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Does Timing of Locomotor Onset Play a Mediating Role?

By

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University of Manitoba

A Thesis
Submitted to the Faculty of Graduate Studies
In Partial Fulfillment of the Requirements
For the Degree of

Master of Arts

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Abstract

Previous literature has reported: a) seasonal patterns for earlier locomotion attainment; b) better cognitive and school performance for those who showed early motor attainment; and c) season of birth patterns in school achievement. This combination of findings raises the possibility that early locomotor onset mediates the relationship between season of birth and cognitive performance. We tested this idea on data from a cohort of infants from the National Longitudinal Survey of Children and Youth (NLSCY) who had information on season of birth, age at first walking, and Peabody Picture Vocabulary Test – Revised performance at four or five years of age. The assumptions of a formal mediation test were not met because season of birth was not a significant predictor of receptive vocabulary; however, age at first walking displayed a season-of-birth pattern, and earlier walking was associated with better PPVT-R scores. In addition, we found a number surprising relationships involving age at first walking, receptive vocabulary, family income adequacy, number of siblings in the home, and maternal smoking and drinking.

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Season of Birth as a Predictor of Child Cognitive Performance: Does Timing of Locomotor Onset Play a Mediating Role?

Season in high and low latitudes greatly affects behaviours related to nutrition, sun exposure, and outdoor activities. Circumstantial evidence suggests that season of birth has an influence on the development of human infants (Benson, 1993, 1996; Eaton & Bodnarchuk, 2007; Eaton, Bodnarchuk, & Denton, 2008; Martin, Foels, Clanton and Moon, 2004; McGrath Saha, Lieberman, & Buka, 2006; Thompson, 1971), specifically on age of crawling or walking and on cognition or school performance.

Small seasonal differences that appear to begin in infancy are detected years later, suggesting either a permanent effect established in infancy or a link to a mediator, a third explanatory variable, that has an influence on the later outcome. Research on these possible influences and the nature of their relationships to one another can contribute to our understanding of human development, which can in turn serve as groundwork for applied research on child development. The proposed project aims to clarify effects of season of birth on Canadian infants - from early milestones to later development. More specifically, how are season of birth, milestone attainment, and cognition related to one another?

One method to evaluate the role of season of birth on the development of normal infants is to test a mediation hypothesis about a variable thought to lie between season of birth and later cognitive performance. Season of birth has been correlated with the age of learning to walk (Benson, 1993, 1996; Eaton & Bodnarchuk, 2007; Eaton et al., 2008). Interestingly, the age of first walking has been linked to cognitive performance (Campos, Kermoian, & Zumbahlen, 1992; Hebert, Gross, & Hayne, 2007; Murray, Veijola, Moilanen, Miettunen, Glahn, Cannon, et al., 2006) and even to education levels in adulthood (Taanila, Murray, Jokelainen, Isohanni, & Rantakallio, 2005). These outcomes above appear to be associated to one another, beginning with the season of birth. Therefore, we seek to learn, not only if the season of birth has such an influence on early milestones and later cognition, but also if the age of attaining certain milestones such as walking mediates cognitive abilities. The linkage of all three variables would suggest a cascading series of influence that begins with the season of birth, a variable that warrants additional research. In addition, a linkage may shed light on whether age at school entry is to blame for birthday-school performance correlations because cognition was tested before the children entered grade school. Moreover, if the age at milestone attainment proves to be a mediator of the season-cognition link, we may illustrate a seasonal effect that is related to motor development, and largely independent of the age at school entry.

Season of Birth

Season is correlated with a surprisingly large number of behaviours, especially in samples found at high latitudes. In such locales, individuals tend to stay indoors to avoid the cold weather during the winter. They use indoor heating, wear warmer clothing, and eat food that is generally canned, preserved or imported from a warmer location. On the other hand, summer months allow more outdoor activities and exposure to sunlight, and the public can experience longer days and fresher produce. For example, a New Zealand study by Watson and McDonald (2007) found seasonal intake differences for several nutrients. It is clear that, despite advanced technologies, Mother Nature continues to influence our daily lives with changing weather conditions.

Just as season has a notable influence on human behaviour, it also has been linked to fetal growth. McGrath, Keeping, Saha, Chant, Lieberman, and O'Callaghan (2005) found in a sample of 350,171 Australian infants that those born in the winter and spring had heavier birth weights, longer limbs, and narrower hips than infants who were born in the summer and autumn. These researchers suspect that their observed seasonal effect are caused by varying levels of 25 hydroxyvitamin D_3 (vitamin D) during gestation. If so, it is apparent that season may affect growth, even before birth. We will discuss possible influences and seasonality of vitamin D later in this paper.

Bodnarchuk (2001) identified a link between season of birth and birth weight in her research. Using data from Statistics New Zealand, Bodnarchuk assessed the birth weights of over a million live births in New Zealand between January 1980 and December 1999, and found that factors associated with season (e.g., temperature and day length) are related to fetal growth during the gestational period, which in turn affects birth weight. Newborn infants in New Zealand tended to be the lightest in July, and the heaviest in November. These results are not too dissimilar to those of McGrath et al. (2005) who found that infants were lightest in May and heaviest in October. If we translate the findings of these two studies into seasonal terms, infants born in the late fall and winter tend to be lighter than infants born in late spring and summer. In addition to these studies, others have reported seasonality effects across the world (e.g., Roberts, 1975; Wohlfahrt, Melbye, Christens, Anderson, & Hjalgrim, 1990).

Another area where season of birth appears to be linked to performance is in sports: Success in professional sports such as hockey, tennis, and soccer appears to co-vary with season of birth (Barnsley & Thompson, 1988; Dudink, 1994). That is, athletes born in the first several months of the year are more likely to play in top tier leagues than summer- and fall-born individuals are. This effect appears to be caused by the system of cut-off dates for competitive tryouts: At the start of the competitive season, older and more physically developed players tend to be selected for more elite teams than players who are up to a year younger in age at the boundary date for younger and older teams. In other words, annual cut-offs for grouping kids can lead to differential experiences and selection outcomes.

The season of birth has also been linked to mental disorders. Davies, Welham, Chant, Torrey, and McGrath (2003) reported in a meta-analysis that a small but significant proportion of individuals with schizophrenia have been born in the winter/spring months. The studies they reviewed used samples from the Northern Hemisphere, where perinatal viral exposure and low levels of prenatal vitamin D are more likely in winter. Thus, season is related to third variables, which may influence a particular outcome, such as schizophrenia.

A temperamental trait that appears to be influenced by season of birth is extreme shyness (Gortmaker, Kagan, Capsi, & Silva, 1997). Longitudinal data were available for 1,204 children aged two- to seven-years from the National Longitudinal Survey of Labor Market Experience Youth cohort (NLSY) in the United States and from a cohort of 1,024 three-year-old children in Dunedin, New Zealand. Although these countries were situated on opposite sides of the globe, interviewer reports for both samples produced results that linked short days (winter) during mid-gestation to the likelihood of extreme shyness. The authors speculate that changes of neurotransmitters or corticoids that fluctuate with season (e.g., melatonin or serotonin) may cause this effect.

Season of birth has also been linked to allergies. Kuzume and Kusu (2007) studied 2,136 infants who were born in (and utilized follow-up care at) the Nishinihon Matsuyyama Hospital in Japan from 1995 through 2000: They identified the infants who had atopic dermatitis (AD) up to 12 months. AD is otherwise known as eczema, a chronic skin disease, often identified by skin reactions to allergens. Of the 630 infants with AD, the lowest incidence occurred for those born in the spring, and the highest incidence occurred for those born in the autumn. A sample of 369 infants received allergy-related blood tests (total serum IgE levels and CAP-RAST levels with egg white) at three months of age. Further analyses demonstrated an inverse relationship between sunshine amount three months before and after birth and AD. Kuzume and Kusu propose that epidermal thickening (induced by exposure to ultraviolet rays, such as those from the sun) alleviates AD symptoms; however, this skin barrier is less likely to be developed in the autumn and winter due to low exposure to the sun. They explain that sun exposure may be beneficial in early infancy, as this is an important time for allergy sensitization.

The examples above demonstrate how season of birth can directly or indirectly influence many parts of our lives. In addition, a case could be made that the season of birth could also influence performance on tests of cognition and performance at school entry. This possibility is based on the following arguments that will be elaborated below: 1) season of birth influences the rate of motor attainment; and 2) rate of motor attainment influences cognitive outcomes in childhood. These propositions lead to the core hypothesis of this study, namely that motor attainment mediates a relationship between season of birth and childhood cognitive performance. The two propositions above are not widely known or accepted so it is to these literatures that we now turn.

Season of Birth and Locomotion

Season of birth appears to have an effect on motor development at northern latitudes. Benson (1993) was the first researcher to explore the relationship between season of birth and age at acquiring the ability to travel independently. Parental reports for 414 infants were obtained from participant records at the University of Denver or through telephone interviews. Benson found a significant relationship between season of birth and age of learning to creep or crawl for at least four feet. Infants born in the winter and spring (December to May) had an average of three weeks' head start in the age at locomotor onset compared to summer and fall-borns (those born in June through November). Benson hypothesized that situational factors provoked by cold weather at six months of age hinder the learning of locomotion by summer- and fall-born infants. Benson attributed the effect to restricted movement due to heavy clothing or limited space indoors; in warm weather, infants wear less clothing and can be brought outdoors to play.

Benson replicated these results for 118 pairs of monozygotic and dizygotic twins born in Colorado (1996). A seasonal effect was implied for walking; however, further analyses showed that this relationship was indirect: Walking was influenced primarily by age at crawling rather than by season. Supplementary analyses on this sample indicated that within-twin correlations for monozygotic pairs were significantly higher than for dizygotic twins for locomotion onset and walking. These twin comparisons suggest a season-biology interaction; however, Benson cautions that measures to control parental bias should take place before these implications can be established.

The relationship between season of birth and motor development was confirmed in Canada (Eaton & Bodnarchuk, 2007; Eaton, et al., 2008). Longitudinal data obtained from daily parental checklists for 613 children resulted in a seasonal pattern for the age of attaining motor milestones such as crawling and walking, where spring-born infants are more likely to attain the milestones at younger ages. Validity of the parent reports were confirmed through home visits by the researchers. Eaton and Bodnarchuk theorized that vitamin D, a hormone prepared by the body in response to sunlight exposure, might provide an advantage in physical development at a critical period after birth. In high latitudes, more synthesis of vitamin D occurs in the summer, at a time when winter-borns are near the age of crawling. On the other hand, summer-borns reach the age of crawling in the winter, when levels of vitamin D are the lowest. Eaton and Bodnarchuk suggested that longer bone growth in winter- and spring-borns (thought to be caused by varying levels of vitamin D, see McGrath et al., 2005) facilitated learning how to crawl and walk.

Independent mobility is a momentous achievement because it changes the way an infant can interact with the world. Moreover, it is reasonable to predict that the cognitive advantages of locomotion and other motor abilities at earlier ages would persist over time. Although finding such continuations are rare, Smith and Thelen (2003) hypothesize that "Even very small differences in beginning states and in developmental histories can amplify and lead to large individual differences" (p.347). If seasonal differences in mobility are found, how does this affect the infant? Do they matter later? Interestingly, these differences may relate to cognitive development, a topic to which we turn next.

Cognitive Advantages to Locomotion

Independent mobility is an achievement that may facilitate cognitive development in infancy. For example, Hebert et al. (2007) found a link between crawling and more flexible memory retrieval at nine months of age. They tested the memories of 96 crawling and non-crawling nine-month-old infants 24 hours after a demonstration with a toy stimulus. Of these infants, 32 served as a control group and did not see the demonstration. Very few infants in the control group were able to perform the task. Twenty-four hours after the demonstration, many of the 32 experimental infants that were returned to the same stimulus and context were able to perform the task. However, of the 32 infants tested in a slightly different context than the demonstration 24 hours earlier, only crawlers had performed the task at a significantly higher rate than the control group. The researchers suggest that experiences enabled by locomotion may facilitate memory retrieval in general.

Although the above study identifies locomotion as a positive factor in development, it lacks a longitudinal design that could confirm that the crawling and non-crawling infants had similar levels of flexible memories prior to the onset of crawling. Similar development up to the point of learning to crawl would separate locomotion as either a facilitator or a co-occurring factor in cognitive development. Future research should clarify the systems surrounding the onset of locomotion and the role of locomotion itself in child development. This paper may clarify the role of some variables occurring before and after the achievement of locomotion, namely season of birth, and cognition at ages four or five years. Another objective of the study is to test the role of locomotion in development, specifically as a mediator between season of birth and cognition in early childhood.

How might locomotor onset influence cognition? Crawling infants may experience more opportunities for exploration of their surroundings, and they experience memories that are more flexible. In addition, crawling infants experience a more complex social and emotional environment, which may influence the way they view their world, and learn from others.

Many social and emotional changes occur for crawling infants as opposed to infants who cannot yet crawl. Using parent interviews, Campos et al. (1992) found that crawling infants experienced more expectations of compliance to directions, more verbal prohibitions and discipline and more expressions of anger and affection as well as more physical punishment from their parents than infants of the same age who had not yet learned to crawl. Accordingly, crawling infants expressed more anger and affection, engaged in more interactive play, showed increased attention to their parent's whereabouts, to distal objects, and people. They also showed increased "checking" with the parent. This "checking" behaviour is crucial for social development (e.g., theory of mind), as it provides the groundwork for communication about items for the sake of sharing an experience. It is a human-specific custom that is necessary for bonding and learning. That shared communication should help cognition and early walkers may get a larger 'dose' of this positive influence and, thus enhance cognitive skills.

The studies on the social and emotional correlates of crawling demonstrate that advantages associated with locomotion are profound and immediate. However, locomotion gains even more importance when these advantages persist into adulthood, through decades of various environmental influences. Few researchers have explored the link between motor milestones and brain development into adulthood. Despite the relatively few studies available in the literature, Taanila et al. (2005) and Murray et al. (2006) performed some remarkable research on relations between infant milestone attainments and adult characteristics.

Taanila et al. (2005) studied a longitudinal sample of 10, 631 Finnish residents and collected information on the ages of motor milestone attainment in infancy and educational level many years later. Earlier attainments of standing without support, walking without support, defecating in a potty and keeping a dry diaper were significantly correlated with participants' school performance at 16 years of age. Taanila et al. found a significant relationship between speaking at earlier ages and school performance for females; however, this link was not significant for males. Years later, the researchers found that individuals who had not stood without support by nine months of age nor defecated in a potty by 12 months of age were less likely to continue beyond the basic level of education at age 31. Of those continuing beyond the basic education, earlier milestone achievers were 1.4 times more likely to advance from secondary to tertiary level than those attaining milestones at later ages. Although educational level in adulthood is not a direct measure of cognition, it is highly correlated with IQ, with a coefficient of about .6 (Mackintosh, 1998). Therefore Taanila et al.'s findings support the idea that persisting cognitive benefits accrue to those who developed early in infancy.

In a related line of research, Murray et al. (2006) discovered a beneficial relationship between learning to stand at younger ages and categorization with working memory in adulthood. They acquired a gender-stratified random sample of 62 male and 42 female participants who lived in Oulu, Finland at the time of the study. These individuals' developmental information was available from the Northern Finland 1966 Birth Cohort, a cohort representing 96% of all births in Lapland and Oulu in 1966. Records on this cohort included developmental assessments during visits to child welfare centres up to 12 months of age. These participants, at 33-35 years of age, completed several cognitive tasks, most of which were computer assisted: categorization (identifying correct groups for target objects) categorization with explicit working memory load (categorization with brief delays between stimuli); visuo-spacial immediate/working memory (recall the colour of randomly replaced ball among a screen of 12 balls); visual object learning and memory (recall and identify 10 target objects among 20 objects); and verbal learning (memorizing 16-item shopping lists). Controlling for gender, paternal social class, and maternal education, Murray et al. found that later learning to stand was associated with poorer categorization and working memory test scores. They theorized that earlier infant motor development involves faster maturation of basic neural circuits, and that this faster maturation benefits the development of more complex cortical-subcortical circuits that last into adulthood.

These studies on milestone attainment and outcomes in adulthood are remarkable; however, we must interpret them with caution. For example, a host of unmeasured covariates may account for both age of milestone attainment and cognitive performance. Moreover, the study by Taanila et al. (2005) analyzes a very large sample, which means that very small effects can result in significant relationships. Nevertheless, the studies reveal interesting findings that may support the notion that the timing of early motor milestones may influence later cognitive outcomes.

The discussions above demonstrate the importance of season of birth, which is associated with the age of locomotor onset. Locomotor onset is, in turn associated with later cognitive performance. Specifically, infants born in the winter and/or early spring are more likely to crawl and walk at younger ages; and infants who can crawl or walk at younger ages are more likely to possess cognitive advantages, perhaps even in adulthood. The logic of the preceding statements leads to the prediction that season of birth is associated with cognitive performance, our next topic.

Season of Birth and Cognition

A small body of research beginning in the 1960s attempted to link season of birth with cognition or intellectual performance later in life with mixed results (Berglund, 1967; Davies, 1964; Kanekar & Mukerjee, 1972; Mascie-Taylor, 1980). As we shall see, these mixed results may be due to factors such as the location of the sample or methodological quality.

McGrath et al. (2006) reported clear associations of both motor development and cognitive ability to season of birth. These researchers conducted a longitudinal study using a sample of over 22,000 children from the US Collaborative Perinatal Project. They adjusted for sex, gestational age, and age-at-testing or duration-of-schooling, and found significant season-of-birth relationships. Winter/spring births were associated with higher scores on the Bayley Motor scale at eight months (but not on the Bayley Mental scale), the Graham-Ernhart Block Sort Test at four years, and the Wechsler Intelligence Scale for Children (WISC) at seven years (but not on the WISC verbal scale). On the other hand, winter/spring-born children did significantly worse on the Bender Gestalt Test (visuo-constructive ability) at seven years of age. The researchers list several possible explanations for the season of birth phenomenon, including reduced placental blood flow or vitamin D levels during mid-gestation, or prenatal infection.

In the study described above, McGrath et al. (2006) did not consider Bayley Motor performance to be a mediator between season of birth and cognitive performance at ages four and seven years; however, their results offer preliminary support to the mediational hypothesis of the present proposal, in that a seasonal difference in motor abilities was apparent during infancy, and similar differences in mental abilities were apparent years later. In McGrath et al.'s sample, developmental milestone attainment, as measured by the Bayley Motor scale, may have served as a mediator (an intervening explanatory variable) between season of birth and later cognitive performance. Infants born in the winter and spring may have learned gross motor skills, such as crawling and walking, at relatively young ages, and the resulting cognitive head start may have, in turn, been reflected in their scores on the intelligence tests in childhood.

Additional research on seasonal effects is found in educational research, and work on school performance. The possible role of season of birth as an explanatory variable has received more attention in the educational literature, probably because of the relative ease of acquiring educational outcome data. The educational findings are of interest because performance appears to follow the same seasonal pattern, that is, lower performances are more likely to occur for summer-born children. A literature review by Martin et al. (2004) revealed that children born during the summer months are more likely to have poorer educational achievement compared to children born at other times of the year. The most cited reason for this result is the relative immaturity of summer-born students at school entry. In the United States, the place of interest for many studies on season of birth and school performance, the majority of states provide a kindergarten entry cut-off that is very close to the beginning of the school year (Graue & DiPerna, 2000). Because schools typically start in September, children born in the summer are typically the youngest in their class, and this relative neurological maturity may lead to negative biases toward summer-born students. On the other hand, some school districts use entry cut-off dates from other times of the year, thus further complicating explanations for season-of-birth findings.

Research on season of birth and school achievement often involves a divided sample (i.e., a sample of children with learning disabilities, or a sample of children without learning disabilities). Hopefully, more researchers will expand their studies to the wider population: Recent behaviour-genetic work (Kovas, Haworth, Dale, & Plomin, 2007) suggests that abnormal (e.g., learning disabled) is normal, in that it is simply the end of a distribution. From such a perspective, both studies on special groups (e.g., consistent with poor performance by summer-borns) and average groups are relevant. The integration of children with and without learning disabilities into a large sample could help to separate erroneous placements to special education classes from real seasonal differences. Studies on school performance highlight two possibilities: (a) the season-of-birth effect is simply an artifact of a cohort definition where summer-born students face educational disadvantages because they are often the youngest and most immature in their class, or (b) the season-of-birth effect is real and is the reason why learning disabilities are more apt to be diagnosed for summer-born students. The second possibility can be investigated with a seasonal effect model (i.e., our mediation hypothesis) and the use of a complete sample of children with and without learning disabilities.

If seasonal factors, such as sunlight are important in school achievement, then latitude should be a factor in assessing seasonal differences. Studies often ignore latitude; however, Jacobs and Alper (1970) supported the idea of seasonal effects on mental abilities when they found null-effects at low latitudes; areas where temperature is consistent throughout the year. The investigators compared month-of-birth to expected month-of-birth frequencies for 2,140 individuals who had been institutionalized for mental retardation in Florida and southern Georgia. As they expected, no significant differences were found. Jacobs and Alper suggest that the area's smaller variation in seasonal temperature caused smaller seasonal effects on mental abilities in its population. This is an important point because if sun exposure and temperature are the likely mechanisms for a seasonal effect, then seasonal effects should be stronger at high latitudes, and weaker at lower latitudes.

Careful examination of the studies above lends support to our hypothesis of advantages for winter/spring-borns in age of motor attainment and in cognitive performance. The differences identified are not necessarily large or seen in everyone, but they indicate that factors associated with season (e.g., sun exposure, day length, temperature) contribute to infant development.

The disorder surrounding literature on relatively low educational achievements in summer-borns can be (at least in part) clarified by the age of locomotion as a mediator between season of birth and cognitive performance: The mediator would promote faster development as a factor in educational attainment as opposed to the current theories, which blame differences in school performance on teacher bias and cut-off entry dates in the school system. Therefore, the addition of age of locomotion onset to the season of birth – school performance model would be desirable in future studies.

In summary, literature to date has explored relationships between (a) season of birth and onset of locomotion (Benson, 1993, 1996; Eaton & Bodnarchuk, 2007; Eaton et al., 2008), (b) onset of locomotion and cognition (Campos, et al., 1992; Hebert et al., 2007; Murray et al., 2006; Taanila et al., 2005) and (c) season of birth and cognition (Martin et al., 2004; McGrath et al., 2006; Thompson, 1971). Results demonstrate that births in the summer/fall pose a risk for both delayed milestone attainment and lowered cognitive performance. In contrast, winter and spring births are associated with both earlier locomotion and higher cognitive performance. To our knowledge, no one has directly tested the possibility that the age of locomotor attainment is a mediator between season of birth and cognition; however, Holmes (1995), who studied history of science, postulated the idea. He aggregated birth dates of 47 scientists who took an early stance in theories of relativity and evolution. Twenty-two of these scientists took a correct stance and 25 took an incorrect stance. Holmes found that 82% of the physicists and biologists that took a correct stance were born in the winter and early spring (December to April), and none were born from May to July. On the other hand, 60% of physicists and biologists that took an incorrect stance were born in May through July, and only 24% were born in the winter and early spring. All of these scientists were born in Europe or North America, at an average of approximately 50° latitude. Holmes audaciously speculated that at the age of learning to crawl, those born in winter and early spring would have more freedom to explore their surroundings whereas those born in the summer would likely be bundled for warmth. He wondered if these early experiences might have influenced scientific attitudes later in life. Holmes' suggestion illustrates the mediation relationship that we propose to test, namely that season of birth influences the timing of locomotion, which, in turn influences later cognitive performance.

Method

The first requirement for testing our hypothesis is a large sample, with births distributed through the year, as this is necessary to meet the assumptions of statistical tests involved in the analyses. Moreover, the participants should reside at high latitude, in order for season-related effects to be operative. In addition, obviously, information on this sample must include all variables relevant to the hypothesis; that is, the dataset must include information on date of birth, milestone attainment, and measures of cognition. Fortunately, a Canadian survey, the National Longitudinal Study of Children and Youth (NLSCY) meets these requirements: It contains longitudinal information on thousands of children residing in Canada, where most of the population live between of 42° and 58° North latitude.

NLSCY

Statistics Canada conducts the NLSCY every two years, with funding from Human Resources and Society Development Canada. Their objective is to monitor the development of Canadian children and youth (Statistics Canada, 2008). The NLSCY began its first cycle of data collection in 1994/95 and continued biennial surveys of its participants throughout 2004/05. This newest data release (cycle 6) was in December 2006 and includes data collected from September 2004 to June 2005. Access to the NLSCY microdata files is possible through Research Data Centres (RDC) located at several sites across Canada.

Children for cycle 4 of the NLSCY were selected from households sampled by the Statistics Canada's Labour Force Survey (LFS). The LFS sample consisted of approximately 54,000 dwellings, which represented the civilian population ages 15 years and older for Canada's ten provinces. Approximately 2% of Canada's 15-and-older population were excluded (residents of Yukon, Nunavut, and Northwest Territories, residents of Indian Reserves, full-time members of the Canadian Armed Forces, and inmates of institutions).

A stratified design was used to ensure a representative sample of the Canadian population: Provinces were first divided into Economic Regions and Employment Insurance Economic Regions; these geographic areas had homogenous economic structures according to federal provincial agreements or as estimated by information from Human Resources and Social Development Canada. These areas were classified as urban, rural, or remote types of areas, where urban areas were further split into apartment or non-apartment areas. A second stratification was conducted to account for low, regular or high income, and low population density. Finally, each stratum was divided into clusters, and a sample of clusters was selected for each stratum. Dwellings were then sampled from the selected clusters, and information was collected via interviews in the participants' homes or over the telephone.

The NLSCY sample of interest for the proposed study is composed of 0- to 1-year-old infants recruited in cycle 4 and followed through to cycle 6. The relevant information for the proposed analyses is available only from this group of children because cycle 4 was the first to obtain parents' estimates of their children's ages (in months) for particular milestone attainments. Cycle 6, which was a longitudinal follow-up, contained information on these children's cognitive performance at ages four to five years. The sample size for the cohort of 0- to 1-year-olds in cycle 4 was 4,909 households with a 77.2% response rate (3,788 households). Statistics Canada followed these children through cycle 6, when the original cohort was four to five years of age with a 60.1% response rate (2,952 households). Table 1 summarizes the longitudinal sample information relevant to our analyses. In order to use this longitudinal information, individuals' data from cycles 4 through 6 were linked. From the resulting longitudinal dataset, a sample of 2,643 children has appropriate information on both milestone attainment from cycle 4 and cognitive measures from cycle 6.

Table 1

Sample Description from Cycles Four and Six of the NLSCY

NLSCY cycle	Age of children (cohort)	Responding househholds (cohort)	Response rate (cohort)	Variables needed	Coverage of NLSCY sample	*n* * for NLSCY variables
4 (Sept 2000- May 2001)	0-1	3,788	77%	Birth date	Children aged 0-18 years	30,307
5 (Sept 2002- May 2003)	2-3	3,291	67%	Reported age of walking (cycle 4 and 5 data combined)	Children >=9 months old and <=47 months at cycle 4 interview	11,244
6 (Sept 2004- June 2005)	4-5	2,952	60%	PPVT-R score	Children aged 4 or 5 years	3,184

*excluding responses "valid skip", "don't know", "not applicable", "refusal", and "not stated"

Season of Birth

The first major variable of interest is season of birth, which served as a predictor for both of age of locomotion onset and cognitive performance at four to five years. Season of birth was entered as a set of three continuous predictors. More specifically, each child's birth date was first converted to a Julian date (days since January 1; range from 1 to 366). The conversion of birthdates to Julian dates allowed for a more detailed analysis of season of birth than previous studies, which used two-, three-, or four-category groupings of births throughout the year. Julian date, a linear variable, was squared and cubed to create quadratic and cubic season-of-birth predictors. The linear, quadratic, and cubic components comprised a set of three predictors that can capture season of birth patterns of different curvilinear shapes. It was important to include the curvilinear quadratic and cubic predictors to represent the rise and fall in temperature throughout the year. Although a linear predictor was included, we did not expect a 'pure' linear relation between birth date and outcome variables. For example, a solely linear effect between Julian date and cognitive performance would mean that cognitive performance continuously rises over time, which is implausible.

Age at First Walking

Earlier sections of this proposal have emphasized the importance of the age of locomotion onset as a potential mediator variable between season of birth and cognitive performance. Because parents are so attentive to their child taking his or her first steps, and because of the milestone's relationship to season of birth (Benson, 1996; Eaton & Bodnarchuk, 2007) and cognitive performance (Taanila et al., 2005), the age at first learning to walk is a suitable measure of independent mobility. It is a good proxy for rate of locomotor development because it is strongly correlated with age of first crawling and other intermediate milestones such as age at standing.

Donoghue and Shakespeare (1967) reported that parents are more likely to remember when their child began walking than any other milestone. They interviewed parents when the children were an average age of three years and seven months for recall of milestones such as smiling, teething, sitting, talking, standing, walking, and keeping a clean diaper. Ninety-five percent of these parents recalled an age for when their child first learned to walk. Moreover, the researchers found a high correlation ($r = .67$) between the parents' memories of the age of walking and Health Visitors' records, with an average discrepancy of 1.4 months. Higher validities have been reported. For example, Pyles, Stoltz, and McFarlane (1936) reported a correlation of .84 between parent report of first walking and recorded child walking; Mednick and Shaffer (1963) reported that 92% of the mothers were correct in their recollections.

Donoghue and Shakespeare's (1967) findings are particularly germane because NLSCY interviewers for cycle 4 asked parents of nine- to 47-month-olds to estimate the age in months that their child first began to walk. The majority of NLSCY parents (n = 8,533) responded by providing an age; whereas, 468 said their child has not walked yet, and 341 either did not know, or did not state an answer, or refused to answer. The result is a similar rate of recollection (96%) to that of Donoghue and Shakespeare (1967); it is plausible that the recollections of mothers between the two studies are also similar in accuracy. Because of the appropriateness and accessibility of this milestone, the age at first walking served as the measure of locomotor onset.

Cognitive Measure

As noted earlier, the NLSCY included child cognitive measures at ages 4 and 5 years. The *Peabody Picture Vocabulary Test-Revised (PPVT-R)* (Dunn & Dunn, 1981) uses stimulus words and matching illustrated meanings to assess a child's hearing vocabulary. The child's score reflects the number of correct selections, which typically increases with age. Based on a standardized sample, this test has an internal consistency of .61 to .88 and an alternate-form reliability of .71 to .91. Based on a subsample, the test-retest reliability is .52 to .90 (Dunn & Dunn). The reliabilities above have lead to a consensus that the test has adequate psychometric properties (McCallum, 1985). Construct validity was confirmed when a theoretical model of the order in which words are learned in general was able to account for 62% of the variance in the acquisition order for PPVT-R stimulus words (Miller & Lee, 1993). The interviewers administered the test directly to the child in his or her home.

The NLSCY provides standardized scores on the *PPVT-R* scores[1], where population averages are set to ~100 with a standard deviation of ~15 (Human Resources and Social Development Canada, 2006). The test is standardized using two-month age groups, which allows comparisons across age. On the other hand, regression analyses allowed a much more specific measure of child age at the time of the interview, so we used the raw scores with exact age at testing as a covariate in our analyses. Ideally, scores should also be adjusted for time spent in an educational setting. Morrison, Griffith, and Alberts (1997) indicate that experience in an academic program improves performance on tests compared to others at a similar age with no school experience. The NLSCY identifies children who are enrolled in junior kindergarten, kindergarten, or grade one, and whether this is full-time or part-time. School experience was calculated on a three-point scale: no school, part-time school, and full-time school; however, the school experience measure lead to multicollinearity problems (it was highly correlated with child age), and so it was excluded from analyses.

Covariates

Because this study is correlational, any relation between earlier characteristics (e.g., season of birth) and later ones (e.g., cognitive level) could be due to other co-varying factors. Consequently, it is important that other plausible predictors be accounted for in the statistical model. We describe below the covariates used in the study's analysis:

Family and biological variables. We take the view that variables that predict intelligence are likely to influence scores on the more specific cognitive measure that we are using (i.e., *PPVT-R*). Predictors of child intelligence have been identified through a cohort of 10,424 children from Aberdeen, Scotland by Lawlor, Batty, Morton, Deary, and Macintyre (2005), who linked the city's neonatal and maternal database with scores on intelligence tests that are administered routinely in primary schools in Scotland. In identifying independent predictors of intelligence, they found that test scores at ages seven, nine, and 11, had positive correlations with high paternal social class, good maternal physical condition, maternal age, gestational age, and birth weight. Negative relationships were observed for number of maternal pregnancies and for whether the child was born outside of marriage. These variables are available from the cycle 4 cohort of children in the NLSCY and will be used as additional predictors in the proposed analysis. Moreover, we excluded premature infants (born at less than 37 weeks of gestation). This exclusion focuses our study on the normal range of development and is consistent with McGrath et al.'s (2005) longitudinal study methods on season of birth and later cognition. The adequacy of family income given the number of individuals living in the home and the income of other homes in the area was used as a measure for the household's social class. This approach is similar to that of Taanila et al. (2005).

Birth order. Birth order has been found to influence intelligence, although this effect has an age-related interaction. Based on the confluence model (Zajonc, 2001; Zajonc, Marcus & Marcus, 1979), younger siblings enjoy higher intellectual maturity until nine to 13 years of age, when the birth order effect becomes reversed. These researchers theorize that younger siblings initially benefit from the teachings of their older siblings, and older siblings simplify their game play to accommodate younger siblings. However, by the age of adolescence, first-born children have experienced many opportunities to serve as an intellectual resource for their younger family members, a valuable skill for intellectual development. Because the cognitive measures from the

NLSCY have assessed children between four and five years of age, a positive correlation between birth position and cognitive scores is anticipated, that is, the children with more siblings are expected to demonstrate higher cognitive levels. This model does not require children in the household to be biologically related, as the effect is social rather than biological (Kristensen & Bjerkedal, 2007). The number of older siblings reported in the NLSCY includes all older children living in the household, including full, half, step, adopted and foster siblings.

Another important variable to consider is the gender of the child. For example, in cycles 4 and 5 of the NLSCY, females consistently outperformed males for each of the *PPVT-R* (Human Resources and Social Development Canada, 2006). By including gender as a covariate, we were able to evaluate season of birth and locomotion influences that are independent of child gender.

Maternal substance abuse. A review by Huizink and Mulder (2006) outlined an association of prenatal exposure to nicotine and alcohol on neurobehavioral and cognitive development. Studies linking maternal smoking or drinking with cognition in early childhood are of interest for the proposed analyses because they may serve as additional co-varying factors on the cognitive scores presented by the NLSCY. Specifically, maternal smoking during pregnancy has been associated with lower general cognitive function at three years of age (Sexton, Fox, & Hebel, 1990) and lower performance on sustained attention, response inhibition, and memory at six years of age (Fried, O'Connell, & Watkinson, 1992). Moderate alcohol consumption during pregnancy has been associated with lower speed of information processing and sustained attention as well as a decrease of nearly five IQ points (Streissguth, Barr, Sampson, Darby, & Martin, 1989). Many studies reviewed by Huizink and Mulder were able to demonstrate a dose-response relationship between prenatal substance exposure and developmental outcomes. Therefore, smoking and alcohol consumption by mothers were included as covariates in the analysis.

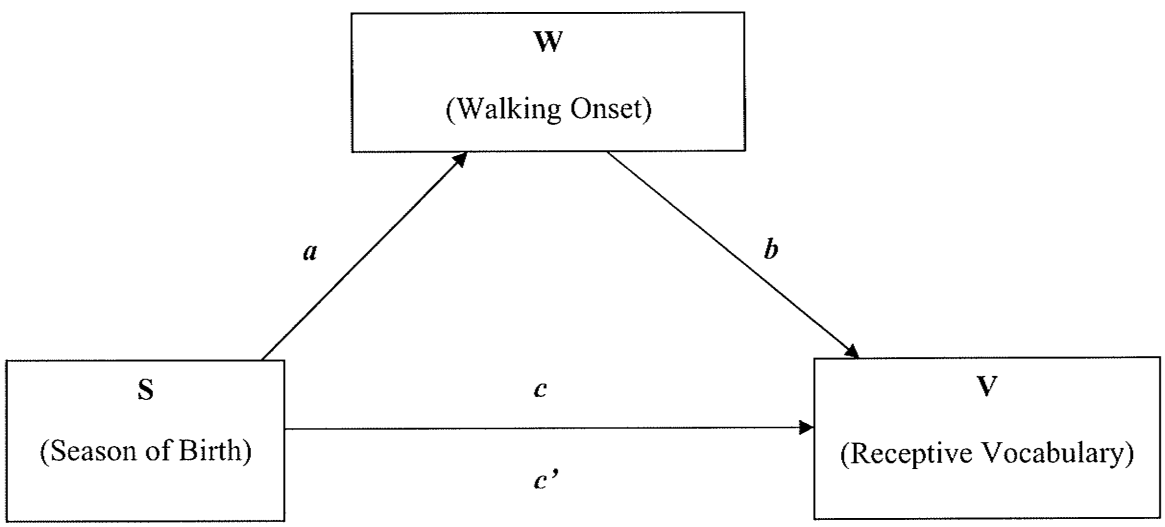
Breastfeeding. We also included breastfeeding as a covariate in the analyses, because it has been shown to have positive effects on cognitive development. It is recommended that Canadian infants be breastfed exclusively for at least the first six months of life (Canadian Paediatric Society, Dieticians of Canada and Health Canada, 1998). For example, a cluster-randomized trial demonstrated that a group receiving breastfeeding promotion intervention resulted in higher IQ scores on the Wechsler Abbreviated Scales of Intelligence (WASI) at six-and-a-half years of age; a difference that is statistically significant for the verbal subtests (Kramer et al., 2008). Further analyses of both the experimental and control groups (n = 13, 889) demonstrated that exclusive breastfeeding for at least three months and six months was related to increasingly higher IQ scores on verbal, performance and full scales of the WASI. Exclusive breastfeeding for three to six months was also related to significantly higher teacher academic ratings for reading, writing, mathematics, and other subjects. It is clear that breastfeeding has a positive influence on cognitive development and so it was included as a covariate in the analyses.

Design

We had planned to apply a mediation analysis to test our hypothesis, namely, that season of birth has an effect on age at milestone attainment, which in turn affects cognitive development. More specifically, we predicted that cognitive benefits from early milestone attainment might persist into school age. Thus, the goal of this mediation hypothesis was to use milestone attainment to clarify the relationship between season of birth and cognition at a later age. In Figure 1, the role of each variable is illustrated in the hypothesized mediation: S represents season of birth, W represents age at learning to walk, and V represents receptive vocabulary. In addition, the relationships between S and W (listed as *a*), W and V (listed as *b*) and S and V (listed as *c*) are illustrated. Whereas *c* is representative of the direct relationship between S and V, *c'* represents the relationship after the mediator (W) is taken into account. If a mediator effect was present, *c'* would have been significantly smaller than *c*.

Figure 1

Mediation Hypothesis



Several steps are involved in establishing mediation (Baron & Kenny, 1986; Judd & Kenny, 1981). Using SAS software version 9.1.2 and the covariates as discussed above, all three relationships can be tested using multiple regression with season of birth and covariate variables as the predictor variables and age at first walking or scores on the PPVT-R as the criterion variables. We tested the hypothesis that there is a relationship between season of birth and age of walking, path *a*. In this regression model, season of birth was the predictor and age of walking was the criterion. Although this has been found in previous literature (e.g., Benson, 1996; Eaton & Bodnarchuk, 2007; McGrath et al., 2006), the present study will provide an extended replication in a Canadian sample. Our second hypothesis is that there is a negative relationship between age of walking and scores on the PPVT-R (the criterion), *b*, namely that earlier walking is associated with better receptive vocabulary. Our third hypothesis was that season of birth predicted receptive vocabulary, path *c*. If these three links were confirmed, we would be able to move to the last hypothesis: a formal test of the role of locomotion as a mediator.

In the last hypothesis, we expected the formal test of mediation to show that *c'* is reduced significantly (partial mediation) or completely (complete mediation) when W is added to the model. The Sobel test (Sobel, 1982) is most commonly used for mediation analysis; however, Preacher and Hayes (2004) explain that because the Sobel test assumes a normal distribution of the product of *a* and *b* (see Figure 1), and because most distributions of products are positively skewed, the test will often have a low power. Preacher and Hayes recommend an alternative method called bootstrapping, which takes multiple samples (with replacement) from the data. The number of samples from the data equals the sample *n*, and an *ab* estimate is computed from each sample. The *ab* estimates are then ordered by size and the 5^{th} and 95^{th} estimates become the lower and upper confidence intervals for *ab*. We followed Preacher and Hayes' (2004) recommendation and prepared to use their SAS macro for both the Sobel and bootstrapping methods.

Results

A sample size of 2,985 was available; however, after excluding cases with missing information on either of the outcome variables, this initial sample size was reduced to 2,643, consisting of 1,356 boys (51%) and 1,287 girls (49%). Age at first walking contained 43 cases of missing values, scores on the PPVT-R contained 315 missing values. Sixteen children had missing values for both variables.

Age at first walking

Parents were asked the question “age (in months) when this child took his first steps”. Parents who reported their child as not yet walking at the time of the cycle 4 interview were asked this question again in cycle 5, thus lowering the number of missing from 922 to only 43. Outliers at the younger end of the distribution were assumed to be typos and were recoded with this consideration. The mean age at first walking was 11.5 months (*SD* = 2.3). The final distribution was positively skewed (skewness = 1.23) and the first and third quantiles were 10 and 13 months respectively.

PPVT-R score

From our initial sample, 2,670 out of 2,985 children took the PPVT-R in cycle 6. We excluded children who had missing data for this or for age at first walking, which resulted in a sample of 2,643. Because the standardization of this score used age, a variable already entered as covariates in the analyses (e.g., age at taking test), the raw PPVT-R score was used. The average score on this test was 60 (*SD* = 19).

The average age of the child for the PPVT-R was 59 months or 4.9 years (*SD* = 6.6 months). Ninety percent of the sample was between 48 and 69 months at the time of testing and no extreme outliers were found.

Apart from gender, eleven covariates of motor development and PPVT-R scores were identified in the literature: Income adequacy, education and marital status of the person most knowledgeable, age of mother at the time of her child's birth, mother's health during pregnancy, the child's gestational age, birth weight, breastfeeding duration, number of children in the home, and whether the mother smoked cigarettes or consumed alcohol at any time after the child's conception or birth. Each variable contained a unique number of nonresponses and formed unique distributions. Their details are described below and are summarized later in Table 2.

Family variables

Income Adequacy. Income adequacy served as a proxy for paternal social class. This item, developed by Statistics Canada, measures the sufficiency of family income relative to the cost of living in the area and number of members in the household. Data for this variable was imputed by Statistics Canada using the Postal Code to estimate income levels of the area. It was coded on a scale from one to five where each rank represented a ratio of household income to the low-income cut-off. We centred this variable on three (n = 725, 27%); however, the mode for this variable was a score of four (n = 1,100, 42% of the sample), or one on the centred version of the variable.

Education of Person Most Knowledgeable. The education of the person most knowledgeable (PMK) of the child was entered as another covariate in the analysis (n = 2,643). Six hundred and nine PMKs (23%) completed the standard high school graduation, the amount of education on which the variable was centered. Relatively few PMKs did not graduate from high school (n = 257, 10%), and most received education beyond high school (n = 1,777, 67%).

Marital Status. All respondents reported their marital status (n = 2,643). Marital status was recoded to reflect one of two situations: legally married and not married. Not married captured individuals who were living common-law, widowed, separated, divorced, or who had never married. This variable was centered on married (n = 1,917, 73% of the sample).

Number of Siblings in the Home. The number of children (assumed to be siblings) in the home was a variable that correlated highly with parity (r = .675), so it made an acceptable replacement. Moreover, all mothers responded to this item (n = 2,643). Many of the children were the only ones in the household (n = 1,078, 41%) and 1,026 children (39%) shared the home with other children.

Maternal variables

Mother Health During Pregnancy. The number of prenatal problems experienced during pregnancy measured the mother's health during pregnancy. The problems included "diabetes", "high blood pressure", and "other", creating a range of zero to three. Data on mother health was available for 1,822 mothers. This measure was centered on the norm, which is zero problems during pregnancy (n = 1,269, 70% of the sample).

Maternal Smoking. Maternal smoking was initially intended to measure prenatal smoking; however, a high nonresponse rate on that variable forced us to consider an alternate measure: smoking during pregnancy or after birth. Smoking during pregnancy was only asked of biological parent of children 24 months or younger: 333 mothers smoked during pregnancy, 1,493 did not, 426 were not asked the question, and 391 chose not to respond to the question.

When combined with the question "have you smoked in the past year", more mothers offered an answer: 1,927 mothers had never smoked, and 687 had smoked at least once during pregnancy or within a year of the cycle 4 interview. This measure of "ever smoking" was used in the analyses.

Maternal Alcohol Consumption. During pregnancy, 1,576 mothers drank no alcohol, 247 mothers consumed alcohol at least once, 394 mothers chose not to respond and 426 mothers were not asked the question. Maternal alcohol consumption presented a situation similar to smoking: Therefore, we combined reported alcohol consumption during pregnancy and after delivery to construct an alternate variable: "ever drink". This new sample (n = 2,612) revealed that 714 of the mothers had consumed no alcohol during pregnancy or in the year prior to the cycle 4 interview and 1,898 mothers had consumed alcohol at least once in either of those time periods. The analyses of this derived variable as a feasible covariate brought about some interesting observations: Both drinking during pregnancy and drinking in the past year were correlated with the PPVT-R ($p < .05$, $p < .0001$). Alcohol consumption in the year prior to the cycle 4 interview was also correlated with age at first walking ($p < .001$). However, maternal drinking during pregnancy and "ever drink" were not significantly related to age at first walking.

Maternal Age at Giving Birth. Data on the age at the time of the child's birth was available for 2,603 mothers. The variable was centred on the mean, which was 29 years (SD = 5.3). By visual inspection, the distribution was normal, with a few outliers at each end of the distribution (skewness = 0.15, kurtosis = -0.23).

Birth variables

Gestational Age. The gestational age of the infant was asked of the mother in cycle 4 (n = 2,083). Several outliers were found as premature births, and so infants less than 259 days (n =

218) were excluded from the analyses, leaving 1,865 records for the analyses. The variable was recoded into weeks of gestation; the mean gestational age was 39 weeks (*SD* = 7.8). Gestational age was centered to 40 weeks, the number for a full-term pregnancy.

Birth Weight. Birth weight was available for 2,086 infants. The mean birth weight was 3,474 grams (*SD* = 592). Although birth length would have been another covariate, it was excluded from analyses due to its collinearity with birth weight.

Breastfeeding. Breastfeeding was initially measured with several ordinal scales, and these were recoded into a single derived interval scale measuring months of breastfeeding. Unfortunately, cycle 5 did not contain follow-up breastfeeding information on this sample, so responses that the mother was currently breastfeeding (*n* = 372) were recoded as breastfeeding up to the time of cycle 4 interview. The recoded sample contained 2,552 records of an estimated time of breastfeeding in months. Five hundred and seventy-eight (23%) infants were breastfed for less than a month or not at all. The mean number of months for breastfeeding was 5.5 months (*SD* = 5.25). Only 122, less than 5%, of the infants were breastfed for 15 to 29 months.

Table 2

Descriptive Statistics for Covariates

Measure	Format	n	Mean (SD)	Frequency
Income adequacy (cycle 4)	1 = lowest 5 = highest	2,643	3.8 (0.9)	
Mother age at Giving birth	Years	2,643	29 (5)	
Siblings in Home (cycle 4)	Number of Children	2,643	2 (1)	
Birth Weight	Grams	2,086	3,743 (592)	
Gestational Age	Days	1,865	275 (8)	
Breastfeeding	Time in Months	2,552	5.5 (5)	
Maternal health (pregnancy)	No problem 1 problem 2 or 3 problems	1,822		1,269 465 88
Marital status (cycle 6)	Married Single	2,643		1,917 726
Maternal Smoking	Never Smoked	2,614		1,927 687
Maternal Drinking	Never Drank	2,612		714 1,898
Education Of PMK (cycle 6)	No graduation High school diploma Post-secondary	2,643		257 609 1,777

Covariate Choices

Some variables that were originally chosen to be entered into the model were excluded from the analysis due to concerns with nonresponse and multicollinearity. These variables include measures of parity of the mother, and grade level of the child at the time of PPVT-R testing.

The parity item (the number of previous pregnancies by the mother) contained 312 nonresponses (12%). The variable also correlates highly with number of children in the home (r = .675). Because the effect of parity on a family is thought to be from the number of children in the home (see confluence model, Zajonc, Marcus & Marcus, 1979; Zajonc, 2001), the number of children in the home was kept in the analyses.

School experience measured the amount of schooling in the public school system and was thought to be a strong predictor of PPVT-R scores. It was calculated by combining several school-related questions along with knowledge of the child's age and the feasibility of entering into junior kindergarten (based on their province of residence). The school experience measure for children attending classes on half days or alternate days were halved. This variable was dropped from the analysis due to the assumptions made in its calculation as well as its high correlation with age at taking the PPVT-R test (r = .65).

Although there was considerable missing data for measures on mother's health during pregnancy, infant gestational age and infant birth weight (see Table 2), these items were strongly supported as predictors for development in the literature and so were kept for the analysis. Moreover, for 60-90% of these nonresponses, the reason for missing data was that the children were considered "not applicable" for the question because the children were outside of the age range for item coverage, and can considered to be missing at random.

A listwise deletion with all 11 covariates for the analysis revealed a sample of 1,612 children. Changes in univariates and frequencies were negligible between the full sample (2,643 children) and the listwise deletion sample (1,612 children), an indication that the nonresponses would not bias the results.

As noted above, another concern for covariates is the potential distortion of results through multicollinearity. Fortunately, correlations between the remaining 11 covariates were small. Some of the correlations were expected; the highest correlations were maternal age and education with family income (r = .29) and maternal age at giving birth with the number of children in the home (r = .32). On the other hand, some correlations were noteworthy; maternal smoking before or after giving birth was correlated with not being married (r = .23). Smoking was also negatively correlated with breastfeeding (r = -.22) and level of education (r = -.24). Breastfeeding and maternal age were positively correlated (r = .22). See Table 3 for a listing of correlations among covariates.

Table 3

Correlations Among Covariates

Label	Income adequacy	Maternal health	PMK not married	Maternal age	Siblings in home	Birth weight	Gestational age	Maternal smoking	Maternal drinking	Breastfeeding	Education of PMK
Income adequacy	--	-.01	-.24	.29	-.10	.04	.02	-.17	.11	.10	.29
Maternal health		--	.02	.01	-.07	-.04	-.11	.03	.01	-.10	-.01
PMK not married			--	-.25	-.12	-.08	.01	.23	.05	-.15	-.19
Maternal age				--	.32	.04	-.10	-.18	-.03	.22	.19
Siblings in home					--	.07	-.04	.02	-.02	.14	-.09
Birth weight						--	.21	-.13	.04	.07	.07
Gestational age							--	.00	.05	.04	.02
Maternal smoking								--	.11	-.22	-.24
Maternal drinking									--	-.04	.01
Breastfeeding										--	.15
Education of PMK											--

Note: n = 1,612 due to listwise deletion.

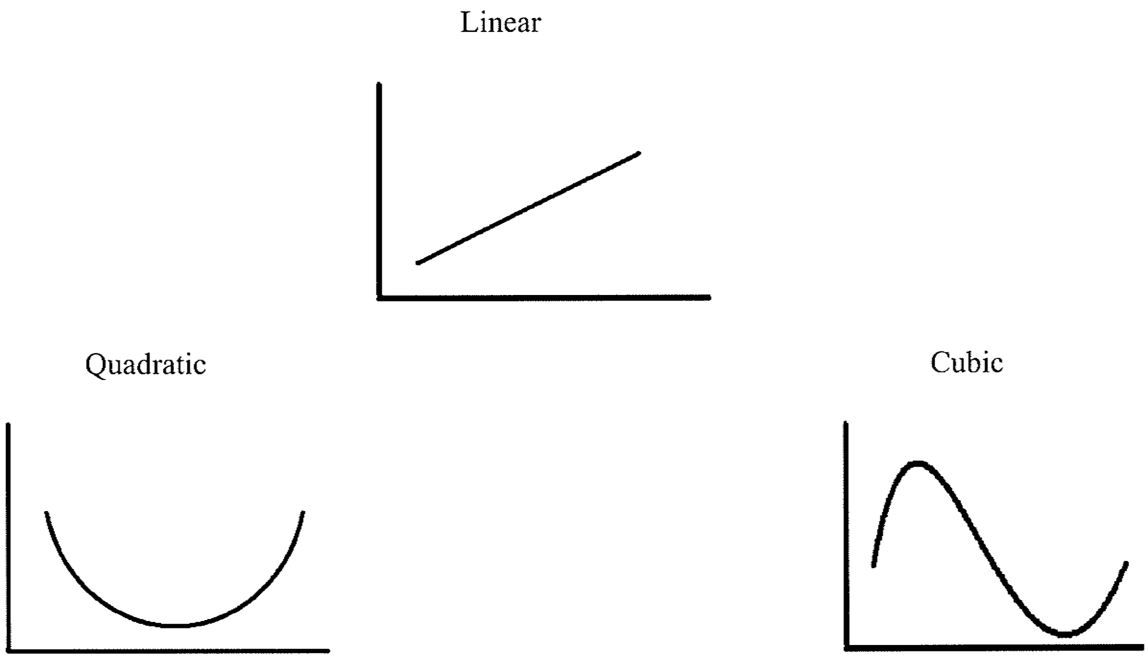
As discussed in the design section of this paper, the first of several steps to test a meditational hypothesis is to confirm the relationships between each part of the mediation model (see Figure 1), that is, (*c*) season of birth and cognition, (*b*) age of first walking and cognition, and (*a*) season of birth and age of first walking. These relationships were tested using multiple linear regression. A forward selection was used because the covariates were theoretically related to each model.

Model c: Season of Birth and Age at First Walking

We tested the relationship between season of birth (the predictor) and scores on the PPVT-R (the criterion) while adjusting for covariates. Season of birth was represented by Julian birthdates (the day of the year, 1-366) and was squared and cubed to provide the rises and dips associated with seasonal variable. These three predictor variables were then centered to reduce the likelihood of collinearity affecting the model and were entered into the model as a set. For example, 183 (the median) was deducted from the linear variable (days 1 to 366); this centred linear variable was squared with a deduction of 10437 to form the second Julian variable; and the centred linear variable was cubed with a deduction of 144511 to form the third Julian variable. The linear - cubic correlation was high ($r = .91$); the linear - quadratic and quadratic – cubic correlations were low ($r = -.05$ and -.07 respectively). These patterns are displayed in Figure 2.

Figure 2.

Julian Patterns Used in Analyses



The three Julian variables and the exact age at testing were entered into the model. The model was significant ($F = 34.61, p < .0001$) and accounted for 26% of the variance in the PPVT-R scores ($R^2 = .26$); however, the relationship between season of birth and PPVT-R scores was not significant ($F = 1.44, p = .23$). See Table 4 for a summary of each regression model in the mediation hypothesis.

Table 4

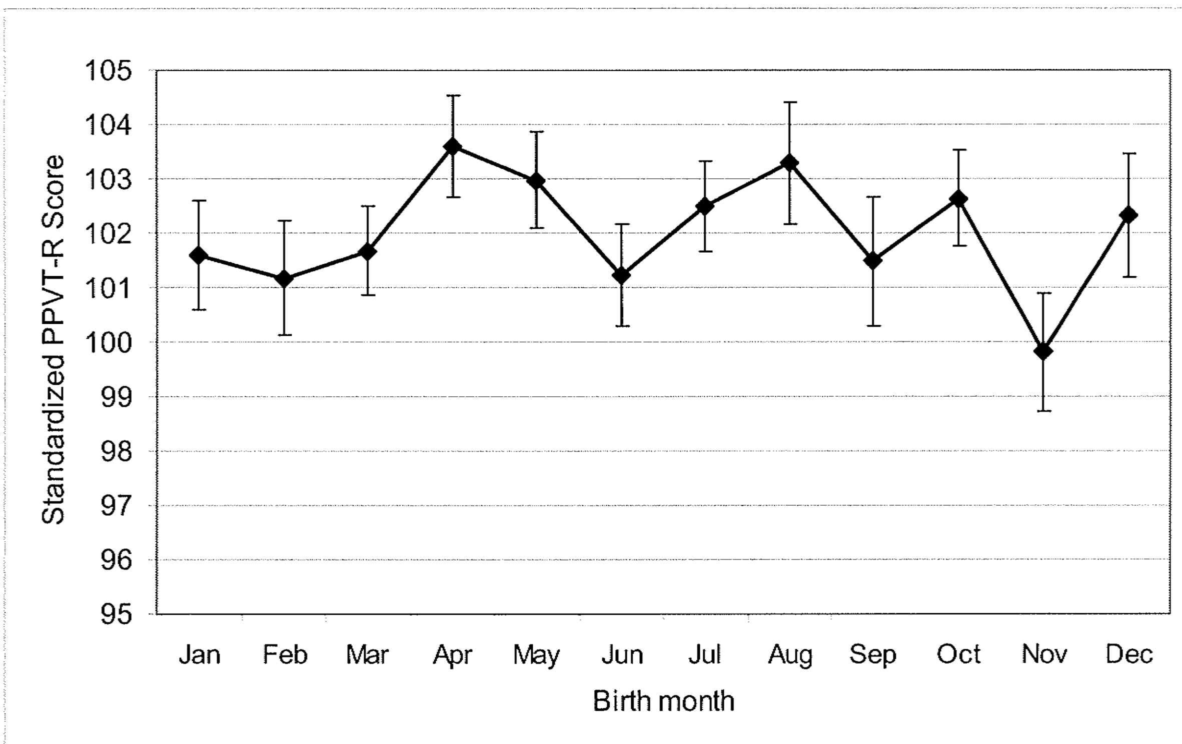
Multiple Regression Results that Test the Assumption of Mediation Model

Variable	Parameter Estimate	Standard Error	F Value	Pr > F
Model *c*: Group Season of Birth as a Predictor of PPVT-R			1.44	0.2288
Intercept	58.36	1.31	1973.11	<.0001
Julian linear (days)	-0.01	0.01	1.24	0.2655
Julian squared (days)	-5.13E-5	9.51E-3	1.57	0.2103
Julian cubed (days)	7.28E-7	4.51E-7	2.60	0.1067
Model *b*: First Steps as a Predictor of PPVT-R			7.88	0.0051
Intercept	64.13	2.40	711.22	<.0001
Age at first walking (mo)	-0.52	0.18	7.88	0.0051
Model *a*: Season of Birth as a Predictor of First Steps			2.44	0.0630
Intercept	10.88	0.17	4031.30	<.0001
Julian linear (days)	-3.26E-3	1.29E-3	6.42	0.0114
Julian squared (days)	2.26E-6	5.54E-6	0.17	0.6830
Julian cubed (days)	1.56E-7	6.06E-8	6.65	0.0100

To illustrate the relation between season of birth and receptive vocabulary, the mean standardized PPVT-R score by birth month is plotted in Figure 3. Consistent with the regression results, the scores do not appear to have a seasonal pattern.

Figure 3

Mean PPVT-R Scores by Birth Month



Although models *a* and *b* suggest a season of birth – walking onset and walking onset – cognition course of development, model *c* (see Figure 3) did not confirm a relationship between season of birth and PPVT-R scores, and so the assumptions of a mediation model were not met (Baron & Kenny, 1986; Judd & Kenny, 1981). Therefore, a formal test of mediation could not be made.

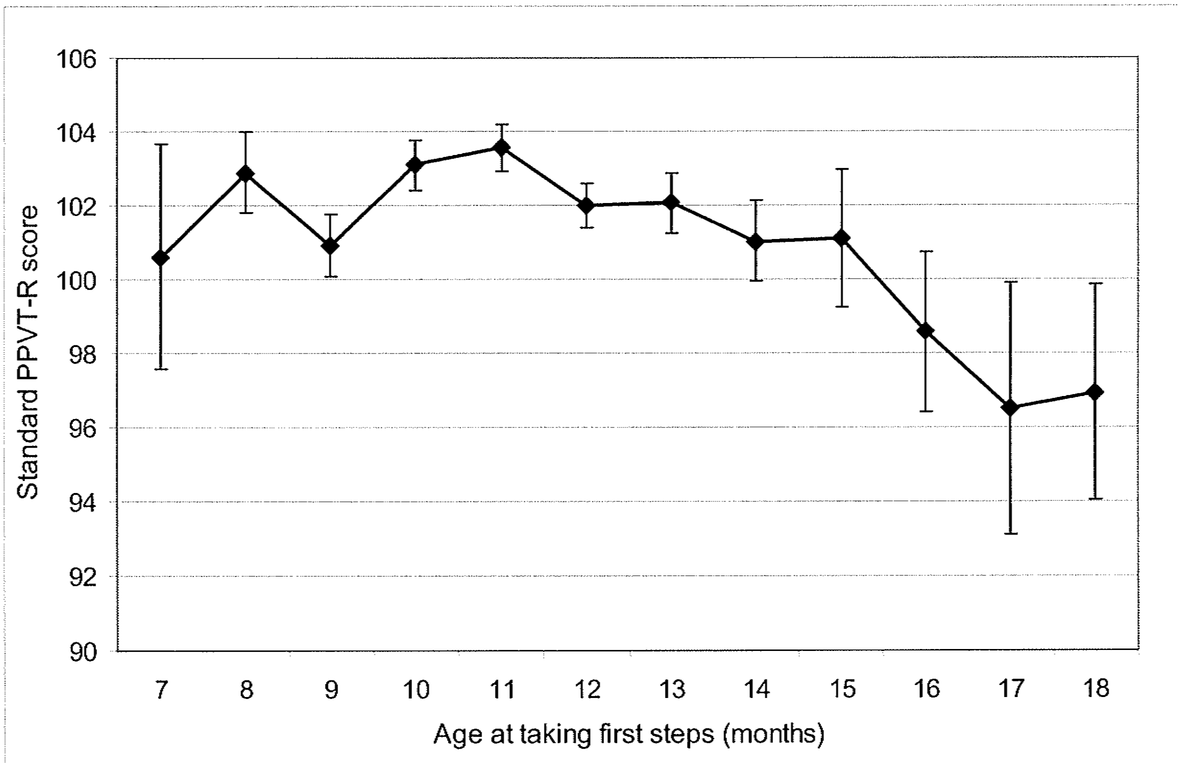
Model b: Age at First Walking and Scores on the PPVT-R

The second model tested the relationship between age at first walking (the predictor) and scores on the PPVT-R (the criterion) while adjusting for covariates. The NLSCY contained a standardized score for the PPVT-R; however, this standardization took the child's age at test-taking into account using two-month intervals. Therefore, the current model used the raw PPVT-R score while controlling for the more precise measure of exact age at taking the test.

Model *b* was significant ($F = 39.95$, $p < .0001$) and accounted for 26% of the variance in score on the PPVT-R ($R^2 = .26$). Age at first walking was a significant predictor of PPVT-R scores ($F = 7.88$, $p < .01$) and this relationship was inverse, suggesting that attaining walking at younger ages was associated with better receptive vocabulary a few years later. On the other hand, it should be noted that the correlation, though significant, is very small ($r = -.027$), so, although the relationship is highly significant, the effect magnitude is quite small. The mean standardized PPVT-R score by age at first walking is displayed in Figure 4. Keep in mind that a large majority (70%) of the sample had walked between ten and 13 months of age.

Figure 4

Mean PPVT-R Scores by Age at Taking First Steps



Some covariates had significant associations with scores on the PPVT-R: The person most knowledgeable's education, family income adequacy, infant breastfeeding and child age at taking the test had significant positive relationships with PPVT-R scores. Number of siblings in the home had a significant negative relationship with PPVT-R scores. Marital status, mother's health during pregnancy, gestational age and gender appeared to have no relationship with scores on the PPVT-R. Table 5 contains a summary of the results for model *b*.

Table 5

Model b: PPVT-R Scores as Predicted by Age at First Walking and Covariates

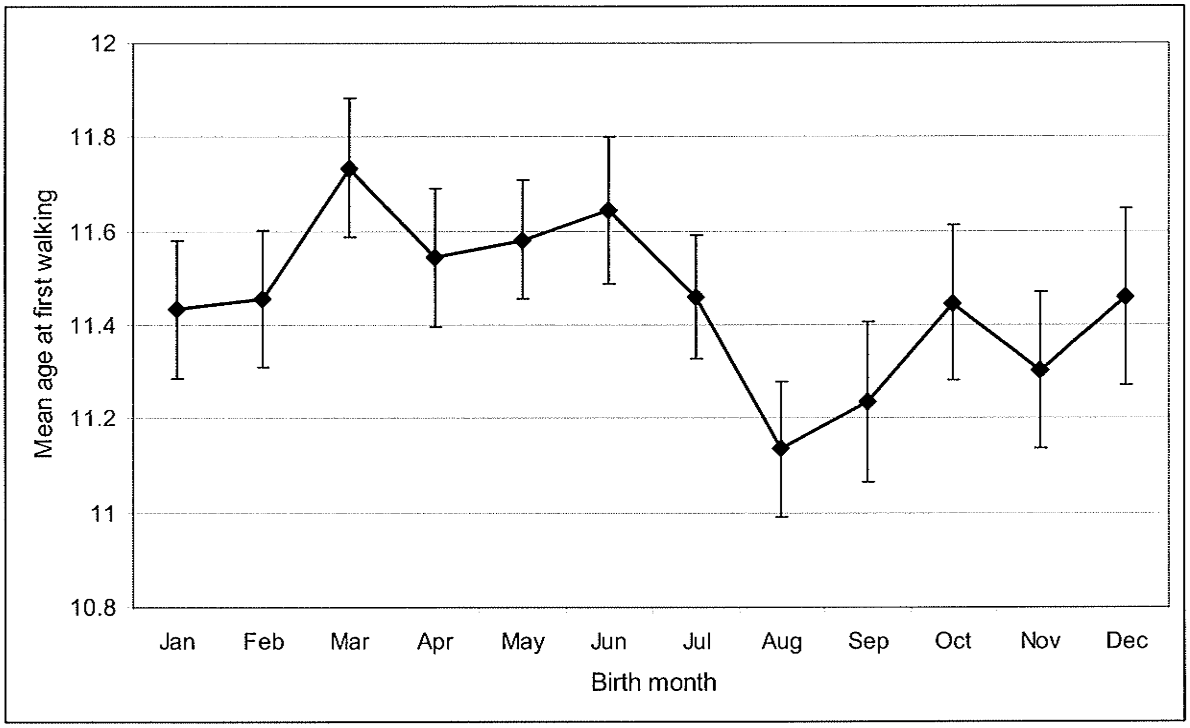
Variable	Parameter Estimate	Standard Error	F Value	Pr > F
Intercept	64.13	2.40	711.22	<.0001
Family Characteristics --			21.46	<.0001
Education of PMK (diploma)	3.19	0.65	24.05	<.0001
Income adequacy (5- point scale)	1.70	0.49	12.00	0.0005
PMK not married (single = 1)	- 0.30	0.95	0.10	0.7563
Siblings in home (number)	- 2.12	0.46	21.34	<.0001
Maternal Predictors --			3.58	0.0064
Maternal health (# problems)	0.80	0.72	1.22	0.2702
Alcohol consumption (yes = 1)	2.24	0.89	6.28	0.0123
Maternal smoking (yes = 1)	-1.61	0.98	2.73	0.0984
Mother age at birth (yrs)	0.19	0.09	4.60	0.0321
Birth Predictors ---			4.20	0.0057
Gestational age (days)	0.01	0.05	0.01	0.9323
Birth weight (grams)	1.66E-3	7.75E-4	3.94	0.0473
Breastfeeding (mos)	0.24	0.09	8.05	0.0046
Child Characteristics --			178.70	<.0001
Gender (male = 0, female = 1)	0.13	0.79	0.03	0.8742
Age at testing (mos)	1.28	0.07	357.38	<.0001
First Steps --			7.88	0.0051
Age at first walking (mos)	-0.52	0.18	7.88	0.0051

Model a: Season of Birth and Age at First Walking

We tested the relationship between season of birth (the predictor) and age at first walking (the criterion) while adjusting for several covariates. Model *a* was significant ($F = 4.14$, $p < .0001$) and accounted for 3.7% of the variance in age at first walking ($R^2 = .0375$); however, the relationship between age at first walking and the Julian variable set was only marginally significant ($F = 2.44$, $p = .063$). The highest order Julian variable, Julian cubed, was the best predictor of the set for age at first walking ($F = 6.65$, $p = .01$). Contrary to the hypothesis, this relationship was positive, indicating that births in the summer were more likely to walk at younger ages. The mean age at first walking by birth month is plotted in Figure 5.

Figure 5

Mean Age in Months at First Walking by Birth Month



Many covariates made a significant contribution to age at first walking (see Table 6). Walking was more likely to occur at older ages in families with higher income and more siblings in the home. The consumption of alcohol before or after giving birth was associated with older ages of walking; however, smoking before of after giving birth was associated with walking at younger ages. Heavier birth weight was associated with earlier walking.

Some covariates were not significantly related to age at first walking. The education of the person most knowledgeable and their marital status were nonsignificant. The mother's health during pregnancy and age at giving birth were also nonsignificant. Lastly, gestational age, being breastfed, and gender did not appear to be related to age at first walking.

Table 6

Model a: Age in Months at First Walking as Predicted by Season of Birth and Covariates

Variable	Parameter Estimate	Standard Error	F Value	Pr > F
Intercept	10.88	0.17	4031.30	<.0001
Family Characteristics --			4.03	0.0029
Education of PMK (diploma)	-0.06	0.08	0.41	0.5240
Income adequacy (5-point scale)	0.19	0.06	8.13	0.0044
PMK not married (single = 1)	0.22	0.12	2.97	0.0850
Siblings in home (number)	0.19	0.06	9.14	0.0025
Maternal Predictors ---			6.04	<.0001
Maternal health (# problems)	0.01	0.10	0.02	0.8967
Alcohol consumption (yes = 1)	0.29	0.12	6.01	0.0144
Maternal smoking (yes = 1)	-0.59	0.13	20.24	<.0001
Mother age at birth (yrs)	1.37E-3	0.01	0.01	0.9085
Birth Predictors --			4.44	0.0041
Gestational age (days)	-0.01	0.01	3.16	0.0757
Birth weight (grams)	-2.41E-4	1.05E-4	5.28	0.0217
Breastfeeding (mos)	-0.02	0.01	2.17	0.1410
Child Gender --			0.74	0.3893
Gender (male = 0, female = 1)	0.09	0.11	0.74	0.3893

Season Predictors --			2.44	0.0630
Julian linear (days)	-3.26E-3	1.29E-3	6.42	0.0114
Julian squared (days)	2.26E-6	5.54E-6	0.17	0.6830
Julian cubed (days)	1.56E-7	6.06E-8	6.65	0.0100

Discussion

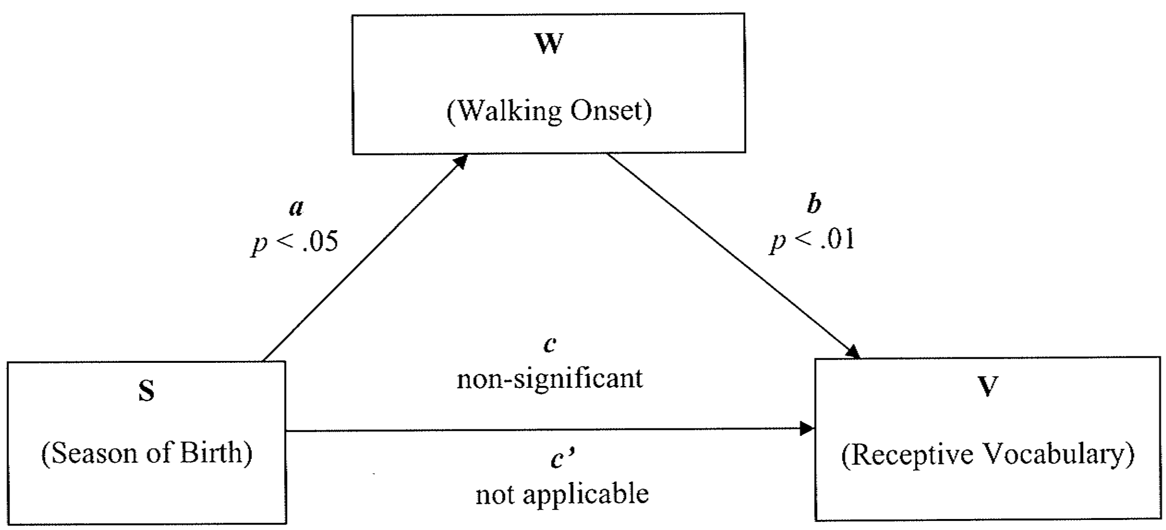
Our hypothesis was that age at first walking mediated the effect of season of birth on cognition in a sample of Canadian children. A formal test of mediation requires first that all three variables be linked: We did find relationships between a season of birth and age at first walking (path *a*) and age at first walking and receptive vocabulary (path *b*); however, we did not find a significant relationship between season of birth and receptive vocabulary (path *c*). Because path *c* was non-significant, the assumption for a formal test of mediation was not met, and our mediation hypothesis could not be tested.

Although the mediation hypothesis could not be tested directly, the relationships observed in each path are intriguing and highlight season of birth and motor milestone attainment as active contributors to infant development. Moreover, the patterns observed are statistically significant, but are not clinically important. This allows researchers to use this information toward solving puzzles in infant development without alarming parents of winter-borns or late walkers. One theory supported by the current study is that season of birth does not directly affect receptive vocabulary in early childhood. That said, season-of-birth differences may appear at later ages if relative child maturity interacts with school cohort timing (e.g., Martin et al., 2004;

Pumfrey, 1975; Thompson 1971). Figure 6 visually depicts our results. Each of the three paths in the mediation hypothesis are discussed below.

Figure 6

Mediation Results



Season of Birth and Receptive Vocabulary. With relationships evident for both paths *a* and *b*, one would expect to find a significant relationship for path *c*, that is, season of birth and scores on the PPVT-R; however, this relationship was not established. Several interpretations can be made from this analysis, the first being that the linkage between paths *a* and *b* were not strong enough to observe a linkage in path *c* or that other aspects of cognition besides receptive vocabulary might demonstrate a seasonal relationship.

Another explanation for non-significant relationship for path *c* could be an inconsistent mediation, where a mediation effect is present even though the relationship between season of birth and receptive vocabulary is not identified (MacKinnon, Fairchild, & Fritz, 2007). This is possible when the direction of one effect in the mediation model is the opposite of another; the two opposing relationships amount to a zero relationship between the predictor and criterion (Blalock, 1969; Davies, 1985; MacKinnon, Krull, & Lockwood, 2000). In this study, the model for path *a* presented a positive relationship and the model for path *b* presented a negative relationship, thus creating a situation where path *c* could be the result of an inconsistent mediation.

Walking Attainment and Receptive Vocabulary. Age at first walking was a predictor of receptive language in that walking at a younger age was associated with better receptive vocabulary three to four years later. One might hypothesize that the flexible memory retrieval for early crawlers, as reported by Hebert et al. (2007), creates effects that persist into early childhood. Another plausible influence is the increased interaction associated with early locomotion, as reported by Campos et al. (1992), which could promote a wider receptive vocabulary.

The relationship between early attainment of locomotion and receptive vocabulary is in accordance with the findings by Taanila et al. (2005), who linked early milestone achievements with early speaking in childhood, school performance in adolescence, and level of education in adulthood, because both studies found relationships between physical development and advantages associated with vocabulary. A similar argument can be made with Murray et al. (2006) who found that age at learning to stand was related to categorization and working memory in adulthood. The theorized mechanism for these relationships is a faster maturation of basic neural circuits for early motor development, which allows more complex cortical-subcortical circuits to develop (Murray et al., 2006).

Season of Birth and Walking Attainment. Julian dates cubed, the highest order seasonal pattern, was significantly related to age at first walking, suggesting an "s" curve pattern (see figures 2 and 5). Taking one's first steps is achieved an average of 18 days later for infants born in March than for infants born in August. This is the opposite pattern found by Benson (1993), who reported earlier motor attainment for infants born in the winter and spring (December to May). Eaton and Bodnarchuk (2007) also reported earlier milestone achievements for infants born in the winter and spring. One reason for this discrepancy may be the methodology in research; for example, these previous studies used self-selected samples from localized urban areas. On the other hand, the NLSCY sample was selected from a stratified design and the participants resided in a wide range of areas across Canada. It is possible that the participants from the NLSCY possessed variable characteristics, which lead to a unique seasonal pattern compared to samples selected from previous studies. Another explanation for the opposite season-of-birth patterns may be the differences in measures and data acquisition: Benson (1993), and Eaton and Bodnarchuk (2007) used daily diaries to indicate the day of first walking; whereas the NLSCY used a recall method for age at taking first steps (in months).

No matter what the seasonal pattern is, it is desirable to identify the mechanism behind the phenomenon: why is there a season-of-birth pattern for motor development? A number of explanations for the relationship between season of birth and infant development are possible; the likeliest being our seasonal variation in vitamin D synthesis.

Vitamin D levels co-vary with season because our main source of this vitamin is through sunlight exposure (Holick, 2003). Alternative sources of vitamin D are certain foods (e.g., milk, oily fish) and vitamin supplements. However, the diets of most Canadians contain little vitamin D, and few vitamin supplements contain 1,000 IU of vitamin D, the recommended daily amount (Holick, Shao, Liu, & Chen, 1992). Therefore, most Canadians may have low vitamin D levels in the winter due to little exposure to the sun.

Researchers (e.g., McGrath et al., 2005) suspect that infant body composition (e.g., birth weight) is related to neonatal vitamin D levels (acquired through the mother), which co-vary with season. Biological mechanisms support the hypothesis that a mother's vitamin D level predicts her infant's birth weight. Vitamin D plays an important role for suppressing excess cell growth, and for apoptosis, the elimination of unneeded cells in the body (DeLuca, Krisinger, & Darwish, 1990). Therefore, a prenatal deficiency in vitamin D may result in superfluous cells, evidenced by a longer and heavier body at birth. The seasonal effect may be linked to the level of vitamin D in the mother's third trimester, a time when the fastest neonatal growth occurs (McGrath et al., 2005). Infants born just after months of warm weather may have lighter birth weights than those born just after months of cold weather.

Evidence discussed above indicates a possibility that the seasonal effect on birth weight is linked to prenatal levels of vitamin D. Vitamin D may play a postnatal role as well. Eaton and Bodnarchuk (2007) found a seasonal variation for age at learning to crawl and walk, but not for sitting. This specificity of the milestones influenced by season of birth prompted them to state that, "vitamin D influences long bone growth, which is likely more important for crawling and walking than for sitting." If a lack of vitamin D occurs at a critical period of growth for Canadian infants, it is feasible that the deficiency could affect age at first walking through bone growth.

Predictors of Receptive Vocabulary

In addition to the discoveries found in the mediation analyses, some interesting and surprising relationships were observed between the covariates and the outcome variables. Some of the covariates presented unexpected relationships with scores on the PPVT-R, namely the number of siblings in the home and mother alcohol consumption. According to the confluence model (Zajonc, 2001; Zajonc, Marcus & Marcus, 1979), young children with older siblings in the home have access to a tutor and theoretically possess a higher intellectual maturity, and it is not until the pre-teen years that the advantages reverse. Using this model, we expected children with siblings in the home to have better receptive vocabulary; however, the opposite finding was observed. More siblings in the home predicted lower PPVT-R scores three to four years later. An explanation could be that parents simplified their vocabulary to accommodate multiple children in the home or that parent language was diluted with conversation between children. In addition, the older children could not tutor receptive vocabulary to younger siblings because it is language that one can recognize or understand, but not necessarily express.

The other surprising observation was the positive relationship of PPVT-R scores with mother alcohol consumption (during pregnancy or in the year prior to cycle 4 interview), implying that abstinence from alcohol throughout pregnancy and early infancy is associated with lower receptive vocabulary scores in early childhood. Although this is a controversial observation, it may be a result of the particular methodology in this study. It is possible that the group of mothers who reported drinking had drunk moderate amounts of alcohol at a time, and that this consumption was after giving birth. It is also possible that the outcome variable was inappropriate for the detection of alcohol-related developmental problems. For example, Sayal et al. (2009) reported a significant relationship for hyperactivity/inattention in children whose mothers drank heavily during pregnancy, but did not find a relationship for performance or verbal IQ scores. These possibilities, combined with recent findings on health-related benefits for light or moderate drinkers (e.g., Powers & Young, 2007) may have presented the optimal conditions for this surprising observation.

The relationships observed above portray unexpected patterns that require further investigation on their own; however, overall the sample that contains similar characteristics to most North American samples for research on infant development. Older mothers with higher education levels, adequate family income, heavier infant birth weight and longer breastfeeding duration all contributed to higher receptive vocabulary scores.

Predictors of Age at First Walking

As expected, heavier birth weight was associated with earlier motor attainment; however, many other covariates presented surprising relationships with age at first walking. Lower income adequacy was associated with earlier walking, the opposite finding from previous literature (e.g., Lima et al., 2004). More siblings living in the home was associated with motor attainment at later ages, an interesting finding that is not found in current literature. One might hypothesize that siblings in the home would help the mother entertain the infant, bringing them whatever toy they desired; thus eliminating the need for the infant to make early attempts at travelling on his or her own.

A particularly surprising observation was the negative relationship between maternal smoking (at any time before of after giving birth) and age at first walking, suggesting that maternal smoking was associated with earlier walking. On the other hand, other studies have found null effects of maternal smoking on child motor development (e.g., Trasti, Vik, Jacobsen,

& Bakketeig, 1999), and one should remember that the amount of cigarettes and the developmental stage at which the mother smoked was not specified for this variable. Therefore, we assume that some unknown characteristic among smokers changed the appearance of what might have been a neutral or harmful effect on development into a beneficial relationship.

Although the season of birth pattern for walking onset, and the relationship between walking onset and receptive vocabulary are statistically significant, they are not clinically important. The results should be used to help determine factors in child development rather than to develop treatment or diagnosis strategies. The predictors of age at motor attainment discussed above are especially valuable to the literature on infant motor development because little information is available on the topic.

Conclusion

In this study, a season of birth pattern was observed for age at first walking; however, this should be replicated in other samples, as the pattern does not match those in previous reports. It is hypothesized that the mechanism for this relationship is vitamin D levels at critical stages of development.

Whatever the cause of variation in milestone attainment at a young age, the relationship between locomotor attainment and PPVT-R scores suggests that milestone-related experiences likely influence later cognitive development. One example is the research by Hebert et al. (2007) where previous experience of locomotion (crawling) is associated with more flexile memory retrieval at nine months of age. For both crawlers and non-crawlers, traveling was prevented during the tests, indicating that the memory benefit was not necessarily associated with the act of crawling, but was instead linked to a cognitive experiences associated with the milestone.

Although nearly all children develop flexible memory by the age of four or five years, the age at which the NLSCY cognitive measures are implemented, it is plausible that the benefits of this achievement at younger ages can be amplified as additional experiences and parental expectations evolve. It is also possible that the experience of independent locomotion occurs at a critical period of brain development, a period where only a few weeks can make a big difference. Remember that Murray et al. (2006) hypothesized that earlier motor development involved a faster maturation of basic neural circuits, thus promoting the development of more complex cortical-subcortical circuits at a critical period in development. If this theory is correct, it is possible that the faster maturation will have been initiated by experiences gained from motor attainment.

In previous literature, season of birth has been linked to the age at which the infant first begins to walk as well as to later cognition and school performance. Interestingly, the age at first walking has also been linked to cognition, which creates a triangle of related variables. In this study, season has been linked to age at first walking, which in turn is related to scores on the PPVT-R; however, a season-cognition relationship was not observed. Although it is possible that these relationships are simply a string of coincidences, no published study has combined the three variables in a single analysis with a prior hypothesis. In addition, several surprising associations were observed between some covariates and outcomes, which can make new contributions to existing literature on determinants of age at motor attainment and of receptive vocabulary. This paper explored the idea that season of birth influences the timing of independent locomotion. Earlier locomotion, in turn, leads to more cognitively relevant experience that should improve cognitive performance in subsequent years.

References

Barnsley, R. H., & Thompson, A. H. (1988). Birthdate and success in hockey: The key to the NHL. *Canadian Journal of Behavioural Science. 20,* 167-176.

Baron, R. M., & Kenny, D. A. (1986). The moderator-mediator variable distinction in social psychological research: Conceptual, strategic and statistical considerations. *Journal of Personality and Social Psychology, 51,* 1173-1182.

Benson, J. B. (1993). Season of birth and onset of locomotion: Theoretical and methodological implications. *Infant Behavior and Development, 16,* 69-81.

Benson, J. B. (1996, April). *Replication study: Seasonality and locomotor onset.* Paper presented at the International Society for Infant Studies, Providence, RI.

Berglund, G. W. (1967). A note on intelligence and season of birth. *British Journal of Psychology, 58,* 147-151.

Berlin, L.J., Brooks-Gunn, J., McCarton, C. & McCormick, M. C. (1998) The effectiveness of early intervention: Examining risk factors and pathways to enhanced development. *Preventative Medicine, 27,* 238-245.

Blalock, H. M. (1969). *Theory construction: From verbal to mathematical formulations.* Englewood Cliffs, NJ: Prentice-Hall.

Bodnarchuk, J. L. (2001). Seasonal factors and birth weight: New evidence from the southern hemisphere. (MA Thesis) University of Manitoba.

Campos, J. J., Kermoian, R., & Zumbahlen, M. R. (1992). Socioemotional transformations in the family system following infant crawling onset. In N. Eisenberg & R.A. Fabes (Eds.), *Emotion and its regulation in early development* (pp. 25-40). San Francisco: Jossey-Bass.

Canadian Paediatric Society, Dieticians of Canada and Health Canada. *Nutrition for Healthy Term Infants.* Ottawa: Minister of Public Works and Government Services Canada, 1998.

Davies, A. D. M. (1964). Season of birth, intelligence and personality measures. *British Journal of Psychology, 55,* 475-476.

Davies, G.,Welham, J., Chant, D., Torrey, E.F., & McGrath, J. (2003). A systematic review and meta-analysis of Northern Hemisphere season of birth studies in schizophrenia. *Schizophrenia Bulletin, 29*(3), 587-593.

Davies, J. A. (1985). *The logic of causal order: Sage university paper series on Quantitative applications in the social sciences, series No. 07-055.* Beverly Hills, CA: Sage

de Lemos, M. & Doig, B. (1999). *Who am I? Developmental Assessment Manual.* Camberwall, Victoria, Australia: Australian Council for Educational Research Ltd.

DeLuca, H. F., Krisinger, J., & Darwish, H. (1990). The vitamin D system. *Kidney International Supplement (29),* S2-8.

Donoghue, E. C., & Shakespeare, R. A. (1967). The reliability of paediatric case-history milestones. *Developmental Medicine and Child Neurology, 9,* 64-69.

Dudink, A. (1994). Birth date and sporting success. *Nature, 368,* 592.

Dunn, L. M., & Dunn, L. M. (1981). Peabody Picture Vocabulary Test-Revised manual. Circle Pines, MN: American Guidance Service.

Eaton, W. O. & Bodnarchuk, J. L. (2007, August). *Season-of-birth patterns in gross motor milestone attainments.* Poster presented at the European Conference on Developmental Psychology, Jena, Germany.

Eaton, W. O., Bodnarchuk, J. L., & Denton, M. (2008). *Seasonal Influences on the Rate of Infant Gross Motor Development.* Unpublished manuscript. University of Manitoba.

Fried, P.A., O'Connell, C. M, & Watkinson, B. (1992). 60- and 72-month follow-up of children prenatally exposed to marihuana, cigarettes, and alcohol: Cognitive and language assessment. *Journal of Developmental and Behavioral Pediatrics, 13,* 383-391.

Gortmaker, S. L., Kagan, J., Capsi, A., & Silva, P. A. (1997). Daylength during pregnancy and shyness in children: Results from northern and southern hemispheres. *Developmental Psychobiology, 31*, 107-114.

Graue, M. E., & DiPerna, J. (2000). Redshirting and early retention: Who gets the gift of time and what are its outcomes? *American Educational Research Journal, 37,* 509-534.

Hebert, J., Gross, J., & Hayne, H. (2007). Crawling is associated with more flexible memory retrieval by 9-month-old infants. *Developmental Science, 10,* 183-189.

Holick, M. F. (2003). Vitamin D: A millennium perspective. *Journal of Cellular Biochemistry 88,* 296-307.

Holick, M. F., Shao, Q., Liu, W. W., & Chen, T. C. (1992). The vitamin D content of fortified milk and infant formula. *New England Journal of Medicine 326,* 1178-81.

Holmes, M. (1995). Revolutionary birthdays. *Nature, 373,* 468.

Human Resources and Social Development Canada, the Public Health Agency of Canada, & Indian and Northern Affairs Canada. *The Well-Being of Canada's Young Children: Government of Canada Report 2006.* Retrieved August 2008 from http://www.socialunion.ca/well_being/2007/en/well_being.pdf

Huizink, A. C., & Mulder, E. J. H. (2006). Maternal smoking, drinking or cannabis use during pregnancy and neurobehavioral and cognitive functioning in human offspring. *Neuroscience and Behavioral Reviews, 30,* 24-41.

Jacobs, J. F. & Alper, A. E. (1970). Support for relationship of season of birth upon intelligence. *Mental Retardation, 8,* 12-15.

Judd, C. M., & Kenny, D. A. (1981). Process analysis: Estimating mediation in treatment evaluations. *Evaluation Review, 5,* 602-619.

Kanekar, S., & Mukerjee, S. (1972). Intelligence, extraversion, and neuroticism in relation to season of birth. *Journal of Social Psychology, 86,* 309-310.

Kovas, Y., Haworth, C. M. A., Dale, P. S., & Plomin, R. (2007). The genetic and environmental origins of learning disabilities in the early school years. *Monographs of the Society for Research in Child Development, 72,* vii.

Kramer, M. S., Aboud, F., Mironova, E., Vanilovich, I., Platt, R. W.Matush, L., Igumnov, S., Fombonne, E., Bogdanovich, N., Ducruet, T., Collet, J., Chalmers, B., Hodnett, E., Davidovsky, S., Skugarevsky, O., Trofimovich, O., Kozlova, L., & Shapiro, S. (2008). Breastfeeding and Child Cognitive Development: New evidence from a large randomized trial. *Archives of General Psychiatry, 65,* 578-584.

Kristensen, P., & Bjerkedal, T. (2007). Explaining the relation between birth order and intelligence. *Science, 317,* 1717.

Kuzume, K., & Kusu, M. (2007). Before-birth climatologic data may play a role in the development of allergies in infants. *Pediatric Allergy and Immunology, 18,* 281-287.

Lawlor, D. A., Batty, G. D., Morton, S. M. B., Deary, I. J., Macuntyre, S. (2005). Early life predictors of childhood intelligence: evidence from the Aberdeen children of the 1950s study. *Journal of Epidemiology and Community Health, 59,* 656-663.

Lima, M., Eickmann, S., Lima, A., Guerra, M., Lira, P., Huttly, S., Ashworth, A. (2004). Determinants of mental and motor development at 12 months in a low income population: a cohort study in northeast Brazil. *ACTA Paediatrica, 93,* 969-975.

MacKinnon, D. P., Fairchild, A. J., & Fritz, M. S. (2007). Mediation analysis. *Annual Review of Psychology, 58,* 593-614.

MacKinnon, D. P., Krull, J. L., Lockwood, C. M. (2000). Equivalence of the mediation confounding, and suppression effect. *Prevention Science, 1,* 173-81.

Mackintosh, N. J. (1998). *IQ and human intelligence.* Oxford: Oxford University Press.

Martin, R. P., Foels, P., Clanton, G., & Moon, K. (2004). Season of birth is related to child retention rates, achievement, and rate of diagnosis of specific LD. *Journal of Learning Disabilities, 37,* 307-317.

Mascie-Taylor, C. G. N., (1980). Season of birth, IQ components and personality traits. *Journal of Genetic Psychology, 137,* 151-152.

McCallum, R. S. (1985). Review of the Peabody Picture Vocabulary Test-Revised. In J.V. Mitchell (Ed.), The ninth mental measurements yearbook (Vol. 2, pp. 1126-1127). Lincoln: University of Nebraska Press.

McGrath, J. J., Keeping, D., Saha, S., Chant, D. C., Lieberman, D. E., & O'Callaghan, M. J. (2005). Seasonal fluctuations in birth weight and neonatal limb length; does prenatal vitamin D influence neonatal size and shape? *Early Human Development, 81,* 609-618.

McGrath, J.J., Saha, S., Lieberman, D. E., & Buka, S. (2006). Season of birth is associated with anthropometric and neurocognitive outcomes during infancy and childhood in a general population birth cohort. *Schizophrenia Research, 81,* 91-100.

Mednick, S. A., & Schaffer, J. B. P (1963). Mothers' retrospective reports in child-rearing research. *American Journal of Orthopsychiatry, 33,* 457.

Miller, L. T., & Lee, C. J. (1993). Construct validation of the Peabody Picture Vocabulary Test-Revised: A structural equation model of the acquisition order of words. *American Psychological Association, 4,* 438-441.

Morrison, F. J., Griffith, E. M, & Alberts, D. M. (1997). Nature-nurture in the classroom: Entrance age, school readiness, and learning in children. *Developmental Psychology, 33,* 254-262.

Murray, G. K., Veijola, J., Moilanen, K., Miettunen, J., Glahn, D.C., Cannon, T.D., Jones, P.B., & Isohanni, M. (2006). Infant motor development is associated with adult cognitive categorization in a longitudinal birth cohort study. *Journal of Child Psychology and Psychiatry, 47*, 25-29.

Okamoto, Y. (2005). The *Number Knowledge Assessment.* Unpublished manuscript. University of Southern California.

Peirano, P. D., & Algarìn, C. R. (2007). Sleep in brain development. *Biological Research, 40,* 471-478.

Powers, J. R., & Young, A. F. (2007). Longitudinal analysis of alcohol consumption and health of middle-aged women in Australia. *Addiction, 103,* 424-432.

Preacher, K. J., & Hayes, A. F. (2004). SPSS and SAS procedures for estimating indirect effects in simple mediation models. *Behavior Research Methods, Instruments, & Computers, 36,* 717-731.

Pumfrey, P. D. (1975). Season of birth, special educational treatment and selection procedures within an LEA. *Research in Education, 14,* 55-76.

Pyles, M. K., Stoltz, H. R., & McFarlane, J. W. (1935). The paediatric anamnesis: Inaccuracies in eliciting developmental data. *Child Development, 6,* 165.

Reilly, T., & Peiser, B. (2006). Seasonal variation in Health-Related Human Physical Activity. *Sports Medicine, 36,* 473-485.

Roberts, D. F. Environment and the fetus. In: Roberts D. F., Thomson, A. M., editors. *The Biology of Human Fetal Growth.* London: Taylor and Francis; 1975.

Sayal, K., Heron, J., Golding, J., Alati, R., Smith, G. D., Gray, R., Emond, A. (2009). Binge pattern of alcohol consumption during pregnancy and childhood mental health outcomes: Longitudinal population-based study. *Pediatrics, 123,* e289-e296.

Sexton, M., Fox, N. L., & Hebel, J. R. (1990). Prenatal exposure to tobacco: Effects on cognitive functioning at age three. *International Journal of Epidemiology, 19,* 72-77.

Smith, L. B. & Thelen, E. (2003). Development as a dynamic system. *Trends in Cognitive Sciences, 7,* 343-348.

Sobel, M. E. (1982). Asymptotic confidence intervals for indirect effects in structural equation models . In Leinhardt (Ed.), *Sociological Methodology 1982* (pp.290-312). Washington DC: American Sociological Association.

Spering, A. P. (1946). Psychology for the Millions. F. Fell. Inc. University of Michigan.

Statistics Canada, Human Resources and Social Development Canada (2008). National Longitudinal Survey of Children and Youth: Survey Instruments for 2004/2005 Data Collection, Cycle 6, Books 1 and 2. Retrieved March 1, 2008 from http://www.statcan.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=4450&lang=en&db=IMDB&dbg=f&adm=8&dis=2

Streissguth, A. P., Barr, H. M., Sampson, P. D., Darby, B. L., & Martin, D. C. (1989). IQ at age 4 in relation to maternal alcohol use and smoking during pregnancy. *Developmental Psychology, 25,* 3-11.

Taanila, A, Murray, G. K., Jokelainen, J., Isohanni, M., & Rantakallio, P. (2005). Infant developmental milestones: a 31-year follow-up. *Developmental Medicine and Child Neurology, 47,* 581-586.

Thompson, D. (1971). Season of birth and success in the secondary school. *Educational Research, 14,* 56-60.

Trasti, N., Vik, T., Jacobsen, G., Bakketeig, L. S (1999). Smoking in pregnancy and children's mental and motor development at age 1 and 5 years. *Early Human Development, 55,* 137-147.

Watson, P. E., & McDonald, B. W. (2007). Seasonal variation of nutrient intake in pregnancy: Effects on infant measures and possible influence on diseases related to season of birth. *European Journal of Clinical Nutrition, 61,* 1271-1280.

Weissbluth, M., & Weissbluth, L. (1992). Colic, sleep inertia, melatonin and circannual rhythms. *Medical Hypotheses, 38,* 224-228.

Wohlfahrt, J., Melbye, M., Christens, P., Anderson, A. M., & Hjalgrim, H. (1990). Secular and seasonal variation of length and weight at birth. *Lancet,* 352, 9145.

Zajonc, R. B. (2001). The family dynamics of intellectual development. *American Psychologist, 56*, 490-496.

Zajonc, R. B., Markus, H., & Markus, G. B. (1979). The birth order puzzle. *Journal of Personality and Social Psychology*, *37*, 1325-1341.

Footnotes

[1]The original intent of this thesis was to also include a measure on *Emerging literacy skills – Who Am I?* scales as well as a measure of quantitative knowledge – *Number Knowledge. Who Am I?* (de Lemos & Doig, 1999) is a development assessment tool that focuses on a child's literacy and numeracy skills, and the *Number Knowledge Assessment* (Okamoto, 2005) was developed to examine children's understanding of the whole numbers system: Due to missing data on these tests, their inclusion would have reduced the sample size a great deal, so we excluded them from the analyses.