Longitudinal Study of the Acquisition of Locomotion, Motor Activity, and Infant Development

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LONGITUDINAL STUDY OF THE ACQUISITION OF LOCOMOTION, MOTOR ACTIVITY, AND INFANT DEVELOPMENT

BY

JANETTE BAIRD

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN PSYCHOLOGY

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ABSTRACT

This study explored the relationship between the age of development of 5 locomotor behaviors, the level of infant activity for the locomotor behaviors, and the performance of the sample of infants on standardized indices of infant development (Fagan Test of Infant Intelligence, FTII; Bayley Scales of Infant Development, BSID-II). A total of 157 infants were assessed at 6, 9, and 12 months for their activity levels on the 5 locomotor behaviors of interest, and the age at which each locomotor behavior occurred was obtained through records maintained by each infants’ caregiver. The results of the regression path analysis indicates that that the timing of acquisition of locomotor behaviors is reciprocally related to how active infants are, and that over time these factors contribute to how infants perform on more global measures of development. The main implications of these findings are that the rate of development of future infant locomotor behavior was influenced by how active the infant was in a current locomotor behavior. The acquisition of specific locomotor behaviors (i.e., standing unsupported and walking supported) was significantly and negatively correlated with infant performance on a Psychomotor Development Index of a standardized measure of infant development (BSID-II, Bayley, 1993).
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The purpose of this study was to explore the relationship between infant locomotor milestone acquisition, infant motor activity, and infant development. It was the intention of this research to determine whether the rate at which infants achieved locomotive behaviors, and the degree of locomotor activity exhibited by infants, explained variations in infant performance on measures of psychomotor and cognitive development. The target sample was a cohort of Chinese infants that came from an area of mild iodine deficiency (ID) in Hunan Province in the People’s Republic of China (mild iodine deficiency in a neonate is defined as serum TSH > 5mU/L at a population level of 3-19.9% (Delange, 1999).

This study was based on recent dynamic systems approach to understanding motor development and motor activity as fundamental components in the development of cognitive and social skills (Bai & Berenthal, 1992; Campos et al., 2000; Lockman & Thelen, 1993; Thelen, 2000a; Thelen & Smith, 1994). Such research suggests that most healthy infants transition from passive and dependent motor behavior to more active and independent motor behavior within a normative time scale. However, it is conjectured that variations in the timing of such transitions and in rates of occurrence of motor behavior may inhibit or enhance other areas of development.

Dynamic motor development theory argues that infant motor activity, particularly locomotor activity that enables the infant to independently explore the environment, is important for the development and refinement of cognitive processes, such as perceptual discrimination, object permanence, depth perception
and self-referencing (Bai & Berenthal, 1992; Campos et al., 2000). In turn, mastery of these skills is important in order for the infant to engage in more sophisticated thinking about, and interactions with the environment. For example, when infants achieve object permanence they are able to mentally act on objects even when the infant has no direct contact with the object. As such infants who achieve object permanence will search for an object even when the object has been hidden. Dynamic systems theory suggests that the age at which the infant achieves object permanence is affected by the age at which the infant develops locomotion (Campos et al., 2000; Piaget, 1980; Rose & Orlian, 2001).

Due to the physical control and coordination of the infants’ muscles and limbs, locomotive infants are able to actively explore their environment. Locomotion and activity are self-organizing systems whereby changes in the biomechanics and organization of muscles and limbs can produce new forms of movement. In turn increased activity and exploration will alter the perceptual and social experiences of the infant (Thelen & Smith, 1994). A dynamic systems approach to development proposes that cognition arises from the everyday physical engagement that the infant has with the environment and develops from perception, action, and memory associated with those interactions (Thelen, Schoner, Scheier & Smith, 2001).

The theoretical basis of this study is drawn from areas of research into motor, psychomotor, cognitive and neural development. This study is based on the central hypothesis that locomotor development and activity provide a fundamental base for infant exploratory behavior, which in turn provides motor
and perceptual experiences important for cognitive and social development. The predictions and research questions to be examined in this study evaluate possible mechanisms and explanations of the interaction and relationship between the timing of locomotion skills, the amount of locomotor activity, and psychomotor and cognitive development.
LITERATURE REVIEW

Historical Perspective on Motor Development

As an emerging discipline in the 1920’s and 1930’s, psychology approached the study of child development from a normative perspective that built on the work of Binet and Simon in the area of intelligence. Early developmental psychologists compiled scales of infant and child ability that were based on systematic observations of change in the motor, social and intellectual abilities of infants and children over time. Such scales made little reference to the context in which the observed behavior occurred. The central tenet of this early approach was the notion that in all but the most extreme circumstances, development of human psychological and physical abilities progressed along an ordered sequence. The aim of this approach was to detail and record examples of normative motor and mental activities that could be used to indicate both concurrent and future levels of the performance of an individual when compared to same aged peers (Case-Smith & Bigsby, 2001; Gesell & Thompson, 1934; McGraw, 1943).

An early and influential measure of infant motor and mental development based on a neurological maturational model was the Gesell Developmental Schedules (1941). This normative scale focused on the sensori-motor skills, such as locomotion, and visual and auditory acuity, which were believed to be indicative of underlying nervous system functioning. However these early scales of infant development were not heralded as measuring intelligence per se, but
rather that the assessment of sensori-motor functioning reflected a measure of overt behaviors that were the precursors of later intellectual ability (Colombo, 1993).

From detailed observations of the motor development of 107 infants over the first year of life (using then state-of-the-art cinematic observation techniques), Gesell postulated that changes in infant posture and locomotion resulted mainly from the influences of intrinsic growth factors such as cortical maturation (Bergenn, Dalton, & Lipsitt, 1992; Gesell & Thompson, 1934; McGraw, 1943).

According to early motor theorists, primary reflexive behaviors such as the primitive stepping reflex of the neonate were controlled by subcortical nuclei in the brain stem. Later these reflexive motor behaviors were modified, through cortical maturation, into activity that was linked to stimuli and purposeful activity. This traditional view of motor development emphasized the invariance of the general timing of motor skills acquisition as a process that was little influenced by the environment or motor practice (Bergenn, Dalton, & Lipsitt, 1992; McGraw, 1943; Thelen & Smith, 1994; Vgotsky, 1986).

Early motor theory drew a parallel between motor and cognitive development only in terms of the possible epigenesis of these domains rather than postulating any interdependence between these developmental domains (Gesell & Thompson, 1934). For example, McGraw reflected from her observations that an infant’s increasing ability to coordinate visual and motor behavior to reach for and grasp a distant object was evidence of the coordinated development of sensory
and motor functions, reflecting the reorganization of the central nervous system. McGraw reasoned that maturational changes that resulted in more effective motor performance could not be associated with any specific changes in infant cognition (McGraw, 1943). However, according to the early motor theorists, the motor performance of the infant was indicative of the general integrity of the CNS, and a deficiency in motor development could be paralleled by a deficiency in intellectual ability.

As detailed observations of large samples of infants and children led to the development of normative scales of motor and intellectual ability in the United States during the first half of the 20th century, in Europe the individualistic approach of Piaget dominated developmental research. In his theory Piaget emphasized the importance of change and discreet transition as the hallmark of child development. Piaget viewed the sensori-motor activities of the infant both as a primary means by which the infant learns about the environment, and as a fundamentally important mechanism of infant cognitive development (Piaget, 1972, 1978, 1980). According to Piagetian developmental theory, motor activity during the sensori-motor level allowed the infant to directly interact with and experience the environment. Initially infant activity was reflexive and circular (primary circular responses) in that the motor actions of the neonate would be produced in the absence of any environmental stimulus (Piaget, 1972, 1978, 1980; Thelen & Smith, 1994). Piaget observed that subsequent stages of motor action resulted in more control over the initiation of movements and in linking movements to some external goal, such as reaching for and grasping an object.
Piaget reasoned that the direct interactions that the infant had with the environment were essentially egocentric. From these direct actions logical errors were likely to arise (such as not searching for an object that is hidden in a new location; the A-not-B paradigm) that could only be addressed through changes in internal cognitive structures. These changes, which according to Piaget began to emerge at around 9 months, resulted in the infant being able to create and operate upon mental representations of objects that were separate from the infant, or the action of the infant upon objects (Campos et al., 2000; Goswami, 2001; Piaget, 1972, 1978, 1980; Van Geert, 2000;). Piagetian emphasis on the notion of cognitive structures suggested that the representation of reality existed separately from sensory information and motor action. This implied that it was change in mental representation (e.g., object permanence, language, and conservation) rather than changes in sensory processing or motor development that underlay cognitive development (Hadders-Algra, 2000; Thelen & Smith, 1994).

Although early theories of infant and child development emphasized the importance of sensori-motor skills in indicating the integrity of CNS development, there has been little empirical evidence to demonstrate that sensori-motor activity is an indicator of global development past infancy. Research has consistently demonstrated that measures of infant development, which emphasized sensori-motor skills, had poor predictive validity when later measures of child and adult intelligence were used as a comparison. In some instances the findings of research indicated that the correlation between infant and later child measures of intelligence approached zero (Bendersky & Lewis, 2001; Colombo,
1993; Thompson, Fagan, & Fulker, 1991), except in the case of infants at risk from developmental delay (Maisto & German, 1986).

Piagetian theory with its emphasis on cognitive change being achieved through mental representation appeared to provide a better model for understanding the development of cognitive ability. As a result psychology’s interest in motor activity and development was to wane during the latter half of the 20th century (Thelen, 2000a). The reduced interest in motor development was coupled with the ascendancy of behaviorism and later computer models of cognition in the 1960’s and 1970’s. Behaviorist and information processing models of cognition emphasized exogenous factors as an explanation for human behavior and development. This approach seemed to relegate motor development research to the realm of a description of mechanical processes that had little direct influence over more complex cognitive and social behavior (Campos et al., 2000; Thelen & Smith, 1994).

Current Understanding of Motor Development: Dynamic Systems Theory

It was not until the last decade of the 20th century that psychology would start to embrace control systems, network theory and more sophisticated brain imaging techniques as a way of beginning to understand how complex neural processes could interact with environmental experiences to shape the motor, social and cognitive responses of the infant (Thelen, 2000a). Included in this new direction for psychology was a re-emergence of motor research using computer programs to model and understand the development of infant motor activity and
to expand on a more detailed theory of the neurological changes that may underlie emerging motor achievements (Bushnell & Boudreau, 1993).

A dynamic systems approach argued that cognition could not be explained without reference to the dynamic and emergent interactions of changes in motor and perceptual ability, environmental opportunities to explore, and parental interactions (Thelen & Smith, 1994; Thelen et al., 2001; Van Geert, 2000). According to a dynamic systems approach, all aspects of development are self-organizing because change arises from a different configuration of the component parts within the developmental system. Just as changes in locomotion occur because of the reorganization of maturing muscles to overcome gravity, in turn locomotor activity changes the sensory perspective and perception of the mobile infant, resulting in the reorganization of the sensorimotor and cognitive systems of the infant (Thelen & Smith, 1994; Thelen et al., 2001).

According to dynamic systems theory perception arises from sensory input that is moderated by motor actions. This action-perception coupling is, according to a dynamic systems approach, the keystone of cognition, as our knowledge and understanding of the environment is dependent on our interactions within the environment (Campos et al., 2000; Piek, 2002; Thelen, Schoner, Scheier, & Smith, 2001).

Attempting, and then perfecting complex motor acts, enables the infant to be able to link information from the sensory systems to specific motor actions (Thelen & Smith, 1994). Infants develop the ability to produce specific motor actions to stimuli that are frequently encountered by entraining the coordinated
response of groups of muscles and limbs (Gazzaniga, Ivry & Mangun, 1998; Llinas, 2001). Although most healthy infants develop gross motor skills such as crawling or walking within a normative time frame, dynamic systems theory argues that each motor behavior arises not as a preprogrammed occurrence, but because the infant develops motor behaviors that will more effectively enable the infant to achieve particular goals. As muscles mature and strengthen variations in motor behaviors and coordination become more apparent. However, dynamic systems theorists argue that changes in the motor repertoire should not be regarded as merely developmental or maturational, but instead changes in motor behaviors come about because of infant interaction with the environment, and as a motor behavior becomes limiting the infant is motivated to further develop his/her motor repertoire (Thelen, 2000b).

In tandem with changes in motor behavior are changes in the amount of activity exhibited by the infant. During the first month of life the neonate spends more time in sleep than in active states, and when active shows a general pattern of uncoordinated movements of all limbs during periods of excitement or irritability (Colombo, 2000; Hadders-Algra, 2002; Piek, 2002). Low incidences in the types and frequencies of generalized whole body motor movements that occur between 6-20 weeks post gestation, has been used as an indicator of neurological abnormalities (Prechtl et al., 1997). Periods of alertness and activity continue to increase during the first year of life, and activity has been suggested in many studies as an important consideration in the exploratory and developmentally stimulating behavior that the infant engages in (Wachs, 1989).
Dynamic systems theory employs the term “embedded” to describe the interrelationship between the nervous system, physical action, and cognition (Thelen, 2000b). The use of this term implies that cognition is an emerging process that is a function not only of how the nervous system has organized physical responses to the environment at any point in time, but also how it is influenced by previous activity. Unlike the traditional view of development which relegated sensori-motor experiences as an elementary foundation (at best) of later cognitive development, a dynamic systems approach argues that there is no time during development that physical action and nervous system operations become divorced from cognition (Sporns & Edelman, 1993; Thelen, 2000b).

A dynamic approach to understanding the interaction between motor and cognitive development must include an examination of important structural and neurological changes. Such structural and neurological changes underpin the increasing control and modification of motor, sensory, and cognitive ability that the infant exhibits over the first year of life.

*Neurological Development*

One of the central roles of the brain is to transform sensory information into planned motor action, as a complex and hierarchically organized process that involves input and output sensory and motor feedback loops at the cortical and subcortical levels (Gazzaniga, Ivry, & Mangun, 1998; Llinas, 2001). Motor activity initiated at the level of the cortex involves planning motor responses (dorsolateral prefrontal cortex), activating cortical and subcortical structures (primary motor cortex, cerebellum), the use of sensory and motor memory...
(distributed), and the synthesis of cognitive and perceptual interpretation of sensory input (primary somatosensory cortex and association areas) (Carlson, 1998; Gazzaniga, Ivry, & Mangun, 1998; Llinas, 2001; Rhoades & Pflanzer, 1996). Early in gestation there is dominance of the physiological development of the motor and sensory system, and this continues until the end of the second postnatal year (Webb, Monk, & Nelson, 2001). The interrelationship between motor and sensory neural development can be seen in the effects of insults to which the developing fetus is particularly vulnerable. Such insults can have wide ranging consequences beyond the function associated with the particular neural area affected.

As an example, which is particularly pertinent to this current study, the effects of fetal and infant iodine deficiency (ID) on neurological development have been associated with sensory, cognitive, and motor deficits. For the developing fetus a continuous dietary supply of iodine is important for the thyroid gland to synthesize the thyroid hormones (triiodothyronine (T3) and tetraiodothyronine (T4 or thyroxine)) necessary for body metabolism and neural growth (Rhoades & Pflanzer, 1996; Sperelakis & Banks, 1996). The thyroid hormone thyrotropin (TSH) is a marker of thyroid status as balanced thyroid function and normal serum TSH levels of below 5mU/L determine a euthyroid state. In the hypothyroid state TSH levels are elevated because there are insufficient circulating thyroid hormones to suppress production of thyrotropin (Rhoades & Pflanzer, 1996; Sperelakis & Banks, 1996).
Experimentation on human and animal models suggests that the level of thyroxine (T4) affects fetal neuronal differentiation and synaptogenesis; particularly in the cochlea, basal ganglia, cerebellum, and motor cortex areas. These are key neurological structures for sensory, motor, and cognitive development (Fantz, Dagogo-Jack, Landenson, & Gronowski, 1999; Karabinas & Tolis, 1998). The fetal thyroid gland does not develop until the 12th gestational week; as such, maternal iodide is the sole dietary source for the fetus (Karabinas & Tolis, 1998). Exposure to maternal hypothyroidism during pregnancy (indicative of inadequate dietary iodine or deficiency in synthesizing dietary iodine) has been associated with poorer developmental outcomes for the progeny (Haddow et al., 1999). Children exposed to an inadequate supply of thyroid hormones during gestation performed worse on measures of intelligence at age 7, in comparison to children who had an adequate supply of thyroid hormones during gestation. The poorer performance was shown during tests of attention, language, and visual-motor performance (Haddow et al., 1999). Infants exposed to maternal hypothyroidism, as a result of severe iodine deficiency during gestation, also exhibit poor locomotor gait, delayed locomotor development, and degrees of cerebral palsy (Porterfield, 2000; Zhang & Lazar, 2000).

It is not only fetal neural development that is important. Postnatally the cerebellum, prefrontal, and motor cortices have been identified as key neural areas whose prolonged morphological growth has been associated with continued cognitive (e.g., working memory, learning new tasks, allocation of attentional resources), motor planning (e.g., planning and initiating motor response, timing of
motor action), and motor behavior development (i.e., gross and fine motor skills, and the control of the output of the CNS and autonomic nervous system) (Diamond, 2000; Ivry & Keele, 1989).

In addition, despite the popular notion that motor skills develop and are completed early and that cognitive and perceptual skills have a later and more prolonged development, it is now recognized that both have prolonged and interrelated developmental sequelae (Diamond, 2000; Teeter & Semrud-Clikeman, 1997). As an example, children with Williams' syndrome (WS, a genetically based developmental disorder) often have difficulty in matching their motor activity to changes in the demands of a task. Children with WS can identify the elements of a task (posting a letter through a slot), but when the angle of the slot is altered the children with WS are less able than non-WS children to properly match a change in presentation of the letter with the change in angle of the posting slot. The authors of the study suggest that although the children with WS may know what to do, when the perceptual information changes (i.e., different angle of slot) the WS children are unable to reconfigure the action to differences in perceptual information (Atkinson et al., 2003).

It is suggested that the visual system present information from the environment to the cortex in different streams. Two of these streams separate visual information for action (control and guidance of movement, mediated by dorsal visual stream) and visual information for perception (creation of an internal representation of the world for cognitive processing, mediated by the ventral visual stream). In the letter posting experiment children with WS could properly
identify the elements of the task but were unable to complete the motor component of the task. This suggests that as a result of deficits in the dorsal visual processing stream, changes in perceptual information (i.e., change in the angle of the posting slot) is not matched with changes in motor action (Atkinson et al., 2003).

The organization and coordination of any motor activity requires the integration and connection of multiple cortical and subcortical structures, and a mechanism by which there is a connection and coordination between sensory input, cognitive processing, and motor response (Gazzaniga, Ivry & Mangun, 1998; Llinas, 2001). Neuronal Group Selection Theory (NGST; Sporns & Edelman, 1993) offers a putative model for the dynamic interaction between experience and neural organization in explaining infant motor and cognitive development. This theory is based on the perspective that changes in an infants' exploratory motor behavior will result in changes to the still plastic brain; it is known that action and experience as well as maturation help to strengthen neural links and to establish the development of sensory and motor neural networks (Stiles, 2000).

The decision to act in particular ways arises from the processing of sensory information integrated with motor memory and planning to produce the required movement (Thelen, 2000b). According to NGST the initial emergence of a gross motor behavior (e.g., moving an arm or leg) is supported by weighted primary connections among neural structures that are the results of phylogeny and embryology (this is similar to Piaget's description of primary circular motor
responses). Experience directly moderates these initial connections and produces a greater variation in behavior until the activity matches the demands of the environment, and produces a motor behavior through the process of experiential selection (Sporns & Edelman, 1993). For example, infant movement will become gradually more coupled to perception and cognition through refining gross movements of arms and legs to more controlled movements that allows the infant to plan and use the motor act to attain an end goal (such as reaching for an object) (Hadders-Alga, 2000). Each organized and generated movement brings the infant into contact with associated perceptual information from the different sensory modalities (Angulo-Kinzler, 2001). The connections of motor and sensory pathways become established but will also remain flexible enough for the infant to reconfigure changes in the networks in relation to physical, environmental, and cognitive change. For example, upright locomotion (walking) will be achieved by the appropriate combination of changes in infant body weight, muscle development, neural development, and infant motivation to overcome gravity. In developing the ability to walk the same muscles and limbs that support early locomotor activities, such as crawling, have to be reorganized, and this also results in a reorganization of the neural networks that supported earlier motor behaviors (Hadders-Algra, 2000).

The rapid and extensive neural reorganization of motor networks occur because early in neonatal and infant development there is a proliferation of neuronal connections that are exposed to a Hebbian style selection (Hadders-Algra, 2002). The neural connections between cortical and subcortical structures...
are dynamically reorganized through the strengthening or weakening of connections as a result of experience (Sporns & Edelman, 1993). The production of a stable and efficient motor behavior indicates that the neuronal group selection has also become stabilized. This neural reorganization is achieved biologically through cell extension and contraction, cell migration and cell death. Changes in the speed of production of motor activity have been associated with increased myelination that occurs towards the end of the first year of infant development (Hadders- Algra, 2000; Sporns & Edelman, 1993).

Dynamic systems theorists argue that the distinction between perception, neural response, cognition, and action often becomes blurred when actions become familiar (Thelen, 2000b). For example, recordings of the electrical activity of monkeys executing a reaching task have shown that many areas of the brain are activated during reaching. However, what is also interesting is that after the monkey becomes skilled in executing the reaching task, the same brain areas that were activated when the monkey was actually reaching for an object become active when the monkey had visually located but not yet reached for the familiar object. This suggests that during a motor task the same areas that are involved in executing an act may also be involved in planning the motor act. As such, it may be difficult to firmly draw the neurological line between perception, action and cognition (Georgopoulos & Grillner, 1989).

Research has demonstrated that the dominance of motor and sensory development during gestation and infancy serves to form a neurological foundation for the relationship among action, perception, and cognition. Activity
causes the infant not only to have different perceptual and sensory experiences, but also to alter the knowledge that the infant has about the environment.

Dynamic systems theory argues that the plasticity of the infants’ neural system allows the infant to select motor and sensory networks that become, through experience, associated with particular knowledge that the infant has about how to operate within his/her environment. Just as Piaget argued that the cognitive structure of the infant becomes accommodated or assimilated through experience, dynamic systems theory argues that neural restructuring allows experience to alter the associations between action, perception, and cognition, and vice versa (Sporns & Edleman, 1993; Thelen, 2000b).

In tandem with neurological changes there are also interactive changes in the physical growth, muscle maturation and motor repertoire of the infant. Infants develop discrete motor skills that are often referred to as milestones as they herald important transitions in motor control (e.g., sitting upright, rolling over from a supine to prone position). The development of self-locomotion in particular has been identified as key to understanding how action and perception are linked (Reiser, 2000).

**Motor Maturation**

**Motor milestones**

For most healthy infants the developmental trajectory of voluntary motor ability involves the increased coordination of groups of large muscles that control gross motor activities and the production and control of finer muscles and motor actions that are utilized in grasping and manipulating objects (Bushnell &
Boudreau, 1993; Thelen, 2000a). During the first two months of life, infants usually develop the ability to hold their head upright for increasing periods of time. This progresses to being able to push the chest up from the arms when placed in a prone position. Between the third and sixth month infants progress from sitting assisted to sitting unassisted, and at the end of the sixth month they are typically able to support their own weight for brief periods (Seifert, Hoffnung, & Hoffnung, 2000). Initially when infants begin to stand they tend to do so by holding onto objects, and later they progress to standing without support, which is important in obtaining and maintaining balance, an essential prerequisite for unsupported walking, and overcoming the effects of gravity. The onset of walking is dependent upon the sufficient development of skeleton and muscle mass to allow the infant to be able to support his/her weight on one leg while elevating the other to complete the walking step (Thelen & Smith, 1994).

During the latter half of the first year of life the infant begins to develop locomotive behavior. At first this may be an inefficient creeping movement with the infant moving forward on the stomach while in a prone position. Stationary rocking on all fours may follow creeping, the infant may then engage in pushing forward using two hands or legs at a time. Usually, more efficient crawling movements follow with the infant using opposing hands and legs in a more fluid sequenced movement. This efficient way of moving across multiple surfaces will start to be replaced towards the end of the first year with an unsteady and inefficient upright locomotion (Adolph, Vereijken, & Denny, 1998; Seifert, Hoffnung, & Hoffnung, 2000).
Research has indicated that there are differences in the age at which infants and children from different cultures achieve gross and fine motor behaviors (Campos et al., 2000; Crowe, McClain, & Provost, 1999; Santos, Gabbard, & Goncalves, 2001). It has been suggested that variations in child-rearing practices, differences in the exposure of the infant to passive or active motor stimulation, as well as differences in the cultural value placed on independent locomotion, may account for variations found in the age of development of motor milestones. A dynamic systems perspective would argue that cultural variations in attaining motor, and particularly locomotor behavior, could be viewed as variations in exposure to environmental circumstances that would necessitate the infant to reconfigure the organization of muscles to produce new motor behaviors (Campos et al., 2000). However, it is important to determine if age differences in the attainment of locomotor behaviors are predictive of infants’ development in other domains, before a discussion of cultural variation in locomotor development can be meaningful.

Motor coordination

Over the first year of life infants show enormous changes in how coordinated and directed motor behaviors become. In order to interact with and acquire information about the environment, the infant uses these coordinated motor behaviors more frequently.

During infancy these initial uncoordinated limb movements in kicking, reaching, and stepping behaviors become more fluid and coordinated resulting in more efficient and responsive patterned motor behaviors (Berenthal, Rose, & Bai,
A small sample observation of the motor activity of infants (n=14), demonstrated that infants (1-3 months old) who had higher frequencies of generalized motor activity were more likely to begin coordinated reaching for objects earlier than infants who had lower frequencies of generalized motor activity levels (Thelen, Corbetta, & Spencer, 1996). Reaching for and manipulating objects such as toys have been used by researchers to measure the amount of exploratory and stimulating activity in which the infant is engaging (Bremner, 2000; Wachs, 1989). The control and direction of motor activity to achieve a goal is an important exploratory behavior that infants use to engage with the environment. Although all healthy infants will display this propensity, engaging in meaningful goal-directed behavior has been advocated as an important component in cognitive development (Angulo-Kinzler, 2001; Wachs, 1989).

The coordination of limb and motor activity increases during the first year, for example when developing crawling it was found that as a result of practice infants progressed from clumsy and inefficient crawling to become more coordinated and quicker in producing crawling action (Adolph et al., 1998). Further, from the detailed recording of infants' progress in locomotion, the amount of motor activity exhibited by the infants was related to the strength and weight of the infant. In particular arm strength was related to the timing of crawling, with smaller and slimmer infants tending to crawl earlier and more often than heavier infants (Adolph et al., 1998).
Locomotor Acquisition

Developmental psychologists have referred to locomotor behaviors that enable the infant to move around and explore his/her environment as developmentally meaningful as they engage the infant in the organization of sensory and motor information (Thelen & Smith, 1994). Dynamic systems theory further postulates that when the infant finds that a current locomotor behavior limits the ability to move about and explore the environment, the infant develops new motor skills. As a result of developing new locomotor skills the infant engages in information processing of perceptual stimuli from a new postural interface with the environment (Berenthal et al., 1997). Much of the dynamic systems research on infant development has involved an examination of putative models of the processes that may underlie the relationship between locomotor and cognitive development.

Central to these models has been an examination of the effects that early acquisition and use of locomotor behavior (usually defined as a motor behavior that enables the infant to move independently from a stationary position over a distance of at least one meter) has on cognitive and perceptual processes (Campos et al., 2000). It must be pointed out that research into the effects of the timing of locomotor acquisition on perceptual and cognitive development does not suggest that age per se is important. It should be considered that age is a convenient proxy for comparing the acquisition of a locomotor skill, and length of time of practice in the skill. Much of the research that has examined the effects of locomotor
acquisition on perceptual and social skills has used same aged infants who vary in
the length of time that they have used locomotor behaviors.

Locomotion is important for the development of infants’ perceptual
abilities, and in particular the perception of depth, distance and relative movement
(Gibson, 1979, 2000). Locomotion affords the infant certain perceptual
advantages such as; a) negotiating obstacles while moving, b) perceiving haptic
and visual information about the traversed surface and, c) gaining information
about differences in traversed surfaces that require posture and motor changes,
such as moving up or down a slope (Adolph, Eppler, & Gibson, 1993). Research
has demonstrated a difference in the perception of depth in relation to locomotor
experience. When placed on a clear surface that shows the ground below, the
heart rates of locomotor infants who had crawled longer (41 days) were more
elevated (the physiological fear response associated with depth perception) than
the heart rates of same aged locomotor infants with less crawling experience
(11 days) (Campos, Berenthal, & Kermoian, 1992). Subsequent research has
demonstrated that although infants who crawl demonstrate anxiety when
perceiving depth, they do not appear anxious when crawling on an inclined
surface. When infants begin to walk the infant has to overcome a fear of heights,
and this is replaced by a fear of walking on inclined surfaces, until the gait of the
walking infant is steady (Adolph et al., 1998; Thelen & Smith, 1994).

With the onset of locomotion interpretation of optic flow is important for
perceiving and acting in a 3-D environment. An infant has to learn to
differentiate between perceiving the movement of an object when the infant is
stationary and self-movement when the object is stationary. Both events will cause the image of the object on the retina to shrink, but differentiation of what or who is moving will occur when the infant can demonstrate size constancy and use of distance cues (Corbetta, Thelen, & Johnson, 2000; Cornilleau-Peres & Gielen, 1996). Changes in optic flow present the infant with an opportunity to learn about velocity, such as learning when to reach for an object that is moving (Van der Kamp & Savelsbergh, 2000). Infants who have locomotor experience appear to utilize optic flow information more appropriately than non-locomotor infants. In an experiment that altered the type of optic information received by 7-9 month old infants (whole room moving or one part of the room moving) only those infants who had locomotor experience compensated posturally for changes in optic information (Higgins, Campos, & Kermoian, 1996).

As has previously been stated, the ability of the infant to determine that an object exists even if the infant has no direct contact with the object is heralded, in classical Piagetian theory, as an important determinant of cognitive change. The role of locomotion has been considered in the development of object permanence.

In a variation of the Piagetian A-not-B experimental paradigm using two different colored cups, a toy was hidden under one cup and the infant was then rotated 180 degrees around the table so that the cup with the toy was now at the opposite hand. After adjusting for the age of the infant the authors of the study found that infants who had crawled earlier, and therefore had more crawling experience, were significantly more likely to correctly find the toy on the first trial after rotation. The authors conclude that locomotor infants use spatial encoding
strategies outside of reference to the self to locate the object and that locomotion is a mechanism for the development of such strategies (Horbin & Acredolo, 1986). It has also been suggested that correctly searching in the new location for the hidden object demonstrate that the infant is using cognitive processes, such as working memory to maintain a truer representation of where the object has been hidden in relation to the spatial position of the infant. Infants who gain spatial cues by independently moving about their environment may be using an interactive mechanism for demonstrating (if not developing) an important cognitive function (object permanence). Object permanence coupled with memory demonstrates an important change in the way in which infants symbolically rather than concretely represent the existence of animate and inanimate objects.

Research has also demonstrated that infants with developed locomotor skills are better able to attend to gestures that refer to distance than prelocomotor infants (Campos et al., 2000). Infants who move about independently have main caregivers that frequently have to communicate to their infant about avoiding obstacles that are at a distance. As such locomotor infants are better able than prelocomotor infants to follow arm movements or other forms of communication that refer to a distal object. This difference in referencing distal objects is found even when the age of the infant is controlled for, meaning that it is not maturation alone that accounts for the development of referencing behavior. It appears that the length of experience in locomotion is a better predictor of referent behavior than the age at which locomotion began.
Despite variations in the timing of motor milestones and variations in areas of cognitive and perceptual development related to locomotor acquisition, it must be stated that most infants develop locomotor behaviors within a normative time frame. There is no evidence at present that these normal variations in locomotor acquisition affect the global cognitive development of infants. However there are two important considerations to be made for the need to further research the relationship between motor and cognitive development.

First, it is important to fully understand the interrelationship between developmental mechanisms. It appears that locomotion provides a means by which the infant gains information and that in turn this collection of information may provide an impetus for the infant to develop motor and locomotor skills that enhance the perceptual and cognitive ability of the infant. Such an approach, supported by dynamic systems theory, would elevate the importance of locomotion beyond a mechanical means of self-transportation to an important explanatory and exploratory mechanism for overall development.

Second, when examining the development of infants who have been exposed to insults and trauma during gestation and infancy, delays in motor development may provide some insight into why the cognitive development of such infants is often delayed. Examining the mechanisms that may explain the relationship between motor and cognitive delay in a population of infants whose development has been compromised may also provide an explanation for the role of motor behavior in the development of infants not exposed to insult during gestation or infancy. Infants whose development has not been compromised may
not show sufficient variance in either the rate at which they develop important motor behaviors (such as crawling and walking), or in the amount of motor activity displayed, to demonstrate that variations in the rate of acquisition and performance of motor behaviors effects performance on more global (and possibly predictive) measures of cognitive development. However, this does not negate the importance of motor behavior for such infants.

Delay in acquisition

As has been stated, the normal motor and locomotor developmental trajectory of healthy infants has provided evidence that locomotion plays a role in the development, display, and refinement of important perceptual, social and cognitive skills. However, when the physical growth of the infant has been compromised through biological and/ or environmental hazards, there is often a corresponding effect on the motor and cognitive development of the infant.

As an example, research on low-birthweight infants has suggested that a continued trajectory of poor physical growth may be associated with a delay in motor and cognitive development. Infants who are born very pre-term (less than 32 weeks) and/or with very low birthweight (less than 1500g) are likely to (compared to infants born at term and/or with weight appropriate for gestational age) continue to have height and weight gains that are at or below the 10th centile at age two years, and this may elevate the risk of these infants for motor and cognitive developmental delays (Connors, O'Callaghan, Gray, Tudhope, Mohay, & Rogers, 1999). Infants with very low birthweight and who maintain height and weight gains below the third centile are particularly likely to have poorer
cognitive and motor development outcomes (measured by standardized tests of development) at age two and 7 years, even when the effects of maternal education and social and economic status (SES) have been controlled for (Samson et al., 2002; Connors et al., 1999). It is not known if the mechanisms that result in poor physical growth directly account for delays in other developmental domains, or if poor physical growth mediates the relationship between the cause(s) of the poor physical growth and motor and cognitive delay.

**Activity**

An important companion to the acquisition of motor and locomotor behaviors is the concept of activity. Research on activity and its relation to developmental outcomes has employed activity as both a measurement of how much and how often a specific locomotor behavior has occurred (Meeks Gardner, Grantham-McGregor, Chang, Himes, & Powell, 1995; Pollitt, Huang, & Jahari, 1999) and as a description a developmentally meaningful behavior (Pollitt, 2000b; Pollitt & Gorman, 1989). For example, research on the effects of protein-energy malnutrition on infant development has considered the energy expenditure involved in various forms of locomotor behavior when defining activity. This approach has measured activity by estimating the energy costs of a locomotor behavior in association with the frequency, and/or duration, and/or intensity of the locomotor behavior (Durnin, 1989; Meeks Gardner et al., 1995; Walka & Pollitt, 2000).
From a dynamic systems perspective reduced activity (lower frequency and or duration) of important high energy locomotor behaviors (e.g., crawling and walking), results in a more limited use of developmentally meaningful exploratory behaviors (or activities) (Wachs, 1989). Reduced activity has been hypothesized to negatively impact developmental outcomes (Jahari, Saco-Pollitt, Husani, & Pollitt, 2000).

The importance of locomotor behavior in the development and refinement of perceptual and cognitive skills has led to research that has tested the hypothesis that the reduced rate of locomotor behavior (activity) is an important mediating variable in the frequently found relationship between malnutrition and infant development (Pollitt, 2000b). For example, in a study conducted in Jamaica the effects of supplementation (energy and micronutrients) and stimulation (psychosocial) on motor activity and the development of stunted (low height for age) children were compared against a same-aged control group of non-stunted children (Meeks Gardner et al., 1995). The infants/children were between 9 to 24 months old at the start of the study and those who were identified as stunted were assigned to either supplementation alone, psychosocial stimulation alone, supplementation and psychosocial stimulation, or control (n=32 in each group). The progress of a group of non-stunted children was also followed over the 24 months of the intervention.

At the start of the study the stunted children were delayed in locomotor development compared to the non-stunted children (using the Griffith Subscales). In addition, the stunted groups had a significantly lower mean motor activity
score than the non-stunted children. In this study activity was measured as a product of the percentage of time that the infants spent in each activity and the estimated energy cost of each activity summed over all activities (Meeks Gardner et al., 1995).

Following supplementation it was found that activity increased among all children and that this was associated with increased age, independent of supplementation status. Further, irrespective of treatment group assignment, the association between activity and psychomotor performance was no longer significant (Meeks Gardner et al., 1995). In contrast, in subsequent analyses using behavioral measures of activity (e.g., exploration and activity) rather than energy expenditure, the authors found that stunted children's behavior was associated with developmental scores on the Griffiths, 12 to 24 months later (Meeks Gardner, Grantham-McGregor, Chang, & Himes, 1999).

A supplementation study conducted in rural Indonesia also found a relation between amount of motor activity and motor development, with early energy and micronutrient supplementation positively affecting the intensity of motor activity and degree of motor development (Jahari, Saco-Pollitt, Husaini, & Pollitt, 2000). In this study motor activity was calculated from the product of the energy cost of a motor/locomotor behavior, the intensity of the performance of the behavior, and the duration of the behavior. There was a greater increase in the frequency of locomotor behaviors that were more energy demanding (e.g., walking), and a sharper decrease in low-energy behaviors (e.g., sitting) for the high energy/micronutrient supplementation group compared to the energy
supplementation only group. It was also found that the high energy/micronutrient supplemented group had higher motor development scores than children receiving the low-energy/placebo and the micronutrient supplement (Jahari et al., 2000). Further analyses of these data demonstrated that among younger infants (12 months), but not older infants (18 months), activity predicted performance on a measure of psychomotor development (Bayley PDI), which in turn predicted performance on a mental index (MDI) (Pollitt, Jahari, & Walka, 2000).

It has been argued that locomotion is not wholly sufficient in itself for cognitive change to emerge, as many of the cognitive and perceptual processes that have been referred to may begin to develop prior to locomotion. Perceptual processes such as depth perceptions are also evidenced when non-locomotor infants reach for occluded objects, or objects within containers. However, current research on motor behavior suggests that the development of locomotion and levels motor activity, supported by important neurological changes, enables the infant to directly interact with the environment and provides a mechanism for the development of perceptual, cognitive and social skills (Campos et al., 2000; Reiser, 2000; Thelen, 2000b).

The concept of meaningful activities has been used in more recent nutritional research to describe the exploratory content of infant motor and locomotor behavior. In particular the role of activity that engages the infant in manipulating objects and moving around the environment has been examined (Pollitt, 2000a). Research on infants from malnourished populations has provided a putative model of the relationship between motor and cognitive development
through the mediation of exploratory behavior. This perhaps affords us the best opportunity for observing variations in motor activity and motor milestone acquisition that can be incorporated into a dynamic systems theory of development (Gorman, 1995; Pollitt, 1996; Pollitt, 2000b; Pollitt & Gorman, 1989).

**Statement of Problem**

Research conducted on infants has shown that locomotion is important for the development of perceptual, social and cognitive skills. Much less is known about the relationship between locomotion (acquisition and activity) and later global measures of infant development. Since locomotion enables the infant to explore his/her environment, it would be expected to contribute to overall infant development. Dynamic systems theory argues that infants’ active exploration of the environment provides a putative explanatory mechanism whereby changes in perceptual experiences become incorporated into the developing understanding and knowledge that the infant gains about the environment.

Exposure to energy deficiency through malnutrition during gestation and infancy has been associated with delay in motor milestone acquisition and reduced motor activity. This finding suggests a putative model for the relationship between how active the infant is and the development of locomotor behaviors that could be further tested in infants. Such a model would test the dynamic systems perspective on development that emphasizes the interaction that the infant has with the environment as providing both opportunity and motivation.
to develop new locomotor behaviors (Campos et al., 1999; Thelen & Smith, 1994).

Pollitt (2000b) argues that motor development and activity are functionally important for cognitive development, and coupled with emotional regulation these domains contribute to overall child development. Motor abilities are an important element in measures of infant development. For example, the most widely used clinical and research measure of infant development, the Bayley Scales of Infant Development-II (Bayley, 1993), has scales that measures both psychomotor and mental development. The substantial correlation (. 50 to . 80, Bayley, 1993) between psychomotor (measuring fine and gross motor abilities, and motor coordination) and mental scales (measuring perceptual discrimination, sensory-motor integration, and object permanence) suggests that these two domains may tap into similar developmental processes, and/or that change in one domain affects performance in the other. This may suggest that in infancy changes in motor development promote changes in cognitive development (Pollitt et al., 2000).

Current Study

The purpose of this current study was to add to the developing field of dynamic motor research by examining the interrelationship between locomotor and cognitive change over the first year of life in a sample of infants. The literature review of current theories of motor development indicated that locomotor behaviors, especially those that engage the infant and child in the exploration of the environment, are instrumental in organizing and providing
impetus for changes in perceptual, cognitive and social development. It has been proposed in the literature on activity and development that infants and children who are active in using locomotor behaviors (in comparison with less active infants and children) are more likely to be experiencing stimulation that is important for development (Gibson, 2000; Wachs, 1989). There are also biological changes during fetal and infant development that support the interrelationship between sensori-motor and cognitive development.

In this current study it was anticipated that if locomotor behavior and cognitive development were interrelated, then infant measures of cognitive and psychomotor development would be related to locomotor acquisition and activity. For example, it was expected that locomotion and motor activity would affect the visual discrimination ability of the infant. It was also of interest to determine if engaging in more passive behaviors (i.e., sitting, lying or being carried) would affect the cognitive and psychomotor development of the infant. If infants spend less time in locomotor behaviors that promote an active exploration of the environment then the cognitive and perceptual abilities influenced by locomotor behaviors may be affected.

It was also posited, from a dynamic systems perspective that the acquisition of a locomotor skill that the infant used in exploring the environment would be a base on which the infant would develop and use new locomotor skills. Rather than being viewed as a product of maturation, it was suggested that the motivation for such muscular and locomotor reconfiguration comes from the opportunity the new motor behavior affords infants’ to interact with the
environment, to achieve the goals and rewards that exploring the environment offers. As such it is anticipated that infants who are active in using locomotor behaviors will be more interested and likely to develop new locomotor behaviors that further extend the mobility and exploration of the infant.

Much of the research to date on infant motor activity and locomotor development had not involved measures of infant motor and cognitive development over multiple time points. Nor had the issue of the interaction between the consistency in the rate of achievement of locomotor behaviors, infant activity and infant performance on measures of cognitive and psychomotor ability been addressed. In the review of literature there also had been no identified research that indicated that rates of motor activity and the age of motor milestone acquisition have a bi-directional relationship (i.e., early acquisition of a locomotor behavior effects motor activity which in turn effects subsequent acquisition of locomotor behaviors). As such it was of interest to determine if active infants were more likely to develop locomotor skills early, and if this interrelationship was predictive of infants' performance on more global measures of cognitive and psychomotor development.

Some of the infants from the current study sample may have been exposed to mild iodine deficiency (i.e., at birth serum TSH levels of > 5mIU/L that occurs in 3-19.9% of the neonatal population of the area) (see: Method), and the effects of this micronutrient deficiency (referred to previously) had to be considered, as these may explain some of the variance in motor behavior among the sample. It is estimated that over two billion of the world's population live in areas that are
iodine deficient, and as such are exposed to the attendant hazards of a range of disorders known as Iodine Deficiency Disorders (IDD) (DeLange, 2000; Hetzel, 1989, 2000; Kretchmer, Beard & Carlson, 1996).

To date most of the research into IDD has been conducted in areas of severe ID and has shown the consequences of the disorder for the fetus (abortion, stillbirths) and infant (cretinism, psychomotor and cognitive deficits) (Delange, 2000; Fierro-Benitez et al., 1982; Haddow et al, 1999; Hetzel, 1987). In children and adults hypothyroidism has also been associated with lethargy and general reports of low energy levels (Hetzel, 1987). In addition, the benefit of iodine prophylaxis on reversing the effects of severe ID on fetal development has also been demonstrated (Connolly, Pharoah, & Hetzel, 1979; Delange, 1995; Hetzel, 1983; Jiang X, et al., 1994; Lucas, Morley, & Fewtrell, 1996; Morreale de Escobar, Obregon, & Escobar del Rey, 2000; O’Donnell et al, 2002; Pharoah, Butterfield, & Hetzel, 1971). Limited research in areas of mild ID indicates that even in the absence of the more severe motor and cognitive deficiencies associated with cretinism and goiter, infants and children exposed to mild ID do not perform as well as children who are not ID on tests of motor and cognitive skills (Lombardi et al., 1995).

The effects of parental demographics (e.g., income, education, age, intelligence, and occupation) and infant anthropometrics (e.g., birthweight, gender, and gestational age) factors were also considered as possible covariates in this current study.
HYPOTHESIS

The data for this study came from a larger study that tested the relationship between subclinical maternal hypothyroidism and infant developmental outcomes. In a randomized clinical trial, prepregnant women were assigned to either iodized oil or placebo oil supplementation groups. The hypotheses and predictions being tested from the clinical trial study do not overlap with those that were tested in the current study (see, Gorman et al., unpublished manuscript).

This current study was based on a central hypothesis that both the development of locomotor behaviors and the amount of locomotor activity are fundamental components of infant psychomotor and cognitive development. It was hypothesized that variations in the timing of locomotor milestones that lead to locomotive behaviors (e.g., age to attain creeping, crawling, standing, and walking), and variations in infant locomotor activity itself, result in variations in infant performance on measures of cognitive and psychomotor development. The specific research predictions and questions addressed in the analyses also took into account the possible interrelationship between locomotor milestone acquisition and activity. It was of interest to determine if infants who developed locomotor behaviors early were also likely to be more active (or vice versa), and if these interactions were more predictive of infant cognitive and psychomotor development than either motor activity or the age of locomotor milestone acquisition alone.
There were three main research predictions, with attendant questions, that were posited in this current study. The predictions and questions were tested on the sample described in the Method section.

Prediction 1

A higher score on infant measures of cognitive and psychomotor performance could be predicted from infants’ early progress in the attainment of locomotor behaviors (i.e., crawling, creeping, standing and walking).

What are the locomotor behaviors that predicted infant performance in measures of cognitive and psychomotor development? It was expected that higher scores on the FTII (Fagan Test of Infant Intelligence, Fagan & Shepherd, 1987) at 7 months could be predicted from the age that infants creep and crawl. It was expected that higher scores on the PDI (Psychomotor Development Index, from the Bayley Scales of Infant Development II, Bayley 1993) and MDI scores (Mental Development Index from the BSID-II, Bayley 1993) at 12 months could be predicted from the age of attainment of creeping, crawling, standing, and walking. This would result in significant negative standardized regression weights (i.e., negative correlation) between the age of acquisition of locomotor behaviors and the developmental outcomes.

Prediction 2

A higher score on infant measures of cognitive and psychomotor performance could be predicted from higher rates of locomotor activity and lower rates of motor passivity (measured at 6, 9, and 12 months).
Did the rates of motor passive and/or locomotor active behavior at 6 months predict performance on the FTII? Similarly, did the rates of motor passivity and/or activity measured at 9 and 12 months also predict performance on the PDI and MDI? It was expected that high rates of locomotor activity at 6 months would predict higher scores on the FTII, and that higher rates of locomotor activity at 9 and 12 months would predict higher scores on the PDI and MDI. This would result in significant positive standardized regression weights (positive correlation) between the relevant locomotor activity and the developmental outcomes. It was expected that high rates of motor passive behaviors at 6 months would predict lower scores on the FTII, and that higher rates of motor passivity at 9 and 12 months would predict lower scores on the PDI and MDI. This would result in significant negative standardized regression weights between the relevant motor passive measure and the developmental outcomes.

Prediction 3

Locomotor activity (measured at 6, 9, and 12 months) would interact with the age of locomotor attainment in predicting infants’ scores on the measures of cognitive and psychomotor development.

1. Was there a correlation between the rates of infant motor passive behaviors (e.g., lying down, sitting, being carried) and/or active locomotor behavior (e.g., crawling, creeping, standing and walking) at 6, 9, and 12 months and the timing of attainment of locomotor behaviors (i.e., age of creeping, crawling, standing, and walking)? It was expected that there would be significant
negative correlation between the rates of infant locomotor activity and the age at which the locomotor behaviors were attained, but significant positive correlation between the rates of infant motor passivity and the age at which the locomotor behaviors were attained.

2. Was the classification of infants' based on the age of acquisition of locomotor behaviors relative to the mean (i.e. earlier than average, at the average, or later than average) associated with significant differences in the rate of change of locomotor activity between 6 and 12 months? It was expected that infants who attained locomotor milestones earlier than average (group 1) would have a significantly greater change in their rates of active behavior over this time frame when compared to those classified as achieving locomotor milestones at the average age (group 2), and those later than the average age (group 3).

3. Did the rate of locomotor activity, at 6, 9, and 12 months, mediate the association between the age of attainment of locomotor behaviors and performance on the FTII, MDI, and PDI? In testing a developmental model of the interrelationship between locomotor activity and locomotor milestone acquisition, using a predictive path analysis model, it was expected that there would be negative and significant paths between locomotor activity and the age of attainment of locomotor behaviors. It was expected that locomotor activity would be a mediator, as it would have explained the relationship between the timing of locomotor attainment and performance on the FTII, MDI, and PDI (Baron & Kenny, 1986). It was also expected that both locomotor activity and the age of
attainment of locomotor behaviors would have significantly accounted for the variance in infant performance on the FTII, PDI, and MDI.

Additional information on family demographics, neonatal birthweight, gender, and thyroid functioning (TSH) had also been collected, to be analyzed as possible covariates prior to the statistical analyses of the main study predictions. The main dependent variables were infant performance on the FTII, PDI, and MDI. The main independent variables in this current study were: 1) the record of observation of infant motor activity and passivity, and, 2) the parental record of the age at which the infants' attained each of the five locomotor behaviors (i.e., creeping, crawling, standing supported, standing unsupported, walking supported; see, Method).
METHOD

The current study used data from a larger randomized controlled clinical trial of iodine supplementation of women prior to pregnancy, conducted in Hunan Province in the People's Republic of China. A survey of areas in China indicated that Changsha City in Hunan Province, the site of the clinical trial, has very little goiter (<10%) with no new cretins recorded for the past 40 years, and was therefore an area of mild iodine deficiency. Although some local salt was iodized, much of it fails to meet recommended standards. The agreement of local health officials and the local university made this a suitable site for the study.

The original supplementation study involved the recruitment of women at the time of marriage registry. Over 1300 women were recruited into the original study. After giving full permission to be involved in the study, women were randomly assigned into treatment (iodine supplementation) and control groups ( placebo oil). To ensure adequate numbers of women with elevated TSH levels (i.e., >5mU/L whole blood) the ratio of women in the placebo and supplemented groups was 3:1. Supplementation was given on a yearly basis to ensure that at the time of pregnancy the supplemented women would be iodine replete. The women were followed during pregnancy and their infants were followed over the first year of life. There was a total of 311 pregnancies from the original recruitment sample, 220 (71%) from the control group and 91 (29%) from the treatment group. A total of 269 infants were followed for the first year of life: 49% were female. The selection criteria involved only infants who were born at full term.
and who were not small for gestational age (for a complete description of the supplementation study, see, Gorman, unpublished manuscript).

Current Study

Participants

The sample for this study consisted of 157 infants on whom complete motor milestone, motor activity, and cognitive data were available (see: Data screening section on page 57). The mean birthweight of the infants was 3.4kg or 7.5lbs (SD = .51kg or 1lb, n=147, range 2.15- 6.6 kg or 4.7-13.2 lbs.) with a mean gestational age of 39.7 weeks (SD=1.7, n=97, range 33-43 weeks), 53% of the infants were male (n=81; female n=72).

Measures

Motor milestone record.

Using a pictorial booklet, the age at which an infant attained 17 motor behaviors was recorded (Appendix A). Information on the age of motor milestone acquisition was obtained from the biweekly record kept by the main caregiver. For this study, motor milestone behaviors that were specific to infant locomotion (i.e., creeping, crawling, standing supported, standing unsupported, walking supported, and walking unsupported) were included for analysis. The information recorded on each behavior represents, in days, the age at which the infant first attained each behavior. The low incidence of reports of the age at which independent walking (i.e., walking unsupported) was achieved (N=132) resulted in this variable not being included from this data set. The record of
motor milestone was first developed to examine the effects of nutritional supplementation on motor development in a malnourished population in Indonesia (Pollitt, 2000a). This record was adapted for use in the main iodine supplementation study (Gorman, unpublished manuscript). The pictorial examples used in this booklet are taken from McGraw’s (1943) classical description of motor milestone acquisition in the first year.

Motor activity

Using a computerized program, the frequency, duration, and percentage of time that infants spent in 66 different activities (including motor activities, social activities, and feeding) were recorded by trained observers during two-hour observational visits conducted at three time points (6, 9, and 12 months). For the purposes of this research two motor composite variables (motor active and motor passive) were created (see, Data Transformation). The computer program used was adapted from research conducted of the effects of nutritional supplementation on motor activity in a malnourished population in Indonesia (Pollitt, 2000a). The computer program was adapted and extended for use in the main iodine supplementation study.

Fagan Test of Infant Intelligence (FTII, Fagan, & Shepherd, 1987).

The FTII is a measure of infant cognitive processing that is administered between 66 and 71 weeks post conceptual age (i.e., when the infants are between six and seven months old) (Fagan & Shepherd, 1987). The FTII is a test of infant visual attention and information processing, and uses a paired stimuli paradigm to
assess the preference for infants’ gaze at novel rather than at familiar stimuli. There is evidence that performance on the FTII can be indicative of future performance on measures of cognition (Fagan & Detterman, 1992; Rose Orlian, 2001). The mean novelty preference score is 59% (a ratio of gaze at familiar to gaze at novel stimuli) with a standard deviation of 6.5%. Novelty preference scores of < 53% have been associated with later developmental delays (Fagan & Detterman, 1992).

*Bayley Scales of Infant Development- II (BSID-II, Bayley, 1993).*

The BSID-II was administered when the infants were approximately 12 months. This measure of infant development provides a standardized score of infant psychomotor development (Psychomotor Development Index (PDI)) and a standardized score of infant cognitive development (Mental Development Index (MDI)). The PDI measures an infant’s control of gross and fine motor movements, and coordination. The MDI provides a measure the infant’s cognitive, perceptual, language and object constancy. Both scales have a mean of 100 and a standard deviation of 16. Data on the BSID-II show that it has a test-retest reliability of .83 for the MDI and .77 for the PDI when the median retest was 4 days (Bayley, 1993).

*Covariates.*

Information on infant gender, gestational age, birthweight, and cord-blood TSH levels were collected at, or shortly after birth. Infant thyroid status was determined from whole blood samples taken from the umbilical cord shortly after birth and assays sensitive to levels of TSH (thyroid stimulating hormone,
thyroxine) determined thyroxine levels. Levels of TSH in neonates are considered to be sensitive indicators of iodine deficiency as TSH tends to be elevated (> 5mU/L) in iodine deficient populations during the perinatal period. A range of additional parental variables (age, education, occupation, income and intelligence) were also included to determine if they were associated with the performance of the infants in the main variables of interest (motor activity/passivity, age of locomotor behaviors, performance on the FTII, PDI, and MDI).

**Procedures**

The recruitment of the women into the original iodine supplementation study has already been described. After recruitment, but prior to supplementation, venous blood samples were drawn to measure the levels of prepregnancy TSH. All women were then monitored until pregnancy, and were followed through pregnancy and over the first year of the infants’ life. All women received the standard medical care from their local community health center.

A member of the research team visited the women shortly after the birth of their infants and explained the motor milestone acquisition record that each mother (or other main caregiver) was asked to complete.

Trained testers from Hunan Medical University School of Public Health conducted home visits when the infants were 3, 6, 9, and 12 months, to collect data on infant development and parental demographics. During the home visits it was expected that the infants’ would be alert and active during this testing. If the
infant was unwell or asleep during the arranged testing time, the visit was rescheduled for another date.

Three month visit

The testers gathered information from the motor milestone acquisition record maintained by the primary caregiver and entered this into a central data file. The caregiver was instructed to continue the motor milestone acquisition record. At this visit, information on parental variables (i.e., age, education, occupation, and income) and infant health and growth was updated.

Six/seven month visit

At this visit the FTII and the first two-hour observation of infant activity were conducted. When observing the infants' activity the testers entered a code for each behavior as it occurred in real time directly onto a computer. The testers also updated the motor milestone acquisition record and information on parental variables and infant health and growth.

Nine month visit

The second two-hour observation the infants' motor behavior was conducted. The testers also updated the motor milestone acquisition record and information on parental variables and infant health and growth.

Twelve month visit

The trained testers administered BSID-II. The third two-hour observation of infant motor behavior was conducted. The testers also updated and collected
the motor milestone acquisition record and information on parental variables and infant health and growth.

Ethical considerations

The American Psychological Association (1992) has determined a code of ethics that should govern the design and conduct of all psychological research that affects humans and animals. These guidelines are in addition to the requirements of the Institutional Review Board that gives approval for any research that is to be conducted by the members of its university.

Central to the ethical guidelines of the APA is the right for all participants in psychological research to be fully informed of the purposes of the research, including any attendant risks involved in participation. All participants have to give their full consent, or the consent of their legal guardians in the case of minors, before any conditions of the research are applied to the individual. In this supplementation study when the women registered for permission to become pregnant a member of the research team explained the details of the study, including the purpose of the study and that the woman would not be aware of what treatment condition she was being randomly assigned to. It was also explained to each woman that by agreeing to participate in the study her infant would be followed up over the first year of life, but that at any time the woman could withdraw from any further participation in the study. The confidentiality of each participant was assured by allocating a number to all data collected.

It is also incumbent on all researchers to ensure that no participant is exposed to any undue harm or stress during the course of the research. All
women who participated in the study were given standard instructions about diet and health during pregnancy. Included in those instructions was the recommendation that iodized salt should be consumed as part of a regular diet. Although only one group of mothers received iodine supplementation, the positive effect that this may afford to the mother and her infant has not yet been fully established for those who live in areas of mild iodine deficiency. Therefore it was deemed that the placebo group was not being denied any established iodine prophylactic that is administered as part of the normal care for pregnant women in Hunan Province.

Statistical Analysis

Data Transformation

Prior to conducting the statistical analyses two important data transformations were conducted.

First, the mean age at which the main caregiver recorded the achievement of each of the five locomotive milestone behaviors (creeping, crawling, standing supported, standing unsupported, and walking supported) was calculated. For each infant a deviation score (z score) was calculated based on the difference of the individual age at acquisition of each locomotor behavior from the sample mean age at acquisition. Infants were to be classified into earlier than average (more than 1 standard deviation less than the mean age of acquisition), average (within 1 standard deviation above or below the mean age of acquisition), or later than average (more than 1 standard deviation above the mean age of acquisition)
locomotor development groups based on the consistency of their deviation score across the five locomotor behaviors.

However, it was found that no infant had a consistent pattern of earlier than average age (group 1), average age (group 2), or later than average age (group 3) across the five locomotor behaviors and very few showed consistencies across 4 of the 5 locomotor behaviors. It was therefore decided to determine a category of development based on the modal development category obtained. This meant classifying only those infants who demonstrated overall consistency, either in being in group 1, 2, or 3 across at least three of the five locomotor behaviors of interest. This resulted in 34 infants classified into group 1, 49 into group 2, and 26 as into group 3 (n=109).

Second, a subset of the recorded 66 activity variables were summed to reflect the frequency of motor active (creep, crawl, stand supported, stand unsupported, walk supported, and walk unsupported) behaviors, and motor passive (lying down, sitting supported, and being carried) behaviors exhibited by the infants. The frequency (rather than duration or intensity) of the occurrence of the motor active or motor passive summary variable was used in the analyses of the collected information. The active motor variables included directly corresponded to the locomotor milestone acquisition variables that were recorded by the main caregiver. However, it was also possible to record the frequency of independent walking activity of the infant during this computerized record.
Data Analyses

All inferential statistical analyses and examination of univariate outliers were conducted using SAS for Windows (Version 8), and SPSS (Version 11) was used in calculating multivariate outliers. The linear relationship among variables was graphed using MATLAB.

The analysis was conducted in two main parts:

1. Initially the data were screened for univariate and multivariate normality. Data from the key variable, age of attainment for the locomotor behaviors (i.e., age creep, age crawl, age stand supported, age stand unsupported, age walk supported) was checked for missing data, and an appropriate data substitution method was employed. Descriptive analyses of the main independent and dependent variables, infant neonatal and parental demographic variables were conducted. This included the calculation of means, standard deviations and range of scores on the variables. Bivariate correlations between the variables were also conducted. A series of correlation analyses and tests of group differences were conducted between the main dependent variables and the parent demographic and infant anthropometric data to determine if these variables were to be included as covariates when the inferential analyses of the data was conducted.

2. Following the results of the descriptive analyses of the data, inferential statistics were conducted to test the three research predictions and the attendant questions. This involved the use of bivariate correlations, standardized regressions, hierarchical linear modeling, MANOVA’s, and a regression path analysis model.
Probability and Power

Unless indicated all analyses were conducted using an a priori alpha of .05. In analyses that involved multiple correlations, a more stringent Bonferroni correction was employed to control for the effect of multiplicative probability. The use of MANOVA's, with follow up post-hoc ANOVA's, controlled for family wise error rates arising from evaluating the effect of an independent variable (e.g., gender, parent occupation) on multiple outcome variables (Tabachnick & Fidell, 1996). When interpreting the results of the MANOVA's Wilks' Lambda (λ) was used to evaluate the effects of the independent variable on the linear combinations of dependent variables.

Prior to conducting the inferential analysis of the data a power analysis was conducted. This statistical method evaluates the effectiveness of the experimental design to detect any true significant effects or differences in the proposed research models. In any experimental design the sample size and the amount of variance explained by the research model directly effect the interpretation of the statistical analyses. Research models that employ a small sample size to determine a small percentage of any explainable variance will have low statistical power. As a criterion it is recommended that the computation of sample size and effect size should yield an expected power of at least .80 (Tabachnick & Fidell, 1996). For this study power was calculated on the proposed regression path analysis, which was considered to be the most statistically demanding method of data analysis employed in this study (Murphy & Myors, 1998). Using a sequential approach that calculated the change in explained variance across the predictor and dependent variables it was estimated...
that for a small effect size (i.e. $R^2 < .10$) the statistical power associated with this model was at least .77 and less conservatively estimated to be .80 or above (Rossi J, March 2003, personal communication).
RESULTS

Descriptive Statistics

Data Screening

*Missing Data, Normality, and Outliers*

The size of the sample data set was derived from the caregivers’ recorded age at which the infants attained the five locomotor behaviors of interest (i.e., age of creeping, crawling, standing supported, standing unsupported, and walking supported), and this resulted in a sample of 157 infants. This sample size was determined by examining the complete and missing data across the five locomotor behaviors of interest (creeping, crawling, standing supported, standing unsupported, and walking supported). Complete observations for the age at which creeping was acquired became the initial determinant of the sample size (n=162).

Criteria were developed to guide the substitution procedure for missing data.

1. Observations were omitted if more than one locomotor behavior had no age of attainment.

2. Observations were omitted if the age of attaining the final locomotor behavior (walking supported) and subsequent motor behaviors were missing (this reduced age of creeping data to n=159).
From the results of an initial correlation analysis it was demonstrated that there were significant and positive correlations for the age at which infants' attained these five locomotor behaviors, with a lag of one resulting in the strongest correlation (Table 1). It was therefore decided to use a series of regressions to predict missing values in the locomotor variables (i.e., age of creeping predicting the missing values in the age of crawling, the age of crawling predicting missing values in the age of standing supported, age standing unsupported predicting missing values in the age of walking supported) (Tabachnick & Fidell, 1996). After screening the substituted data it was found that two observations were univariate outliers (i.e., SD > 3.5) and these were excluded from further analysis. Consequently, the complete data set with substituted values for the age of attainment of the five locomotor behaviors consisted of 157 infants. Information on the locomotor behaviors before and after missing data substitution is given in Tables 2 and 3; Table 4 provides information about the intercorrelations between the 5 locomotor behaviors after missing data were substituted.

When substituting missing data it was considered important to determine that the data were missing at random. This was achieved by using a series of t-tests conducted on the variable with the most missing data (age of crawling). Missing data for age of crawling and present data for age of crawling were used to classify the groups. Differences between these groups regarding parental factors (Table 5) were evaluated using a series of t-tests; no significant differences were found. It was decided that the data were missing at random.
When conducting the inferential analysis no further substitution for missing data on any other variables was made; therefore the sample size for individual analysis may be less than 157.

The linear relation among pairs of scores of dependent and independent variables (e.g., scores on the FTII, PDI or MDI with frequency of motor activity/passivity, or age of attaining the five locomotor behaviors) was conducted by an examination of the scatterplots (using MATLAB). This revealed that the variables all approximated to a linear relationship. Using a statistical program (SAS) the univariate skewness and kurtosis was examined for all of the independent and dependent variables. The results demonstrated that there were no unacceptable skewness and kurtosis values across these variables (i.e., the values of skewness or kurtosis values divided by their respective standard errors did not produce a significant t-statistic, \( p < .05 \) (Tabachnick & Fidell, 1996).

Multivariate outliers were detected by using Mahalanobis distances on the residuals from multivariate procedures. This technique determines the difference between each residual and the centroid (the mean distances derived from all of the variables), using a critical \( \chi^2 \) value with the number of independent variables as the degrees of freedom (df), and an alpha level of .001 to determine the significance of the largest residual values (Tabachnick & Fidell, 1996). The outcome variables of interest (scores on the FTII, PDI, and MDI) were entered into a regression procedure as predictors, with subject ID as the dependent variable. In this study df = 3, \( \chi^2 \) produced a critical value = 16.27. Using the Mahalanobis distances procedure the largest residual was 15.67, as this was less
than the critical value (16.27) it was therefore concluded that there were no multivariate outliers in this data set.

Sample Descriptives

Participant Characteristics

The anthropometric characteristics of the infants are presented in Table 8. As indicated by the selection procedure these infants are of normal gestational age (M = 39.7 weeks) and birthweight (M = 3.4kgs; or 7.4lbs). The mean maternal venous blood levels of TSH were 2.67 mU/L (n=152), and the mean neonatal cord blood TSH level was 4.46 mU/L (n=152) (Table 8).

Information about the infants’ parents show that most frequently reported occupation, of both mothers’ and fathers’, was a factory worker (Table 10). The average age of mothers was 26 years and 31 years for fathers. Parents had completed an average of 13 years of education, which is equivalent to finishing high school, and some parents reported university and graduate education. On the assessment of parent intelligence (Ravens Progressive Matrices (RPM)) typically both parents performance was at a median level (RPM median = 50), although there is wide variability in the performance of mothers and fathers. There was a large range of reported family incomes (in Yen), that was significantly different across the reported occupations for both mothers (F= (4, 109), =23.1, p > .001) and fathers F= (4, 119), =28.9, p > .001) (Table 9).
Measures

Motor Milestone Record

In general infants showed a steady increase in attaining more complex and independent locomotor behaviors over time, which is in keeping with developmental theory. Infants on average started to creep at about 7 months, crawled at nearly 9 months, could stand unsupported by just over 10 months, and began to walk supported at around 11 months. There was a substantial range in the age at which the infants attained each of these locomotor behaviors (Table 3). The age of attainment of locomotor behaviors was positively and significantly correlated across these five behaviors indicating that infants showed consistency in the rate at which they attain these behaviors (Table 4).

Motor Activity Record

An observation of the mean frequency of motor active and motor passive behavior, recorded at 6, 9, and, 12 months, demonstrated a general trend that infants increased the frequency in which they engaged in active behaviors (i.e., creep (C), crawl (CR), stand supported (SS), stand unsupported (SU), and, walk supported (WS)), and decreased the frequency of passive behaviors (i.e., lying down, sitting supported, and being carried) over time (Table 11).

Infant Cognitive and Psychomotor Development

Information on the measures of cognitive and psychomotor development, suggest that the mean infant performance on the FTII (M = 57.3), PDI (M = 111.6), and MDI (M = 114.7) was within the normal range as described in the
significantly higher scores on the PDI at 12 months than infants who developed these locomotor behaviors later.

Motor Activity and Motor Passivity

The frequency of motor activity was significantly and positively correlated over the three time points that the motor activity data was collected. The correlation was strongest between immediately preceding points of the data collection (Table 15). There were also positive and significant correlations among the motor passivity variables and between the motor active and motor passive variables. That is, infants who were high on activity also spent significantly more time on passive motor behavior as well.

Motor Activity and Cognitive and Psychomotor Development

After controlling for multiple comparisons only motor activity at 12 months remained positively and significantly correlated with infant performance on the PDI. Infants who were more frequently engaged in active locomotor behaviors at 12 months (i.e., C, CR, SS, SU, and WS) achieved significantly higher scores on the PDI (Table 16).

Covariates

Parental demographic and infant anthropometric variables were considered as possible covariates in the prediction of infant cognitive and psychomotor performance. There were no significant correlations between parental age, education, intelligence, or family income and infant performance on the FTII, PDI, or MDI (Table 17). There were no significant correlations between
these parent demographic variables and the age at which infants attained the five locomotor variables, or on frequency of motor activity (Table 18, Table 19). The association between parent occupation (as a categorical variable) and infant attainment of locomotor behavior, infant activity at 6, 9, and 12 months, and scores on the FTII, PDI, and MDI were evaluated using a series of one-way MANOVA's (Appendix B). There were no significant main effects for any of these parental demographic variables on the measures used in this research.

After controlling for multiple analyses, there were no significant correlations between the frequency of infant activity and passivity at 6, 9, and 12 months and infant birthweight, gestational age, or TSH levels (Table 20). The age at which the locomotor behaviors were attained was also not significantly correlated with infant birthweight, gestational age, or TSH levels (Table 21). A series of one-way MANOVA's indicated that the age of attainment of the five locomotor behaviors, and the frequency of infant activity and passivity at 6, 9, and 12 months, did not vary by gender (as a categorical variable) (Appendix B). Infant performance on the FTII, PDI, and MDI was not significantly correlated with infant birthweight, gestational age, or TSH levels (Table 22). A MANOVA was conducted to test the effect of infant gender (as a categorical variable) on performance on these outcome variables. The results of this analysis showed that there was no main effect of gender on infant performance on the FTII, PDI or MDI (Appendix B).
From the analyses described above it was decided that further statistical analyses did not have to control for the effects of parental and infant anthropometric characteristics.

Treatment Effects

As has previously been mentioned, this current research is part of a larger clinical trial that involved the random allocation of women prior to pregnancy to groups that received iodized oil or a placebo oil capsule. To determine the effects of treatment versus placebo condition on infant performance a series of one-way MANOVA's were conducted. The results of these analyses show that treated infants (i.e., mother received iodized oil capsule) \( n=48 \) did not significantly differ from placebo infants \( n=109 \) in performance on the FTII, PDI, or MDI. There were also no significant differences found across the mean age of attaining the five locomotor behaviors or of the mean frequency of motor active or passive behavior at 6, 9 or 12 months (Appendix B).

Testing Of Predictions

The Prediction of Infant Cognitive and Psychomotor Performance from the Age of Motor Milestone Acquisition

It was expected that scores on the FTII, PDI, and MDI could be predicted from the age that infants attained the five locomotor behaviors. Following the results of the bivariate correlations, the age of standing unsupported and walking supported was entered into two standardized regressions to predict performance on the PDI. The results from the standard regressions are shown in Tables 23 and 24. These results indicate that standing unsupported accounted for 4% of the
variance in PDI scores ($F(1, 152) = 7.97, p< .01$) and that walking supported predicted 5% of the variance in PDI scores ($F(1, 152) = 8.79, p < .01$).

The Prediction of Infant Cognitive and Psychomotor Performance from the Frequency of Infant Motor Activity and Passivity

Infants' active and passive behavior at 6, 9, and 12 months was expected to predict infant performance on the FTII at 7 months, and high frequencies of infant passive motor behavior at 6 months were expected to predict lower scores on the FTII at 7 months. Further high frequencies of motor active behavior at 9 and 12 months were expected to predict higher scores on the PDI and MDI at 12 months. Higher frequencies of motor passive behavior at 9 and 12 months were expected to predict lower scores on the PDI and MDI at 12 months. Following the results of the bivariate correlations (Table 16) motor activity at 12 months was entered into a standardized regression to predict performance on the PDI. The results from the standard regression are shown in Table 25. These results indicate that 12 months activity accounted for 4% of the variance in PDI scores ($F(1, 152) = 6.65, p<.01$).

The Interaction between the Timing of Locomotor Acquisition and Motor Activity in Predicting Infant Cognitive and Psychomotor Performance.

This prediction tests whether the association between the timing of locomotor acquisition and activity account for variation in the developmental outcomes. The results of the bivariate correlations revealed a general pattern of associations with earlier acquisition of locomotor behaviors associated with greater amounts of locomotor activity, particularly at 9 and 12 months (Table 13).

To determine if an interaction between locomotor attainment and amount
of locomotor activity predicted any of the variance in the developmental outcomes a regression path model was developed. This model was also developed to determine the direction of influence between locomotor attainment and locomotor activity in predicting variance in PDI and MDI scores. It could have been that early locomotor acquisition resulted in greater motor activity, or it may have been that infants who were more motor active were likely to develop new locomotor behaviors earlier.

The path model evaluated a possible mediating relation between the frequency of motor activity at 6, 9, and 12 months, and the age of attainment of locomotor behaviors in predicting infant performance on the developmental outcomes. As neither the ages of acquisition of the five locomotor behaviors nor the frequency of infant motor activity at 6 months were predictive of performance on the FTII, it was decided to include only the PDI and MDI in this developmental path model.

As it was of interest to determine how activity and locomotor attainment over time interacted in predicting performance on the MDI and PDI all of the activity and locomotor attainment variables were entered into a path regression model. The model was developed to reflect predictive paths between the time that the activity measure was administered (at 6, 9, and 12 months) and the mean ages at which each of the locomotor variables was attained (Table 3). Therefore activity at 6 months predicted to the age of creeping and crawling, the age of crawling predicted to 9 month activity, etc. Predictive paths were developed between all of the activity variables and between all of the locomotor attainment
variables. Infant performance on the MDI was not predicted from either the frequency of motor activity (at 6, 9 or 12 months) or from the age of attaining the locomotor behaviors, but the significant and positive correlation between PDI and MDI ($n=154, r= .53, p < .001$) led to the inclusion of a predictive path between PDI and MDI in this model. The proposed model is detailed in Figure 1.

The paths that were tested in the model were evaluated against recommended fit indices; namely that the $\chi^2$ of the proposed model when tested against a null hypothesis model should be non-significant, that the Goodness of Fit Index (GFI) should be $> .90$, and the Root Mean Square Error of Approximation (RMSEA) should not be greater than $.08$ (Raykov, & Marcoulides, 2000). The model represented in Figure 1 did not fully fit the data, so non-significant paths were dropped and additional paths added after examining the residual data.

A second predictive path model was developed (Figure 2) and regression path analysis was conducted. The fit indices of the overall model ($\chi^2= .17, df=15, GFI = .97, RMSEA = .05$) suggest that the revised model is supported by the research data. The path coefficients and explained variance are shown in Figure 2. The results of this developmental path model ($n=153$) (Figure 2) demonstrated the significant and positive correlation across motor activity, with 6 month activity accounting for 9% of the variance in 9 month motor activity, and 6, and 9-month motor activity accounting for 10% of the variance in 12-month motor activity. A significant and positive relationship between the three included locomotor behaviors is also evident. The age that creeping was attained accounts
for 26% of the variance in the age of standing unsupported, and the age of
creeeping and standing unsupported account for 57% of the variance in the age at
which walking supported is acquired. Infant activity at 12 months significantly
and positively correlates with performance on the PDI and the age of walking
unsupported significantly and negatively correlates with performance on the PDI.
Together the age of walking supported and 12-month motor activity predict 8 %
of the variance in PDI performance. The predictive path between the age of
acquisition of standing supported and walking unsupported and 12-month activity
and performance on PDI, accounted for more of the variance on MDI
performance (27%) than the relationship between PDI and MDI performance
alone (25%) ($F_{\text{change}} (1,151) = 1.83$, $p < .10$).

Of particular interest from this revised developmental path model is the
direction of significant mediation paths between motor activity and the age of
locomotor milestone acquisition. The model suggests that frequent motor activity
was predictive of an early acquisition of locomotor behaviors and that the early
acquisition of a locomotor milestone was a predictor of frequent later motor
activity levels. This suggests that infants' activity was not independent of the age
at which locomotor behaviors were attained. That is infants who are more active
develop locomotor skills earlier and the development of locomotor skills in turn
increases the probability that the infant will continue to be active when measured
at a later time. When the results of this path analysis were compared against the
standardized regressions that were conducted, it was found that mediation paths
between motor activity and motor milestone acquisition were significantly more
predictive of infant performance on the PDI ($R^2 = 8\%$) than the age of attaining standing unsupported ($R^2 = 4\%$) and walking supported ($R^2 = 5\%$), or the frequency of 12-month motor activity alone ($R^2 = 4\%$) ($F_{\text{change}}(1,151) = 5.83, p < .05$).

The Relationship between Classification of Locomotor Development and Motor Activity

This question addressed the prediction that the classification of the rate at which infants attain locomotor behaviors was associated with rates of activity between 6 and 12 months. As was explained in the Method section, infants were classified as earlier than average (group 1), average (group 2), or later than average (group 3), in terms of the age at which they attained the locomotor behaviors. This was based on their modal deviation scores (from the sample mean age of attaining each locomotor behavior) across three of the five locomotor behaviors included in the analysis. The age at which the three locomotor development groups attained the five locomotor behaviors is detailed in Table 24.

Prior to looking at differences in the frequencies of motor activity that could be associated with rates of locomotor attainment it had to be determined that across the sample motor activity did significantly change over time. To determine this, two growth analyses were conducted, with change of active or passive motor behavior as the dependent variables and time (6, 9, and 12 months) as the predictor variable. The results of these growth analyses demonstrated that across the whole sample the frequency of motor activity significantly increased over time ($t(318) = 13.95, p < .001$), and the frequency of motor passivity significantly decreased over time ($t(318) = -9.26, p < .001$).
The motor activity levels at 6, 9, and 12 months of the 109 infants who could be classified (groups 1, 2, and 3) were entered into a hierarchical linear growth model to examine if the rate of change in motor activity over time significantly varied as a function of locomotor development classification. The mean ages at which infants in the three locomotor developmental groups achieve each locomotor behavior and the mean activity rates for each category at 6, 9, and 12 months are shown in Tables 26 and 27.

The results of the hierarchical model showed that in general there was a significant rate of change (i.e., steeper slope) in motor activity over time ($t_{(104)} = 10.95, p < .001$). Figure 3 shows this change in motor activity for the three locomotor development groups over time. What can be observed from this graph is that the difference in the rate of change of activity over time became greater between those acquiring locomotor behaviors earlier than or at the average age (groups 1 and 2) in comparison to those classified as acquiring locomotor behaviors later (group 3).

A MANOVA with follow up ANOVA’s was conducted to determine if the difference in motor activity frequency of the three locomotor development groups was significant across all three time points that activity was recorded. The results of the MANOVA ($\lambda = .87, F_{(6,206)} = 2.44, p = .05, R^2 = .13$) and follow up ANOVA’s, indicate that at 12 months those classified as earlier than average age and average age of locomotor acquisition were significantly more active than those classified as acquiring locomotor behaviors later than average ($F_{(2,106)} = 3.90, p < .05, R^2 = .07$).
The results of this analysis of the activity and locomotor acquisition rates of the three developmental groups support the revised path regression model demonstrating that activity and locomotor acquisition are interrelated.

To better understand the infants who comprised these locomotor development groups (n=109) a series of three one-way MANOVA’s were conducted. These analyses used locomotor developmental groups as the grouping variables, and infant neonatal status (birthweight, gestational age, and TSH levels), parental demographics (mother and father age, mother and father education and family monthly income), and cognitive and psychomotor performance as the dependent variables. There were no main effects of locomotor developmental classification on infant neonatal status, parental demographics, or across performance on the FTII, PDI, or MDI (Appendix B). A series of $\chi^2$ analysis demonstrated that infant locomotor developmental groups did not vary by infant gender or parental occupation (Appendix B).

Summary of Results

Locomotor Behavior

The age of development of the five locomotor behaviors used in this study are all positively and significantly correlated, and the early acquisition of standing unsupported and walking supported was predictive of infant performance on the PDI at 12 months. Infants who were classified as acquiring locomotor behaviors earlier than average or at the average age early showed a steeper slope of increase in motor activity over the first year of life than infants classified acquiring locomotor behaviors later than the average age. The age of acquisition of
Motor Activity

The frequency of motor active and motor passive behavior was positively and significantly correlated over the three time points that data were collected. Infants increase the frequency of active motor behavior over time, and decrease the frequency of passive motor behavior over time. A mathematical summary of the reciprocal relationship between the age of attaining a locomotor behavior and rates of infant activity would be $T_a = 1/A$, where $T_a$ is the time to attain a motor behavior and $A$ is the amount of motor activity (Jacobs, P, personal communication, July 2003). A greater level of motor activity at 12 months is correlated with higher scores on the PDI. The frequency of infant motor active or passive behavior was not associated with any of the infant anthropometric or parental variables included in the analyses.

Locomotor Behavior and Motor Activity

Infant motor activity and infant motor milestone acquisition was significantly and negatively related. An examination of this relationship through a developmental path model demonstrates that high levels of infant activity are associated with early development of a locomotor milestone and in turn early locomotor development is related to greater levels of subsequent infant motor activity. The relationship between motor activity and locomotor development predicts more of the variance in infant PDI performance than motor activity or locomotor development alone.
The implications of these findings will be evaluated in terms of the aims and the theoretical basis of this study in the Discussion section.
DISCUSSION

The aim of this study was to examine infant cognitive and psychomotor development from a dynamic systems perspective by analyzing the effects that the age of attainment of five locomotor behaviors, and the frequency of performing such behaviors, had on these indices of infant development. The main findings of this study indicate that the timing of acquisition of locomotor behaviors is reciprocally related to how active infants are and that over time these factors contribute to how infants perform on more global measures of development.

The predictions tested in this study were based on a dynamic systems approach to understanding infant development. Such an approach postulates that infant motor behavior emerges from the direct interaction that the infant has with the environment. Although phylogeny and structure may provide a basis on which change may take place, all aspects of development have to be observed and understood from the context in which they develop (Gottlieb, 1991). As such, according to a dynamic approach many aspects of cognitive, motor, and social development will be interrelated. In particular, the advent of independent locomotion provides a different set of perceptual, haptic, and social experiences. Such experiences allow the infant to integrate sensation and locomotion with changes in cognitive processes to produce changes in behavior.

Central to the research questions being tested in this study was the premise that by attaining locomotor behaviors early (in comparison to the mean age of the sample) and practicing these behaviors (evidenced by the frequency of occurrence of these behaviors at the observational visits), infants would be utilizing motor
behaviors that previous research had identified as being important in the development of perceptual and cognitive skills (Adolph, Eppler, & Gibson, 1993; Campos et al, 2000; Campos, Berenthal, & Kermoian, 1992; Gibson, 2000). It was anticipated in this study that variations in the rate of acquisition of locomotor behavior would also predict some of the variance in performance on more global indicators of psychomotor and cognitive development. Although there have been criticisms concerning the predictive validity of infant measures of development (Colombo, 1993), such measures do enable a comparison to be made about the current level of development of an infant in comparison to developmental norms.

This study also aimed to develop an understanding of the possible interrelationship between motor activity and the timing of locomotor acquisition. In particular it was of interest to determine if active infants were also infants who developed locomotor skills early, and if this interrelationship was meaningful in terms of being able to predict how infants performed on more global measures of cognitive and psychomotor development.

The design of the research enabled data on locomotor milestone acquisition, motor activity and cognitive and psychomotor development to be collected at multiple time points. This meant that change in the frequency of motor activity and the progress of attainment of locomotor skills could be followed and evaluated as predictors of infant cognitive and psychomotor development. It is important to review the findings of this study from the perspective of the theory that informed the tested research predictions.
Age of Attaining Locomotor Behaviors and Infant Development.

It was expected that attaining locomotor behaviors earlier would predict significantly better performance on the FTII (Fagan Tests of Infant Intelligence), MDI (Mental Development Index of Bayley Scales of Infant Development), and PDI (Psychomotor Development Index of the Bayley Scales of Infant Development). As has previously been stated, the age of attaining a locomotor behavior was used as a proxy measure of timing. This prediction was developed from dynamic systems research that has indicated that once infants have reached a level of muscular and skeletal maturity that would support locomotor behaviors, the infant will use these behaviors to explore his/her environment. Dynamic systems theory suggests that the earlier that these behaviors are performed the more opportunity that the infant has to use these behaviors and gain important shifts in perceptual and social processes (Campos et al., 2000; Gibson, 2000; Thelen & Smith, 1994).

The analysis of the data collected on the age at which infants attained the five locomotor behaviors of interest (i.e., C, CR, SS, SU, and WS) shows consistency across these behaviors. This indicates that in general the age of attaining any particular locomotor behavior (relative to the mean group age) was predictive of the age of attaining a later locomotor behavior. However, there was substantial variation within this sample on the ages that each of these locomotor behaviors was attained. For example the reported ages at which infants first walked supported ranged from eight to thirteen months. Variability in the age of attaining locomotor behaviors in infants is consistent with the findings of most of
the dynamic systems theory research reviewed (Reiser, 2000; Thelen & Smith, 1994).

In this study earlier acquisition of standing unsupported and walking supported was predictive of performance on the PDI at 12 months. That is, there was a significant correlation between an early age of attaining these locomotor behaviors and higher performance on the PDI. The PDI is one of the two indices of the BSID-II and measures the infants' control over fine and gross motor skills, motor coordination, and sensori-motor integration (reaching and grasping) (Bayley, 1993). The findings of this study are supported by research that has examined the relationship between locomotor status and the integration of sensori-motor information. Such research has found that locomotor infants in comparison to prelocomotor infants perform better on tasks that require the incorporation of information about optic flow with motor performance, such as integrating sensori-motor information to reach for and grasp a moving object (van der Kamp & Savelbergh, 2000).

It is perhaps not surprising that in this study infant attainment of locomotor skills would be associated with higher performance on the PDI. In research conducted on malnourished populations, the age at which infants develop locomotor behaviors has also been associated with performance on the PDI (Jahari et al., 2000). It has also been found that when parenting practices result in later infant development of locomotion (e.g., Native American children) there has been an association between delayed infant locomotion and performance on
standardized measures of motor development (Peabody Developmental Motor Scales) (Crowe, McClain, & Provost, 1999).

Given the body of research from dynamic systems theory identifying changes in perceptual and cognitive skills related to the acquisition of locomotion, it was expected that the age at which locomotion was attained would predict infant performance on a standardized measure of cognitive ability (MDI). The MDI measures infant performance on language development, problem solving, perceptual and sensory acuity, and habituation (Bayley, 1993). The rationale for this prediction was based on research that has demonstrated that early locomotor attainment was associated with better performance on tasks of specific cognitive and perceptual skills (Bai, & Berenthal, 1992; Bushnell & Boudreau, 1993; Campos et al., 2000). In this study a measure of specific cognitive ability (FTII) and of a standardized measure of cognitive performance (MDI) were utilized.

However, among this sample there was no correlation between the age of attainment of locomotor behaviors and performance on the MDI or the FTII. In this study the FTII was used as a measure of specific cognitive abilities (information processing and visual discrimination; FTII, Fagan & Shepherd, 1987) and it was expected that locomotor acquisition would be related to performance on the FTII. At the time the FTII was administered (when the infants were approximately 7 months old) infants were just beginning to develop locomotor skills, such as creeping. Therefore as the infants were just beginning to show variability in the timing of locomotor behaviors there may have been too little variability to produce any meaningful statistical correlation. This study
focused on locomotor skills rather than the motor control that the prelocomotor infant develops, such as head and trunk control and visual-motor coordination. As the FTII is administered while the infant is seated on the lap of his/her main caregiver, it may be that prelocomotor behaviors (orienting behaviors) are more related to the task demands of the FTII. It may also be true that the timing of the acquisition of these early prelocomotor behaviors is related to the acquisition of locomotor behaviors.

Despite an absence of association between MDI and the age of acquisition of locomotor behaviors, it may be that other elements of cognition not tapped by the MDI would have shown an association with locomotion. It may also be the case that there is a predictive relation between infant locomotor acquisition and later cognitive development. Just as measures of specific cognitive processes in infancy are more predictive of later cognitive ability than infant measures of global cognitive performance (Rose, Feldman, & Jankowski, 1997), it may also be the case that locomotor acquisition in infancy is more predictive of later cognitive performance.

In this study there was a significant positive correlation between performance on the PDI and MDI. This is in keeping with the findings of the psychometric research conducted in the development of the BSID-II (Bayley, 1993). The significant correlation between the performance of the infants on the PDI and MDI suggests that there is an overlap in what these two scales are measuring. This shared variance may be due to an overlap between the gross and fine motor skills that are measured in the PDI, and those motor skills that are
needed to perform items on the MDI. However, locomotor acquisition is associated with the development of these gross and fine motor skills. This correlation also indicates that infant performance on the MDI can be predicted from performance on the PDI, and it has already been established that the early development of locomotor skills is predictive of performance on the PDI. It therefore appears that in infancy locomotor acquisition may indirectly predict cognitive ability (as measured by the MDI) if locomotor acquisition predicts performance on the PDI.

Relationship between Motor Activity and Infant Development.

It was predicted that higher rates of motor activity would predict a higher score on the measures of infant cognitive and psychomotor development at 7 and 12 months. The corollary of this was also predicted, that high rates of infant passive behavior would predict to lower scores on the outcome measures.

It is known that after the first month of life neonates begin to increase the amount of time that they engage in motor activity, although these movements are initially uncoordinated and not related to directing the actions of external stimuli, but to general emotional states (e.g., excitability or irritability) (Colombo, 2000; Hadders-Algra, 2002; Piek, 2002). Shortly after the neonatal period infants (at around 3 months) display the ability to coordinate the type and rate of motor behavior to produce the contingent activity that would activate an attractive stimulus (mobile) (Angulo-Kinzler, 2001).

Activity is important because using acquired motor skills enables the infant to explore his/her environment. Being active also provides an opportunity
for the infant to reconfigure existing motor skills to develop and practice new skills that will afford the infant an increased capacity to effectively explore the environment (Gibson, 2000). Delayed motor milestone acquisition and reduced motor activity that leads to reduced environmental exploration have been suggested as an explanatory mechanism to understand the relationship between motor and cognitive development. Infants experiencing malnutrition are also likely to spend more time, compared to non-malnourished infants in passive behavior that requires less energy expenditure (Meeks- Gardner et al., 1995).

In this study the amount of activity (sum of the frequency of creeping, crawling, standing supported, standing unsupported, walking supported, and walking unsupported) and passive behavior (sum of the frequency of: lying down, being carried, and sitting supported) that the infants engaged in was measured at 6, 9, and 12 months. The general trend reported was for the frequency of motor activity to increase over the time period and for motor passive behavior to decrease. This gives an indication of the validity of the instrument used to measure active and passive behavior.

There were wide variations in the frequencies of both motor active and passive behaviors exhibited. However, in general there was a significant correlation between the frequencies of motor activity and the timing of acquisitions of locomotor behaviors, with high levels of locomotor activity being associated with early acquisition of locomotor behaviors. This relationship between activity and the acquisition of locomotor behaviors has not been established in previous research. Such a relationship possibly supports a dynamic
systems approach to understanding change in motor behavior not solely as a product of maturation, but influenced by the use of and role that the motor behavior plays in the interaction between the infant and the environment (Sporns & Edelman 1993; Thelen & Smith 1994).

In this study the frequency of locomotor behavior at 12 months was significantly and positively correlated with performance on the PDI. It may be that through locomotion the infant comes into contact with situations and objects in the environment that are important in the refinement and development of gross and fine motor skills (Gibson, 2000). This development and refinement of motor skills coupled with increased motor coordination is captured by the global measure of psychomotor ability obtained from the PDI.

The frequency of locomotor behavior while related to performance on the PDI was not related to infant performance on the MDI or FTII. The lack of a relationship between frequency of locomotor behavior and FTII performance may also be explained by the rationale presented for the lack of association between FTII performance and timing of locomotor acquisition. If the motor behaviors that are important for the development or display of attention and information processing skills develop prior to the onset of locomotion, then the frequency of occurrence of such behaviors would have to be measured before any conclusion about the effect of activity on FTII performance could be reached.

The absence of an association between infant activity and performance on the MDI may not indicate a lack of relationship between activity and cognitive development. Pollitt (2000b) uses the term meaningful activity to describe the
types of behaviors that are linked with cognitive development. The role of meaningful activities in terms of environmental exploration (including exploration and manipulation of objects within the environment) has to be considered to give contextual significance to locomotor behaviors (Gottlieb, 1991). In this study the infants were not just demonstrating specific locomotor behaviors in the absence of any environmental stimuli, but were using these locomotor behaviors to move around the environment to reach distant objects or to explore their environment. However, there were no direct measures of what happened as a result of the locomotor behaviors. Examining what the infants were doing when using locomotor behaviors may have demonstrated a relationship between locomotor behavior, environmental exploration, and cognitive ability.

It was interesting that motor passive behavior was not associated with delayed locomotor acquisition or performance on the outcome measures. The significantly positive correlation between the amount of active and passive behaviors that the infants engaged in may suggest that active infants were using passive behaviors rather than avoiding periods of activity because of energy conservation issues. That is, the infants were engaging in activities that while not requiring locomotion, were still developmentally meaningful (i.e. manipulating objects). Research conducted on infants from malnourished populations, suggests that increased passive (inactive) behavior is associated with the conservation of energy and a decreased ability to engage in more active exploratory motor behaviors (Meeks-Gardner et al., 1995; Meeks-Gardner et al., 1999; Walka & Pollitt, 2000). In this study energy expenditure was not known to be an issue for
these infants, so that passive activity may reflect that the infant is engaged in adaptive behaviors such as sitting and manipulating objects and in seeking comfort from caregivers.

Although the infants in this current study were of normal birthweight and gestational age, the possibility of exposure to mild iodine deficiency during gestation may account for some of the variability in both the timing of locomotor acquisitions and amounts of locomotor activity. As has been previously reported infant exposure to severe iodine deficiency during gestation has been associated with problems in locomotion, gross and fine motor control, as well as sensory deficits (Porterfield, 2000). These patterns of motor deficits have been associated with problems in the development of the pyramidal and extrapyramidal neural systems (important for cortical and subcortical control of voluntary motor activity) during the second trimester of pregnancy (Delange, 2000). However, within this sample of infants (some of whom may have been exposed to mild iodine deficiency) the majority of the infants scored within the normal range on the FTII, PDI, and MDI.

The correlational analysis that was conducted in this sample does not indicate that increased levels of cord-blood TSH (as an indicator of thyroid status) were associated with either activity levels or the timing of locomotor acquisition. The effects of iodine supplementation of infant development are being more fully explored in the original study (see, Gorman, unpublished manuscript).
Locomotor Acquisition and Motor Activity Predicting Infant Cognitive and Psychomotor Performance.

This prediction tested was based on the theoretical position that an active exploration of the environment would provide the infant with the opportunity and need to develop new locomotor skills that could be used in future exploration. As has been established with previous research on locomotor skill development, each new skill would be evidenced by a period of flux, whereby proficiency in the new skill would be less than the proficiency in previously acquired skills (Hadders-Algra, 2002). Through increased practice the infant would establish the appropriate muscular and neural connections that support the locomotor skill (Sporns & Edelman, 1993). Using newly developed locomotor skills is more likely to bring the infant into contact with environmental situations that require the development of new locomotor skills or the refinement and accommodation of existing skills.

The results of the regression path analysis suggest that infants who are active are also likely to be early in developing locomotor skills and that the development of a new locomotor skill is related to future motor activity. That is, active infants are more likely to reconfigure their existing skeletal and muscular configurations to develop new locomotor behaviors, and in turn use these new locomotor behaviors. In predicting infant developmental performance, the interrelationship between activity and locomotor acquisition is significantly more predictive of psychomotor development than either process alone. Also the interrelationship between activity and locomotor acquisition increases the amount
of variability predicted in the relationship between performance on the PDI and MDI. This suggests that the development of gross and fine motor skills was not simply predicted by maturation alone, but rather that by using each new developed skill the infant experiences new situations that require the development of new sets of locomotor and motor skills. The mobile infant is interacting with the experiences afforded by the environment to change and develop perceptual, haptic and social processes (Gibson, 2000) and this may indirectly contribute to aspects of cognitive development measured in the MDI.

Classification of Locomotor Development and Motor Activity

Infants were classified according to their general rate of attaining locomotor behaviors. It was originally intended that this classification would be based on the age at which the infants attained all five behaviors. However, as has been previously reported infants were not consistent in the timing of attaining all five behaviors. That is, infants who were earlier in crawling were not necessarily earlier in walking. What is interesting is that an examination of the classification of the infants in locomotor acquisition across the five locomotor behaviors demonstrates a particular pattern of acquisition of locomotor behaviors. It was found that those classified as developing locomotor behaviors earlier than average (i.e., more than one standard deviation below the mean age of attaining three out of five locomotor behaviors) attained the other two remaining locomotor behaviors at the average age (i.e., the age of attaining a locomotor behavior is within one standard deviation of the mean age) but never at a later than average age (i.e., more than one standard deviation above the mean age for developing a
locomotor behavior). Those classified as acquiring locomotor behaviors later than average for three of the behaviors were also found to attain the remaining two behaviors at the average age, and never earlier than the average age.

This pattern of associations suggests that infants were showing some consistency in the attainment of locomotor behaviors. It was also found that those classified as earlier than average were also more active than those classified as being later than average. The literature reviewed did not find any other research that has shown that rates of activity are predictive of the age at which infants acquire locomotive behaviors or that activity and locomotor acquisition have a bidirectional association over time. As the infants involved in this study were only followed to age 12 months it is not possible to determine if the classification would have continued to walking behavior or beyond.

The lack of a consistency of the age of attainment across all five locomotor behaviors may be reflective of the variability that is an important characteristic of many facets of infant development (Hadders-Algra, 2000; Hadders-Algra 2002; Piek, 2002). However, the way in which infants were classified (as a deviation from the mean age at each locomotor behavior) used a statistically based approach that did not take into account the different strengths of correlation in age of attainment across the five locomotor behaviors. Therefore it may have been more important to have a consistent timing of acquisition of behaviors that were closely correlated (i.e., were successive) than determining consistency based on behaviors that occurred further apart in time.
The classification of infants into different locomotor development groups is not a reflection of a normative rate of development of locomotor behavior. What the results of the classification method do show is that infants who could be classified as either generally earlier than average or at the average age of acquiring locomotor behaviors were more active across the three time points that infant activity were observed. However, consistency of the age of locomotor acquisition (as measured in this study) did not result in any significant difference in performance in cognitive or psychomotor development across the three groups.

It may be that classifying the infant locomotor development groups in relation to age of attainment only on the more predictive locomotor behaviors (i.e., age of standing unsupported and walking supported) would have demonstrated a relationship between locomotor classification and performance on the outcome measures.

Limitations of Current Study

This study employed the use of a variety of measures and techniques to study the effects of infant motor activity and locomotor acquisition on indices of cognitive and psychomotor development. The use of standardized assessments, such as the BSID-II or FTII allows the researcher to evaluate the validity and reliability of the instrument in relation to the experimental design of a study. For example, norms are often provided in standardized measures that are relevant to particular cultural or clinical groups. There were some non-standardized measures used in this study (i.e., the record of motor milestone acquisition and the computerized record of activity), the validity and generalizability of which had
not been determined. In addition there a substantial body of research has indicated some of the difficulties associated with questionnaires that ask for self-report of behavior or parental report of child behavior, as in the caregiver maintained record of locomotor milestones (Anastasi & Urbina, 1997). Such measures are open to a variety of response factors that can produce substantial error in the results. For example, caregivers can vary in how accurate or vigilant they are in recording the age at which each locomotor behavior was attained. Caregivers may also have exaggerated the age at which behaviors were attained, and this may have explained some of the extremely early ages of the behaviors recorded. However, the high degree of agreement among parents' ratings that increased age was associated with different and more independent locomotor behaviors indicates that this measure has some degree of internal validity.

The observation of the activities of infants by the trained testers involved the computerized recordings of 66 different behaviors over a two-hour time period. Infants were expected to be alert at the time of observation, and the data collected does indicate that in general there was an increase in motor activity over the three observations and a decrease in passivity over time. This change in frequencies of passivity and activity in the predicted direction adds to the validity of the instrument. The validity of this instrument was also positively affected by the administration of the instrument at three different time points.

It also has to be pointed out that infant activity is also influenced by both domestic and cultural factors (Pollitt, 2000b). The time that the infants' spent in active and passive behaviors may be a function of what the main caregiver was
doing rather than a reflection of how freely active the infant was. For example, infants’ locomotor behavior (such as crawling or walking supported) may be influenced by how much the caregiver allows the infant to move around unrestricted as opposed to a caregiver who prefers to carry his/her infant (Campos et al., 2000). However, dynamic systems theory would reason that this is further evidence that locomotor development is not solely a product of maturation, but is an emergent process dependent on the experience afforded to the infant (Campos et al., 1999).

The design of the research predictions necessitated the multiple comparisons of many variables. In doing this the researcher has to employ stringent statistical techniques that controls for the likely inflation of type I errors caused through multiple comparisons. In this study a Bonferroni correction was applied to multiple correlations and MANOVA’s were used for multiple tests of differences. These techniques may also result in rejection of correlations and differences that are both meaningful and significant. This has to be addressed in follow up research by reducing the testing of hypotheses and predictions to fewer and more salient variables. For example, using techniques such as factor analysis or structural equation modeling can reduce multiple variables to fewer salient factors or constructs. The statistical techniques used by these modeling methods allows measurement and prediction errors to be built into the model and addressed.

Although infant performance on the independent and dependent variables were not related to parental demographic or infant anthropometric variables, the
incomplete data available on many of these possible confounding variables makes it difficult to draw any firm conclusions. There were also limited data on the physical development and health of the infants over the first year of life; therefore it is difficult to determine if there was a relationship between infant growth factors (e.g., height or weight) and locomotor development. However, information on this sample of infants suggested that the mean gestational age and birthweight were within a normative range, and this was a criterion for infant selection into the main iodine supplementation study.

The generalizability of findings is a major consideration of any research and this is an indication of the external validity of the research (Morgan, Gliner, & Harmon, 1999). In assessing the generalizability of the results of this study it is important to look at the characteristics of the sample in relation to a wider population, and to consider what real life circumstances the results of the study can be generalized. The infants come from the most populous country in the world, and although cultural factors influence child rearing practices and the behavior of the infants, if effects are found in this sample of infants (if the sample is really representative of Chinese infants) then statistically it may be found in other samples of infants. The sample size was sufficient to conduct the statistical procedures used in this analysis, and the important findings of the interrelationship between locomotor acquisition, locomotor activity and infant development should be repeated on other samples of infants to substantiate these findings.
It also has to be remembered that the variability in infant motor behavior (both in the acquisition of locomotor skills and in rates of infant activity) may be related to the iodine status of the infant during gestation and in the neonatal period. Although neonatal TSH levels were not correlated with any of the measures used in this study, as has been reported the effects of iodine supplementation are being more fully examined in the main supplementation study. If iodine deficiency and iodine supplementation is shown to affect the motor behavior of these infants then any conclusions about the application of the results of this study must be tempered accordingly.

Future Research

There are many considerations arising from the results of this study that could be addressed in future research.

First, it would be of interest to examine if any of the prelocomotor skills (e.g., head control, sitting unsupported) were predictive of performance on the earlier measures of cognitive development (FTII). It may be that motor behavior and activity does provide a mechanism for the development of other developmental domains, or that key processes of cognition (attention, visual discrimination, and memory) have a general developmental sequelae that is independent of motor development and action (Campos et al., 2000).

Second, the activities recorded by the observers contain information on a wide variety of areas that could be studied in future research. For example, another interesting metric may be to look at the duration of each motor activity. It was considered important for this study to determine how often infants engaged in
the five locomotor behaviors of interest. The frequency of each locomotor 
behavior was used as a proxy to determine activity, and duration may indicate the 
degree of concentration or interest that a well nourished infant has for the 
behavior that he/she is engaging in. Also information on what infants were doing 
during their periods of locomotor activity would generate data on what the infants 
were responding to in the environment. It may be that infants spend most of their 
time engaged in traveling towards their mother, or towards objects in the 
environment. It would also be of interest to examine the responses of the main 
caregivers that may have either encouraged or discouraged the locomotor 
behavior of the infants, and to look at the emotional responses of the infants 
during locomotion.

A brief post-hoc review of this data has shown that some of these issues 
could be examined in the present data set. For example, it would be possible to 
look at the correlation between the frequency of locomotor behavior and other 
infant activities, such as traveling to the main caregiver or playing with a toy. 
However, finding what events were happening simultaneously would be harder to 
tease out (e.g., what specific emotional responses of the infant were happening 
during each occurrence of active or passive behavior). In future research, the 
activities of the infants during the observation period could be video recorded; 
this would allow activities that were not mutually exclusive to be studied outside 
of the research setting, while information on real time exclusive events could be 
video/computer recorded as they happen. This would require careful analysis of 
the reliability of raters and also an analysis of the validity of the rating method.
used to determine the accuracy of rating the emotional and social behaviors of both infants and care-givers.

Third, future research could examine the relationship between the processes of infant action-perception coupling, and performance on more global measures of infant cognitive development. For example, it would be of interest to determine if the relationship between locomotion and depth perception or optic flow contributed to the performance of infants in more standardized measures of development. Thereby, it could be determined if infants who have developed depth perception and are using locomotor behaviors are better able to conduct tasks in measures of cognitive development that utilize optic flow or other perceptual processes.

Fourth, the effects of later motor behavior on child development should be examined. The results of this present study may indicate that motor behavior has a window of influence in infancy generally in the area of psychomotor development. It may be that cognitive development at the end of infancy and in early childhood becomes more influenced by changes in the representational ability of the developing child (such as language and abstraction), and that the effects of motor behavior on perceptual and cognitive processes are lessened. However, a dynamic systems theory postulates that there is no time during development that action becomes separated from perception and cognition (Thelen, 2000a, 2000b). As children mature locomotor acquisition becomes less varied (i.e. most 3-year olds can walk) but differences in how coordinated locomotor behaviors are or how well a complex motor task is performed becomes
more apparent (Eaton, McKeen, & Campbell, 2001; Swinnen & Carson, 2002). Variations in locomotor coordination and performance on complex motor tasks may offer an insight into the role of motor activity in ongoing development (Kooistra, Schellekens, Schoemaker, Vulsma, & van der Meere, 1998). As an example, children with attentional disorders often have corresponding coordination problems, and it is hypothesized that the lack of control that such a child has with directing or changing attention (as a cognitive process) may be due to problems in the neural circuits involved with the timing of motor behaviors (Diamond, 2000).

Fifth, it would be of interest to replicate this study in an infant population not exposed to nutritional deficiencies (macro or micro). It is the premise of dynamic systems theory that the emergent quality of infant behavior provides a universal approach to understanding development (Thelen & Smith, 1994). In this study the effects of mild iodine deficiency in some of the infants may have resulted in variability in infant motor behavior that would not be found in a population not exposed to micro or macro nutritional deficiencies. The relationship between reduced motor activity and delayed motor development in malnourished populations may indicate differences in the emergent behaviors of such infants. However, it may also be that malnutrition results in subtle and ongoing neural insults that interact with the reduced exploratory behavior of the infant in determining developmental progress.
Conclusions

The results of this study add to the area of research on infant and child development by demonstrating that infant development is a function of related areas of change, where change in one domain cannot be considered in isolation (Pollitt, 2000a). As such the rate of acquisition of locomotor skills are shown to be reciprocally related to infant activity, and that over time these factors contribute to how infants perform on more global measures of development. More specifically, in this study, it has been found that infants who develop locomotor skills early are infants who are active. The relationship between the development of locomotor behaviors and the frequency of locomotor behaviors predicted scores on a measure of psychomotor development (PDI). Moreover, the prediction of infant psychomotor development from infant locomotor attainment and locomotor activity explains a small but significant amount of the variance in cognitive development (MDI). Such a relationship has not previously been demonstrated in the research literature.

The fact that activity and locomotor acquisition are interrelated suggests that using locomotor skills lead to the earlier reconfiguration of the current locomotor behavior to generate additional locomotor behaviors that allow the infant to more efficiently explore the environment. This may have implications for infants who are delayed in the onset of locomotion or who exhibit low levels of activity. Whereas it is important to recognize that infants will show variation in the age at which locomotor behaviors develop, infants who show continued low
levels of activity for a developed locomotor behavior may also show a pattern of
delay in locomotor development.

Theorists invoking a dynamic systems approach to developmental research
have demonstrated the importance of locomotion in contributing to social and
cognitive development. Such research has tended to focus on specific processes
involved in infant cognition (e.g., perception, memory, attention, and object
permanence), rather than the relationship between locomotor development and
more global cognitive performance. In contrast research conducted on
malnourished populations has demonstrated a relationship between delayed
locomotor development, reduced motor activity, and poorer performance on
measures of infant development. Both of these approaches emphasize the
importance of infant exploration in cognitive and psychomotor development. This
current study measured the effect that locomotor acquisition and activity had on
global measures of cognitive ability (MDI) and on some specific cognitive
processes (i.e. information processing and novelty preference measured in the
FTII). However, it is important to examine how future research design could
differently examine the relationship between locomotor behavior (including
activity) and cognitive development. A model for further research should include
the measurement of locomotor activity and acquisition, and explore how these
affect additional cognitive processes (e.g. attention, object permanence, problem
solving) at multiple time points. Such a model could incorporate locomotor
acquisition and activity, and the development of many types of specific cognitive
processes in predicting infant performance on global measures of cognitive ability.
Figure 1: Proposed Developmental Path Model Predicting Infant Performance on the PDI and MDI from Locomotor Activity and the Age of Acquisition of Locomotor Milestones.
Figure 2: Revised Developmental Model Predicting Infant Performance on the PDI and MDI from Locomotor Activity and the Age of Acquisition of Locomotor Milestones.
Figure 3: Frequency of Locomotor Activity vs. Time of Observation for the Locomotor Development Groups
Table 1:
Correlation between Locomotor Development Variables: - Before Substituting For Missing Data (n=127).

| Variable                  | 1     | 2     | 3     | 4     | 5     |
|---------------------------|-------|-------|-------|-------|-------|
| 1. Creep                  | -     | .61***| .48***| .43***| .36***|
| 2. Crawl                  | -     | -     | .46***| .41***| .43***|
| 3. Stand Supported        | -     | -     | -     | .54***| .57***|
| 4. Stand Unsupported      | -     | -     | -     | -     | .62***|
| 5. Walk Unsupported       | -     | -     | -     | -     | -     |

Note. All correlations remain significant after Bonferroni correction.

***p< .001. Age of locomotor variables are in days.
Table 2:  
Locomotor Development Variables: - Before Missing Data Substitution

| Variable            | N  | M     | SD  | Min. | Max. | Range |
|---------------------|----|-------|-----|------|------|-------|
| Creep               | 162| 222.4 | 54.4| 61   | 360  | 299   |
| Crawl               | 139| 268.6 | 52.8| 90   | 361  | 271   |
| Stand Supported     | 156| 279.1 | 57.9| 35a  | 390  | 355   |
| Stand Unsupported   | 151| 307.6 | 50.5| 55a  | 405  | 350   |
| Walk Supported      | 151| 332   | 41.6| 253  | 420  | 167   |

Note: a = univariate outlier. Age of locomotor variables are in days.
Table 3:
Locomotor Development Variables: - Substituting For Missing Data and Omitting Univariate Outliers

| Variable              | N  | M    | SD  | Min. | Max. | Range | %Substituted |
|-----------------------|----|------|-----|------|------|-------|--------------|
| Creep                 | 157| 222.9| 52.8| 61   | 360  | 299   | 0            |
| Crawl                 | 157| 266.8| 50.3| 90   | 361  | 271   | 11           |
| Stand Supported       | 157| 281  | 54.3| 120  | 390  | 270   | < 1          |
| Stand Unsupported     | 157| 311.1| 44.5| 168  | 405  | 237   | 4            |
| Walk Supported        | 157| 334.9| 31.5| 253  | 420  | 167   | 4            |

Note: Age of locomotor variables are in days.
Table 4:
Correlation between Locomotor Development Variables After Substituting For Missing Data (n=157).

| Variable               | 1   | 2       | 3       | 4       | 5       |
|------------------------|-----|---------|---------|---------|---------|
| 1. Creep               | -   | .64***  | .44***  | .48***  | .32***  |
| 2. Crawl               | -   | -       | .44***  | .42***  | .36***  |
| 3. Stand Supported     | -   | -       | -       | .6***   | .51***  |
| 4. Stand Unsupported   | -   | -       | -       | -       | .75***  |
| 5. Walk Supported      | -   | -       | -       | -       | -       |

Note. All correlations remain significant after Bonferroni correction.
*** p < .001
Table 5:
Comparison of Missing/Non-missing Locomotor Development Variables and Parental Demographics: - Randomness of Missing Data.

| Variable          | Age Crawl Missing | Age Crawl Non-missing | Statistic |
|-------------------|-------------------|-----------------------|-----------|
|                   | N | M  | SD | N | M  | SD |           |
| Mother age        | 17| 25.8| 2.1| 122| 25.7| 4.5| t= .07    |
| Mother education  | 18| 12.9| 1.8| 136| 11.6| 3.9| t= 1.43   |
| Father age        | 18| 31.1| 2  | 136| 29.4| 8.4| t= .89    |
| Father education  | 18| 12.6| 3.6| 136| 12.2| 4.1| t= .36    |
| Family income     | 18| 932.6| 1158.8| 136| 1191.9| 1333.8| t= 1.02  |

Note: Age of locomotor variables are in days.
Table 6:
Locomotor Development Variables- Z Scores

| Variable              | N  | M | SD | Min. | Max. | Range |
|-----------------------|----|---|----|------|------|-------|
| Z Creep               | 157| 0 | 1  | -3.4 | 2.6  | 6     |
| Z Crawl               | 157| 0 | 1  | -3.5 | 1.9  | 5.4   |
| Z Stand Supported     | 157| 0 | 1  | -2.8 | 1.9  | 4.7   |
| Z Stand Unsupported   | 157| 0 | 1  | -2.9 | 1.9  | 4.8   |
| Z Walk Supported      | 157| 0 | 1  | -2.5 | 2.7  | 5.2   |
Table 7:
Correlation between Locomotor Development Variables Z Scores (n=157)

| Variable                  | 1    | 2    | 3    | 4    | 5    |
|---------------------------|------|------|------|------|------|
| 1. Z Creep                | -    | .64***| .44***| .48***| .32***|
| 2. Z Crawl                | -    | -    |      | .44***| .42***| .36***|
| 3. Z Stand Supported      | -    | -    | -    |      | .60***| .51***|
| 4. Z Stand Unsupported    | -    | -    | -    | -    |      | .75***|
| 5. Z Walk Supported       | -    | -    | -    | -    | -    |      |

Note. All correlations remain significant after Bonferroni correction.
*** p< .001
Table 8:
Infant Anthropometric Data with Maternal Venous Iodine Levels.

| Variable               | N   | M    | SD   | Min.  | Max.  | Range |
|------------------------|-----|------|------|-------|-------|-------|
| Birthweight (grams)    | 145 | 3390.8 | 512.4 | 2150  | 6600  | 4450  |
| Gestational Age (wks)  | 96  | 39.7 | 1.65 | 33    | 43    | 10    |
| Infant TSH (mU/L)      | 152 | 4.46 | 3.5  | .22   | 17.9  | 17.69 |
| Maternal TSH (mU/L)    | 152 | 2.67 | 2.43 | .20   | 16.65 | 16.45 |
Table 9:
Parent Demographics.

| Variable                      | M     | SD    | Min. | Max. | Range |
|-------------------------------|-------|-------|------|------|-------|
| Mother Age                    | 26.24 | 2.12  | 23   | 34   | 11    |
| Education                     | 12.6  | 2.16  | 9    | 19   | 10    |
| Raven                         | 45.4  | 10.06 | 7    | 57   | 50    |
| Father Age                    | 31.13 | 4.18  | 25   | 64   | 39    |
| Education                     | 13.07 | 2.51  | 2    | 22   | 20    |
| Raven                         | 47.96 | 7.84  | 16   | 57   | 39    |
| Family Monthly Income (Yen)   | 1083.66 | 1279.85 | 100 | 10000 | 9900 |
Table 10:
Parent Occupation.

| Occupation          | Mother |          | Father |          |
|---------------------|--------|----------|--------|----------|
|                     | N      | %        | N      | %        |
| Worker              | 64     | 48       | 61     | 42       |
| Business            | 12     | 9        | 12     | 8        |
| Govt. Official      | 34     | 25       | 45     | 31       |
| Professional/official | 26     | 18       | 29     | 19       |
Table 11:
Mean Frequencies of Infant Locomotor Activity at 6, 9, and 12 months (n=157).

| Variable     | M    | SD    | Min. | Max. | Range |
|--------------|------|-------|------|------|-------|
| Motor Passive |      |       |      |      |       |
| 6 months     | 27.9 | 15    | 0    | 77   | 77    |
| 9 months     | 25.8 | 18.5  | 2    | 102  | 100   |
| 12 months    | 14.4 | 9.5   | 0    | 65   | 65    |
| Motor Active |      |       |      |      |       |
| 6 months     | 14.1 | 10.7  | 0    | 62   | 62    |
| 9 months     | 32.5 | 24.9  | 0    | 137  | 137   |
| 12 months    | 48.9 | 33    | 0    | 160  | 160   |
Table 12:
Means, Standard Deviations and Range of Scores on the Dependent Variables.

| Variable | N  | M    | SD   | Min. | Max.  | Range |
|----------|----|------|------|------|-------|-------|
| FTII     | 144| 57.3 | 11.72| 44.9 | 69.8  | 24.9  |
| PDI      | 154| 111.6| 16.6 | 54   | 145   | 91    |
| MDI      | 154| 114.7| 11.8 | 73   | 140   | 67    |
Table 13: Correlations between Locomotor Activity at 6, 9, and 12 months with Age of Locomotor Milestone Acquisition (n=156).

| Variable | Age                                      |              |         |         |         |
|----------|------------------------------------------|--------------|---------|---------|---------|
|          | Creep | Crawl | Stand Supported | Stand Unsupported | Walk Supported |
| 6 months | -.13 | -.08  | -.12 | -.09 | -.12 |
| 9 months | -.05 | -.02  | -.13 | -.17* | -.17* |
| 12 months | -.07 | -.04  | -.07 | -.20*** | -.25*** |

Note. *p < .05, **p < .01. Correlations in bold remain significant after Bonferroni correction.
Table 14:
Correlations between Ages of Locomotor Milestone Acquisition with Outcome Variables.

| Variable               | FTII (n=144) | PDI (n=154) | MDI (n=154) |
|------------------------|--------------|-------------|-------------|
| Age                    |              |             |             |
| Creep                  | .04          | -.04        | -.07        |
| Crawl                  | .10          | -.07        | .02         |
| Stand Supported        | -.05         | -.12        | -.10        |
| Stand Unsupported      | -.07         | -.20**      | -.10        |
| Walk Supported         | -.05         | -.26***     | .01         |

Note. ** p < .01. Correlations in bold remain significant after Bonferroni correction.
Table 15:
Correlations between Frequency of Motor Activity/Passivity at 6, 9, and 12 months

| Variable                  | 1  | 2    | 3    | 4    | 5    | 6    |
|---------------------------|----|------|------|------|------|------|
| 1. Activity 6 months     | -  | .31*** | .09  | .59*** | .07  | 27*** |
| 2. Activity 9 months     | -  | -    | .27*** | .28*** | .47*** | .14  |
| 3. Activity 12 months    | -  | -    | -    | 18*  | 17*  | 16*  |
| 4. Passivity 6 months    | -  | -    | -    | -    | .27*** | 34*** |
| 5. Passivity 9 months    | -  | -    | -    | -    | -    | .21** |
| 6. Passivity 12 months   | -  | -    | -    | -    | -    | -    |

Note. p < .05, **p < .01, ***p < .001. Correlations in bold remain significant after Bonferroni correction.
Table 16:
Correlations between Locomotor Activity at 6, 9, and 12 months with Outcome Variables.

| Variable | FTII (n=144) | PDI (n=153) | MDI (n=153) |
|----------|--------------|-------------|-------------|
| **Activity** |               |             |             |
| 6 months | .17*         | -.21*       | -.18*       |
| 9 months | .16+         | .07         | -.04        |
| 12 months | .13          | **.22**     | -.06        |
| **Passivity** |               |             |             |
| 6 months | .03          | -.20*       | -.15*       |
| 9 months | .15+         | .01         | .04         |
| 12 months | .16+         | -.13        | -.15*       |

Note. *p < .05. **p < .01. Correlations in bold remain significant after Bonferroni correction.
Table 17:
Correlations between Parental Demographics and Outcome Variables

| Variable                   | MDI  | PDI  | FTII |
|----------------------------|------|------|------|
| Mother Age                 | .15  | .09  | -.04 |
| Mother Education           | .01  | .05  | .02  |
| Mother Raven               | .03  | .03  | -.02 |
| Father Age                 | -.08 | -.05 | .13  |
| Father Education           | .02  | .14  | -.02 |
| Father Raven               | -.16 | -.14 | .05  |
| Family Monthly Income(Yen) | -.01 | .04  | .08  |

Note: n range = 123 – 156.
### Table 18:
Correlations between Ages of Locomotor Milestone Acquisition with Parent Demographic Variables.

| Variable       | Creep | Crawl | Stand Supported | Stand Unsupported |
|----------------|-------|-------|-----------------|-------------------|
| Mother Age     | .13   | -.05  | .00             | .02               |
| Mother Education| -.06  | .07   | .17             | -.09              |
| Mother Raven   | .07   | .09   | .10             | .03               |
| Father Age     | .13   | .04   | .06             | .05               |
| Father Education| .13   | .04   | .03             | .05               |
| Father Raven   | .13   | .10   | .05             | .04               |
| Family Monthly Income (Yen) | .15   | .16   | .18             | .13               |

Note: n = 110 for Mother Age, Mother Education, Father Age, Father Education and Family Monthly Income. 

n = 128 for Mother Raven and Father Raven.
Table 19:
Correlations between Locomotor Activity at 6, 9, and 12 months with Parent Demographic Variables.

| Variable            | Activity     |
|---------------------|--------------|
|                     | 6 months     | 9 months    | 12 months   |
| Mother Age          | -.13         | -.11        | -.20*       |
| Mother Education    | -.06         | .03         | .05         |
| Mother Raven        | -.02         | .06         | -.05        |
| Father Age          | .10          | .01         | -.07        |
| Father Education    | -.14*        | -.08        | .04         |
| Father Raven        | .03          | .04         | .02         |
| Family Monthly Income(Yen) | -.07   | -.12        | .01         |

Note. +p < .1. *p < .05. Correlations do not remain significant after Bonferroni correction. n = 110 for Mother Age, Mother Education, Father Age, Father Education and Family Monthly Income. n = 128 for Mother Raven and Father Raven.
Table 20:
Correlations between Locomotor Activity at 6, 9, and 12 months with Infant Anthropometric Variables.

| Variable    | n   | Activity 6 months | Activity 9 months | Activity 12 months | Passivity 6 months | Passivity 6 months | Passivity 6 months |
|-------------|-----|------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| Gestational age | 97  | .03              | .20*              | .14               | .12               | .03               | .03               |
| Birthweight | 147 | .15⁺             | .13               | .11               | .09               | .01               | -.02              |
| Infant TSH  | 146 | -.13             | -.13              | -.02              | -.07              | -.13              | .10               |

Note. ⁺ p < .1.  *p < .05. Correlations do not remain significant after Bonferroni correction.
Table 21:
Correlations between Ages of Locomotor Milestone Acquisition with Infant Anthropometric Variables.

| Variable      | n   | Creep | Crawl | Stand Supported | Stand Unsupported | Walk Supported |
|---------------|-----|-------|-------|-----------------|------------------|---------------|
| Gestational Age | 97  | -.06  | .06   | -.04            | -.07             | -.05          |
| Birthweight   | 147 | -.2*  | -.07  | -.01            | -.10             | -.07          |
| Infant TSH    | 146 | -.08  | -.14+ | -.06            | -.05             | -.03          |

Note. *p < .10. *p < .05. Correlations do not remain significant after Bonferroni correction.
Table 22:
Correlations between Infant Anthropometric Data and Outcome Variables.

| Variable | Birthweight | Gestational age | TSH     |
|----------|-------------|-----------------|---------|
| MDI      | -.01 (n=150)| -.11 (n=99)     | -.13 (n=149) |
| PDI      | -.06 (n=150)| -.07 (n=99)     | -.10 (n=149) |
| FTII     | -.04 (n=140)| .13 (n=92)      | -.12 (n=149) |

Note: n Range = 92 - 150
Table 23:
Standard Regression Analyses with Age Acquisition of Standing Unsupported Predicting Scores on the PDI.

| Variable                        | B     | SE B | β      |
|---------------------------------|-------|------|--------|
| Age of standing unsupported     | -.08  | .03  | -.22** |

Note. $R^2 = .04$, ** $p < .01$
Table 24:
Standard Regression Analyses with Age Acquisition of Walking Supported
Predicting Scores on the PDI.

| Variable                | B   | SE B | β     |
|-------------------------|-----|------|-------|
| Age of walking supported| -0.12 | 0.04 | -0.24** |

Note. $R^2 = 0.05$, **$p < 0.01$
Table 25:
Standard Regression Analyses with Age 12-Month Locomotor Activity Predicting Scores on the PDI.

| Variable                  | B    | SE B | β     |
|---------------------------|------|------|-------|
| 12-month locomotor activity | .10  | .04  | .21** |

Note. $R^2 = .04$, ** $p < .01$
Table 26:
Age of Attaining Locomotor Behavior for Three Locomotor Development Groups

| Variable               | Early LMA (n=34) | Normal LMA (n=49) | Late LMA (n=26) |
|------------------------|------------------|-------------------|-----------------|
|                        | M    | SD   | M    | SD   | M    | SD   |
| Age                    |      |      |      |      |      |      |
| Creep                  | 166.6| 52.9 | 230.8| 24.8 | 265.4| 50.3 |
| Crawl                  | 215.9| 48.2 | 267.4| 26.6 | 309.7| 36.5 |
| Stand Supported        | 218.6| 45.5 | 295.2| 28.3 | 327.9| 38.4 |
| Stand unsupported      | 252.3| 35   | 315.2| 22.4 | 356  | 24   |
| Walk supported         | 300.3| 27.2 | 339.6| 14.9 | 368.6| 18   |
Table 27:
Frequency of Activity at 6, 9, and, 12 months for the Three Locomotor Development Groups

| Variable     | Early LMA (n=34) | Normal LMA (n=49) | Late LMA (n=26) |
|--------------|------------------|-------------------|-----------------|
|              | M    | SD   | Range  | M    | SD   | Range  | M    | SD   | Range  |
| Activity 6 months | 17.3 | 14.5 | 0-61   | 11.5 | 8.7  | 0-35   | 14.6 | 11.3 | 0-34   |
| Activity 9 months | 40.7 | 31.7 | 10-137 | 33.8 | 20.1 | 1-78   | 28.51 | 11.3 | 1-72   |
| Activity 12 months | 54.3 | 31.2 | 9-160  | 58   | 35.9 | 3-160  | 36.1 | 28.3 | 0-130  |
Motor Milestones

1. Sits with support
2. Sits on own- not upright
3. Sits on own- upright
4. Prone- raising self up
5. On all four's- stomach off the ground
6. Moving backwards- creeping on all fours
7. Moving forwards- crawling on all fours
8. Start standing up
9. Stand holding on for support
10. Stand/walk with support
11. Stand on own
12. Walk with support- feet not steady
13. Walk with support- feet treading
14. Walk few steps by self- not upright
15. Walk own- upright for a few steps
16. Walk own- upright and wider steps
17. Running
APPENDIX B

1. A series of one-way MANOVA’s were conducted to determine if the age of locomotor acquisition and frequency of locomotor activity significantly varied as a function of parental occupation. The results of the analyses show that the age of locomotor acquisition and infant locomotor activity (at 6, 9, and 12 months) were not significantly different for either mother (locomotor acquisition, ? = .85, F (20,399) = .97, p > .05; locomotor activity, ? = .88, F (12,320) = 1.29, p > .05) or father occupation (locomotor acquisition, ? = .95, F (15,365) = 1.49, p > .05; locomotor activity, ? = .93, F (9,324) = 1.17, p > .05).

2. Two one-way MANOVA’s were conducted to determine if infant performance on the FTII, PDI, and MDI significantly varied as a function of parental occupation. It was found that infant performance on the FTII, PDI, and MDI was not significantly different across parent occupation (mother occupation ? = .88, F (12,286) = 1.2, p > .05) (father occupation ? = .96, F (9,290) = .53, p > .05)

3. A one-way MANOVA was conducted that demonstrated that there was no main effect of gender on infant performance on the FTI, PDI or MDI. (? = .97), F= (3, 133), =1.39, p > .05)

4. Two one-way MANOVA’s were conducted to determine if infant age of locomotor acquisition of locomotor activity significantly varied by infant gender. The results of these analyses demonstrate that neither the age of locomotor acquisition (? = .94, F (5,147) = 1.97, p > .05) nor frequency of locomotor activity or passivity at 6, 9, and 12 months (? =.93, F (5, 146) = 2.1, p >.05) were significantly different due to gender.
5. There was no main effect of infant TSH level on infant locomotor activity (\( \beta = .97 \), \( F(3,152) = 1.86, p > .05 \)), or the age of acquisition of locomotor milestones (\( \beta = .99 \), \( F(5,151) = .33, p > .05 \)).

6. There were no main effects of locomotor developmental status on infant performance on the FTII, PDI, or MDI (\( L = .91 \), \( F(6,186) = 1.54, p > .05 \)).

7. Membership of the locomotor milestone developmental groups did not vary by infant gender (\( \chi^2 (2, N=105) = 3.5, p > .05 \)) or parental occupation (mother occupation, \( \chi^2 (6, N=88) = 12.3, p > .05 \), or father occupation, \( \chi^2 (6, N=97) = 8.6, p > .05 \)).
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