

Name of researchers:	Stefan Potoczny B.Sc., Dr. Heidi Sveistrup, and Dr. D.G.E. Robertson
Institution, Faculty, Department:	University of Ottawa, Faculty of Health Sciences, School of Human Kinetics and School of Rehabilitation Sciences
Telephone number:	562-5800 ext. 4246 or 562-5800 ext. 8085
E-mail address:	spotoczny@hotmail.com, hsveist@uottawa.ca dger@uottawa.ca

My signature below has no impact on whether my child can participate in this study or not. By signing below I agree to have the videotapes of my child, that are taken during the testing session, used as an educational tool at a conference or in a classroom teaching setting. I understand that if I do not sign below the videotapes will only be used for data collection and will be locked in cabinet that only the researcher and supervisors have access to. If I do sign below, the videotapes of my child may be used for the purposes described above. Should at any time I wish the tape of the testing session with my child not used for these purposes described above, all I need to do is contact the researcher or supervisors and the videotapes will no longer be used for educational purposes.

Researcher's signature:______________________ Date:_____________

Parent/Guardian's signature:_________________ Date:____________

BABY WALKING: Data Sheet

Infant age (months): ____________________ **SUBJECT #** ________

Term Berth: Y N
If no, Number of Months to term:____________

Sex: M F

BODY PARAMETERS

GENERAL

Height (cm): ____________________

Weight (lbs.): ____________________

SEGMENT LENGTHS (cm)

(note: all segment lengths will be measured between the corresponding markers for that segment)

-THIGH: ____________________ (From hip; greater trochanter to lateral epicondyle of the knee and corresponding axis of rotation)

-SHANK: ____________________ (From lateral epicondyle of the knee and the corresponding axis of rotation to the lateral malleolus)

-FOOT: ____________________ (From the lateral malleolus to ball of foot.)

SEGMENT GIRTHS (cm)

-THIGH: ____________________ (circumference halfway up the thigh segment)

-SHANK: ____________________ (circumference halfway up the shank segment)

-FOOT: ____________________ (**width of the foot** at its widest part)