The Development of Cognitive Inhibition and Motor Activity Level in Young Children

Darren W. Campbell

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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University of Manitoba
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THE DEVELOPMENT OF COGNITIVE INHIBITION AND MOTOR ACTIVITY LEVEL IN YOUNG CHILDREN

BY

DARREN W. CAMPBELL

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

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ABSTRACT

The relations among cognitive ability, motor activity level (AL), and physical maturity were examined on a cross-sectional sample of 66 children, 4- to 6-years-old. Cognitive inhibition, as measured with neuropsychological tasks thought to reflect prefrontal lobe functioning, was compared to control tasks thought to depend on other brain areas. The results of this study provide multiple sources of evidence for the developmental importance of cognitive inhibition in children's intellectual development: 1) inhibition improved with age, 2) inhibition tasks were significantly more difficult than control tasks, and 3) an Age by Task interaction demonstrated that inhibition performance follows a different developmental trajectory than does the control task performance. There was no support for the hypothesis that inhibition was negatively related to motor activity level. A significant positive correlation between AL and age also was unanticipated and implies that the expected developmental decline in AL occurs after 6 years. Other maturational influences, such as gender and relative physical maturity, were not predictive of inhibition or AL. Inhibitory skills in this developmentally important age range were found to rapidly improve. Further study of such tasks, which are based on prefrontal lobe functioning, should help to differentiate the various components of cognitive development.

INTRODUCTION

From an adult's perspective, verbally directing young children's behaviour can be quite difficult. When instructed to do some task, children are easily distracted by the more novel or salient stimuli in their environment. Such behaviour would correspond to "the difficulty of keeping young children on task" often expressed by researchers working with young children (Bjorklund & Harnishfeger, 1990, p. 62). Similarly, trying to encourage children to switch from their present behaviour and begin a new one can also be difficult. For example, watching children in the toy section of a store can be quite humorous. In response to their parents' request, the children begin to comply, but their attention repeatedly returns to a captivating toy preventing them from actually doing as they are told. In contrast to this perseverative behaviour, children given free rein in a room full of toys often switch from one toy to the next. In these examples of young children's behaviour, a young child is either unable to stop doing the same behaviour over and over, or a young child is rapidly switching from one behaviour to another. These behaviours can be explained by the same underlying mechanism, inhibition. That is, young children's underdeveloped ability to inhibit themselves from reacting to environmental stimuli is thought to be responsible for both their distractibility and perseverative behaviours.

The social and cognitive consequences of this inability to inhibit is especially relevant for four to six-year-olds. At this age, children typically begin attending kindergarten or school, in which they must exhibit appropriate social behaviours and perform a variety of focused cognitive tasks. An inability to inhibit socially inappropriate behaviours such as grabbing a desired toy from another child will obviously be problematic for both the child and his or her classmates (Segalowitz & Rose-Krasnor, 1992). Furthermore, cognitive distractibility or perseveration will hinder the child's ability to learn new ideas and operations necessary for future success academically.

These social and cognitive problems have been often associated with overactive preschoolers (Campbell, 1987) and school-aged children (Gorenstein, Mammato, & Sandy, 1989). The fact that these childhood behaviours are related to both inhibition and motor activity level raises the question of whether there is a relation between activity level and inhibition. Examination of the behaviourial characteristics of the prefrontal lobe suggests the answer to this questions is yes. The functioning of the prefrontal lobes has been found to influence both the ability to inhibit (Diamond, 1985, 1991; Fuster, 1989; Goldman-Rakic, 1987) and the control of certain types of motor activity (Fuster, 1989; Goldman-Rakic, 1987; Luria, 1980). Furthermore, both inhibition and motor activity level are a function of maturational status (Dempster, 1992; Eaton, in press), and the maturation of the prefrontal lobes could explain these developmental behaviours and their mutual maturational dependence. Therefore, tracking the developmental progression of both inhibition and activity level would provide a more specific test of the relation between inhibition and activity level, and provide indirect evidence for their dependence on the same underlying mechanism.

The maturation or development of phenomenon is traditionally measured by comparing changes in behaviours against increases in chronological age. Age, however, is a crude measure of maturation (Eaton & Speed, in press; Roche, Wainer, & Thissen, 1975). If the body's physical maturational status is related to the brain's maturational status as some researchers have suggested (Case, 1985; Eaton et. al, in press; Ritchot, 1992), then a physical maturation measure could provide a more precise measure of maturational status. Roche et al., (1975) provided such a physical maturation measure, which they called *relative stature.* Developmentally speaking, this maturation measure, in combination with the inhibition and activity level measures, would allow a number of interesting questions to be addressed.

First of all, is children's performance on a measure purported to tap prefrontal lobe functioning different than their performance on measures not dependent on prefrontal lobe functioning? Secondly, is there a relation between children's inhibitory ability and their motor activity levels? And lastly, does a measure of physical maturation add significantly to an understanding of the maturation of inhibition, activity level, and/or any relations that exist between them, over and above that provided by chronological age? In this thesis, tasks requiring inhibitory responses, an objective and a subjective measure of motor activity level, and a measure of children's relative maturity levels will be used to answer the preceding questions for children of the ages of four- to six-years.

First, however, a more explicit definition of inhibition will be provided, followed by a review of the research that led to the formation of this construct. Research in support of the extended developmental period of inhibition will be rendered, and this research also will expose the strong evidence that inhibitory ability is dependent on prefrontal lobe functioning. A brief examination of the prefrontal lobe's structure, development, and function also uncovers a relation between prefrontal lobe functioning and motor activity and leads to the conclusion that there is a relation between inhibition, motor activity level and prefrontal lobe functioning. Finally, the physical maturity measure of maturation will be described, and findings presented that support its usefulness as a developmental research device.

Inhibition

Definition

Inhibition is a cognitive mechanism that provides "the ability to control interference from both external and internal sources, by enabling the subject to effective[ly] inhibit or suppress stimuli or associations that are not relevant to the task at hand" (Dempster, 1992, p. 46). Thus, the ability to inhibit has both cognitive and behaviourial consequences. For example, poor inhibitory ability will result in people who "can be expected to show more distractibility, to make more inappropriate responses, and/or to take longer to make competing appropriate responses, and finally to be more forgetful than others" (Hasher, & Zacks, 1990, p.215). Although Hasher and Zacks derive their conclusions from research with older adults, these conclusions also are applicable to children (see Bjorklund & Harnishfeger, 1990). Inhibitory ability also is thought to be a mental process necessary for higher order cognitive processes, such as sustained attention or mental problem solving. In addition, this cognitive mechanism has been shown to be a function of both individual differences and maturational status (Dempster, 1992; Reed, Pien, & Rothbart, 1984) suggesting it is a complex construct. The complexity of inhibition becomes more understandable when it is related to the functional development of the prefrontal lobes (Diamond, 1991; Fuster, 1989; Goldman-Rakic, 1987; Luria, 1980).

Theoretical and Historical Context

The construct of inhibition has two fairly independent sources of origin. One source has been the cognitive and developmental psychological research conducted with both adults and children (Bjorklund & Harnishfeger, 1990; Case, 1985; Dempster, 1992; Hasher & Zacks, 1988). Neuropsychological findings from clinical populations (both adult and children) (Diamond, 1985, 1991; Luria, 1973, 1980) and animal studies (Diamond, 1985, 1991; Fuster, 1989; Goldman-Rakic, 1987; Luria, 1973, 1980; Stuss & Benson, 1984) also have made use of an inhibitory explanation of human behaviour. In recent reviews, the integration of these two approaches toward the study of child development has been noted (Dennis, 1991; Stuss, 1992; Welsh & Pennington, 1988), and the prefrontal lobe's involvement in these developmental behaviours offered as the reason for this integration (Dennis, 1991; Stuss, 1992; Welsh & Pennington, 1988). Later in this paper, the empirical evidence in support of the development of inhibition will illustrate how this integrated approach to the study of development can enhance understanding of certain developmental phenomena. Next, however, a brief review of the historical background of the concept of inhibition and its current influences on developmental research will be examined.

Psychological Research Background

Within the history of psychological research, interference theory is the predecessor of the concept of inhibition (Dempster, 1992) and has been used to explain developmental phenomena across the entire life span (Dempster, 1992). However, even with the return to cognitive explanations of behaviour and development brought about by the advance of cognitive psychology, the role of cognitive interference has been neglected. In its place, explanations based on greater resources, faster activation, and/or increasing knowledge base have been offered (Bjorklund & Harnishfeger, 1990; Case, 1985; Dempster, 1992; Hasher & Zacks, 1988). This more recent explanation of development has been termed the "resources" explanation of development. Cognitive interference is not incompatible with this resources explanation of development and may address some of the problems encountered by this resource model's explanation of developmental behaviour. In fact, it will be shown that inhibition is necessary for the explanation of certain developmental behaviours. Therefore, a description of interference theory and its relevance to inhibition will be provided next, and this will be followed by an examination of the resources explanation of development.

Interference Theory.

In Dempster's (1992) theoretical review, inhibition is just a new name for an old concept, interference. Dempster describes interference as a basic element of association theory which has a history going back into the 19th century in verbal learning studies (Ebbinghaus, 1885, cited in Dempster, 1981). Associations or connections are formed between ideas, or thoughts and "these associations may compete with one another, [so that] one association can inhibit or suppress the activation of another [association]" (Dempster, 1992, p.47). Dempster reports that interference research has continued, broadening its definition and expanding its research domains in the intervening years. As a result, three types of interference have been identified: proactive, coactive, and retroactive interference. Inhibitory ability is directed against preventing all three types of interference. Despite the long history interference theory has occupied in psychological research, most of the recent child development research has been aimed at discovering mechanisms responsible for activating thoughts and maintaining short term-memory rather than at discovering inhibitory mechanisms. A review of this activation based explanation or resource model explanation of developmental behaviour follows next.

Resource Models. Cognitive resource models have been used to explain much developmental phenomena in both social (Case, 1985; Chao, Knight, & Dubro, 1986) and cognitive (Bjorklund & Harnishfeger, 1990; Case, 1985; Dempster, 1992) areas. In Bjorklund and Harnishfeger's (1990) review, a resource model explains developmental improvements in performance as a result of increases in mental capacity. Mental capacity is often described as an individual's working memory capacity, the cognitive construct responsible for effortful mental operations (Bjorklund & Harnishfeger's, 1990; Case, 1985). Various mechanisms responsible for this developmental increase in mental resources have been proposed such as: rehearsal strategies (Siegler, 1988), chunking (Chi, 1977), phonological articulation rate (Baddeley, 1990; Kail, 1992), speed of item identification (Dempster, 1981), processing speed (Hale, 1990; Hale, Fry, & Jessie, 1994; Kail, 1991a, 1992), and practice or automaticity (Kail, 1991b; Kail & Park, 1990). The implicit or explicit assumption for all these explanations is that maturation or learning (learned expertise) enables *more* information to be maintained and manipulated in the limited working memory of individuals and, thus, their performance improves (Bjorklund & Harnishfeger, 1990). Empirical and interpretative problems with these resource model explanations of development have lead some researchers to expand the resource model to include an inhibitory mechanism (Bjorklund & Harnishfeger, 1990; Dempster, 1992). Other researchers have abandoned the resource capacity model's interpretation in favour of an inhibitory explanation of certain developmental behaviour (Brainerd & Reyna, 1989; Diamond, 1985, 1988, 1991; Diamond, Cruttenden, & Neiderman, 1994; Diamond & Gilbert, 1989; Hasher & Zacks, 1988). The problems that have led researchers to look for other explanations of developmental behaviour, such as inhibition, will be identified next and reasons why inhibition is a good alternative choice will also be discussed.

Problems with the Resource Capacity Model. The inhibition construct has been able to explain certain developmental behaviour that the resource model cannot explain and explains other developmental behaviour more simply and consistently than does the resource model. Problems with the resource model have arisen because of data that contradict the behavioural patterns predicted by this model. For example, Mitchell and Hunt, (1989, cited in Dempster, 1992) found that the percentage of capacity allocated to a given task does not always correlate with performance. Furthermore, although the activation resource explanations (e.g., speed of item identification, processing speed, and practice or automaticity) of children's development account "for age-related changes in intellectual performance [better] than do differences in strategy use" (e.g., rehearsal strategies, grouping, and chunking [Dempster, 1992, p. 46]), these activation explanations are still incomplete and may be incorrect. In a second example, Diamond and her colleagues examined infant tasks traditionally interpreted from the resource model's perspective (i.e., contiguity of objects, A-not-B errors) and found that infant's performance could be explained more accurately and parsimoniously as a simple failure to inhibit a conditioned behavioural response (Diamond, 1985, 1991; Diamond, Cruttenden, & Neiderman, 1994; Diamond & Gilbert, 1989). Finally, Brainerd and Reyna (1989) have reinterpreted dual task studies traditionally used in support of the existence of a cognitive resource hypothesis. They have suggested that the results are due to output interference rather than to a limited cognitive capacity. They have stated that output interference can be viewed as cognitive or behaviourial interference (Reyna & Brainerd, 1989), which is similar to Hasher and Zacks's (1988) evaluation of cognitive findings from the older adult literature. These three examples support the notion that inhibition may account for certain behaviourial data better and more simply than the resource capacity model. The nature of the development of inhibition will be discussed next.

The Development of Inhibition

Reviews by both Bjorklund and Harnishfeger, (1990) and Dempster, (1992) have indicated that inhibitory ability improves until adulthood, at which point it levels off until old age when inhibitory ability then begins to decline. Although there has been considerable research exploring susceptibility to interference in old age, research directly examining children's susceptibility to interference is more sparse (Dempster, 1992). This review will show that the development of inhibition in four- to six-year-old children is the least examined age group. Additionally, this review will demonstrate the need for continuous, direct measures of inhibition rather than more general indirect measures.

The extended period of development for inhibition is balanced by its extended period of decline in old age (Comalli, Wapner, and Werner, 1962). Comalli et al.

(1962) used the Stroop colour-word interference test on 235 subjects from 7- to 80-years-old and concluded that interference effects are "greatest with young children, decreases with increasing age to adulthood and increases again with older age" (p.50). Similar to Comalli et al., (1962), Tipper, Bourque, Anderson, and Brehaut, (1989) studied the development of inhibition using a series of timed Stroop tasks. They found evidence for the development of an inhibitory mechanism comparing the performance of 7- and 8-year-olds to the performance levels of adults while investigating the mechanisms responsible for developmental improvements in selective attention. Tipper et al. (1989) determined that both habituation to familiar stimuli and the ability to inhibit distracting stimuli were responsible for selective attention. They concluded that habituation and inhibition are distinctively different mechanisms, and that inhibition develops more slowly than habituation. Moreover, Tipper et al. (1989), noted that inhibition is a central processing mechanism, not a function of perception or response action.

Doyle (1973) provides more empirical evidence for the development of inhibition. She measured inhibitory ability using a dual task listening measure on 8-, 11-, and 14-year-old children. She concluded that older children are better able to selectively attend to relevant information and are less effected by distracting material because they are better able to prevent themselves from making a response based on the irrelevant material. Or in Brainerd and Reyna's (1989) terms, older children are better able to prevent output interference. Strutt, Anderson, and Well (1975) also found older children were less susceptible to distracting information than younger children. They used a series of card sorting tasks on children from 6- to 12-years-old. Strutt et al. (1975) found irrelevant material on the cards had a more detrimental effect on performance at younger ages. Both sorting time required and the number of errors produced indicated that children become better able to classify information in the presence of irrelevant material as they become older.

More recently, Chelune and Baer (1986) also used a card sorting task to demonstrate the development of inhibition throughout childhood. They used the Wisconsin Card Sorting Test (WCST), which is a widely used test for prefrontal lobe damage in adults, on 105 children, to establish developmental performance norms for children from the ages of 6- to 12-years-old. The WCST requires subjects to sort the cards into different piles according to one of three criteria: colour, shape, or number of the objects on the card. The subjects are not told to sort the cards according to these criteria, but are told only whether the last card was placed onto the correct pile or not. Three dependent measures are derived for each subject according to their performance on this test: (1) the number of categories achieved, (2) the number of perseverative errors made, and (3) the number of failures to maintain set. Failures to maintain set represent a failure to inhibit either internal or external stimuli. The perseverative errors of a child, repeating a previously failed response, represents a failure to inhibit internal stimuli (Chelune et al., 1986). Failures to maintain set, on the other hand, occur if children overreact to environmental stimuli (Chelune et al., 1986). Thus, the WCST, a traditional neuropsychological test, also is a useful measure of inhibitory development in normal, school-aged children.

Chelune and Baer (1986) found a significant linear trend for all three criteria, with increases in the number of categories achieved and a decrease in perseverative errors showing the most consistent linear development. Comparing the results of the children's WCST performance to those of normal adults, Chelune and Baer (1986) concluded that children reach adult levels of performance on the WCST by 10 years of age on all three criteria. Thus, these results provide evidence that inhibitory ability increases from 6 to 12-years of age. Furthermore, Chelune et al. (1986) found the 6-

year-olds' WCST performance scores were comparable to the performance levels of adults with prefrontal lobe damage, strongly suggesting this improvement in inhibitory ability is at least partially due to the improved functioning of the prefrontal lobe cortex across this age range.

Other neuropsychological tasks also have been used to study the development of inhibition in normal school-aged children (Becker, Isaac, & Hynd, 1987; Passler, Isaac, & Hynd, 1985). For example, Passler, Isaac, and Hynd (1985) used verbal and non-verbal neuropsychological tasks previously found to distinguish adults with prefrontal lobe damaged from those adults with brain damage in other brain regions (Luria, 1980). Each task had an experimental condition and a control condition. The experimental condition created a conflict between the spoken instructions and the direct meaning of the stimulus (Luria, 1980). For example, one task required the children to tap a wooden dowel in response to the experimenter's tap pattern. If the experimenter tapped once, then the child was to tap twice. But, if the experimenter tapped twice, the child was to tap only once. Luria (1980) indicated the subjects must inhibit the tendency to obey the direct meaning of the stimulus and organize his or her behaviour according to the rules of the game. The control condition had exactly the same procedures as the experimental condition but there was no conflict between the instructions of the tasks and the meaning of the stimulus.

Passler et al. (1985), used these tasks on 6-, 8-, 10-, and 12-year-olds. They found children's performance improved with increasing age on the experimental conditions, but their performance on the control tasks remained much the same. Control task performance did not improve very much because the children tested had already achieved close to the maximum scores obtainable on the control tasks - a ceiling effect. Passler et al.'s (1985) findings provide strong support that inhibitory ability develops throughout childhood, and as well supports the proposition that inhibitory ability is dependent on prefrontal lobe functioning. Further evidence for the development of inhibitory ability across this age range was presented by Becker, Isaac, and Hynd (1987). They used nonverbal motor inhibition tasks also known to depend on prefrontal lobe functioning in adults which they modified for computerization. Becker et al.'s significant age effect extended the generalizability of Passler et al.'s (1985) conclusions by using a different set of inhibitory tasks and by including black as well as white children.

In aggregate, the previous studies provide strong evidence for the development of inhibitory ability, and its connection with prefrontal lobe functioning. However, there is a dearth of studies examining the development of inhibition in younger children. The reason for this scarcity of studies on younger children is probably because many of the measures used to show the development of inhibitory ability require children who read or can follow complex testing procedures. Nonetheless, there are some studies examining the development of inhibitory ability in children 6-years-old and younger (Balamore & Wozniak, 1984; Llamas and Diamond, 1991; Luria, 1979, 1980; Reed, Pien, & Rothbart, 1984).

Luria (1979) studied children's ability to follow instructions under various task situations. He found that very young children (1.5 -2 years-old) reacted to the stimulus rather than follow the given instructions. Slightly older children (2 - 2.5 years-old) could follow basic instructions, but these children would fall into inert stereotypes (perseverative behaviours) or stimulus controlled behaviours if the instructions became too complex. Luria (1980) concluded that "not until 3.5 - 4 years does the action program evoked in the child by a spoken instruction become strong enough to ensure the necessary action without distraction and to inhibit irrelevant activities" (p. 309). Luria (1979) interpreted this improved ability to follow instructions as due to the acquisition of *verbal regulation* of behaviour. Children acquire the ability to control their actions with verbal directions (spoken at first, then subvocal-verbal thoughts) rather than only reacting to environmental stimulus. Alternatively, Luria's (1979, 1980) findings could be interpreted as due to the development of a cognitive inhibition mechanism that is more basic than verbal regulation (Reed et al., 1984). This latter interpretation seems more likely, given the earlier evidence that much older children can follow complex instructions under certain conditions and yet fail when the stimulus conditions of the task interfere or distract the child from the cognitively guided behaviour sequence.

Further evidence for the development of inhibition in the preschool years comes from Balamore and Wozniak (1984). They used a Bingo-Bed task with 3- and 4-year-olds that required the children to tap coloured pegs. The tapping order was made to conflict with the expected, or natural, order children would normally tap the pegs (i.e., in position 1, 3, & 2, rather than in position 1, 2, & 3). Balamore et al. (1984) found the older children were able to tap in the correct sequence more often than the younger children. The effect of attending to instructions was also analyzed, and Balamore et al. (1984) found that those children who were attentive had better performance levels, and that the four-year-olds were more likely to be attentive than the three-year-olds. Thus, tapping accuracy and attentiveness to instructions improved with age. Performance on both of these measures was thought to represent a measure of inhibitory ability. Therefore, the results provide evidence that the ability to inhibit develops.

Reed, Pien, and Rothbart (1984) also offered some interesting findings about pre-school children's ability to inhibit. Reed et al. (1984) examined the inhibition performance scores of 40 children, three-and-a-half to four years of age. They concluded that inhibitory ability is a function of individual differences, as well as developmental differences. Inhibitory performance increased with increasing age, supporting the notion that inhibition develops. Secondly, significant positive correlations among their three inhibition tasks, even after the effects of age were factored out, indicated that differences in inhibitory ability existed aside from those due to developmental differences. Because the children's performance declined only on those more difficult tasks requiring inhibition, individual differences can not be attributed as simply due to a general lack of motivation or non-compliance. Therefore, Reed et al. (1984) concluded that the children's performance reflected differences in inhibitory ability, not differences in motivation or compliance. The researchers found that the children demonstrated different performance levels, depending upon the characteristics of the task. If the successful children were more obedient, they would have performed all the tasks equally well, but this was not the case. Thus, Reed et al. (1984) eliminated the alternative interpretation that motivation is responsible for the different performance levels and simultaneously found support for the existence of both developmental and individual differences in inhibitory ability.

Finally, Llamas and Diamond (1991) explored the development of inhibition using seven different tasks on 72 children, who ranged from the ages of 3- to 8-years-old. Their tasks came from various sources: neuropsychological tasks, such as dowel tapping and hand switching (Luria, 1980, 1973; Passler et al., 1985), the three peg Bingo-Bed tapping task used by Balamore et al. (1984), as well as a modified Stroop task, and a multiple box opening task. Llamas et al. (1991) found that inhibitory ability rapidly increased from the ages of 3- to 6-years of age, with a ceiling effect occurring such that after age 6 children's performance was consistently high. Llamas et al. (1991) concluded that either more challenging inhibition tasks were required to show development improvements in inhibitory ability after age six, or that inhibitory ability does not improve during the 6- to 8-year period because of limited prefrontal cortex development. The latter conclusion, however, is unlikely in light of the previous evidence demonstrating the continuing development of inhibition during the school-aged years (e.g., Chelune & Baer, 1986; Doyle, 1973; Passler et al., 1985; Tipper et al., 1989). Thus, Llamas et al.'s (1991) failure to find developmental improvements after age 6 is likely due to the inability of the inhibition measures to capture the full developmental range of inhibitory ability.

What can be concluded from this review of the development of inhibition? The ability to inhibit begins developing early at 2.5 to 3 years of age (Luria, 1979,1980) and continues until early adulthood (Comalli et al., 1962). Inhibitory ability is a function of both developmental maturation and individual differences (Reed et al., 1984). Evidence for the development of inhibition is most scarce in the age range of about four- to six-years of age.

Given the relative scarcity of studies examining the development of inhibition in four- to six-year-old children and the evidence for rapid development of inhibition during this period, I am examining the development of inhibition in children of this age range. Furthermore, the inhibitory ability of six-year-olds will be more fully examined with a subset of tasks slightly more difficult than those used by Llamas et al. (1991). The combination of less and more difficult tasks is aimed at more precisely measuring the inhibitory ability of six-year-olds. The specific tasks used will be identified in the method section; however, each task is drawn from one or more of the studies reviewed above. This selection carries the benefit of being comparable to the previously mentioned studies of inhibition.

In the present study, each task has an experimental condition and a control condition. The experimental condition requires inhibition of a prepotent response, and thus, is thought to be dependent on the functioning of the prefrontal lobes. The control condition is identical to the experimental condition, except that inhibition is not required, and so is not dependent on the functioning of the prefrontal lobes. The control condition tasks, however, are thought to depend on some other brain region that develops earlier than the prefrontal lobes (Diamond, 1991). For example, the control conditions used by Diamond (1985) depended on simple memory ability rather than inhibitory ability, and thus were dependent on parietal development, rather than prefrontal lobe development. The parietal lobes are known to be fully functional before the prefrontal lobes (Diamond, 1991). Thus, tasks for the control condition would be mastered earlier. Therefore, one of my main hypotheses is that the children will have higher performance levels on the tasks of the control condition compared to the inhibition condition tasks. Additionally, because of the relatively extended period of development of the prefrontal lobes, another hypothesis is that inhibitory ability will have a protracted period of development and will demonstrate a strong developmental progression for children in the age range of 4- to 6-years of age. A description of the characteristics of the prefrontal lobes will indicate why prefrontal lobe tasks would be mastered developmentally later, and thus would be more difficult.

The Prefrontal Lobes

Considering cognitive development in relation to the brain's maturation is vital if the underlying mechanisms of development are to be found. Thus, examining the connection between prefrontal lobe development and the development of inhibition, at least theoretically, is important. Segalowitz and Rose-Krasnor (1992) have stated that developmentalists have ignored the role of brain maturation in children's development in the past because of the lack of information. Information about the brain's development, however, is much greater today, and continuing to ignore its role in development is unacceptable. Segalowitz and Rose-Krasnor offered three general findings in support of their position:

> (1) that certain brain functions are specialized for specific types of information processing and that these brain areas do not mature at the same rate as others,

> (2) that the descriptions of mental development that support universal sequences cannot themselves explain the timing of those sequences, and (3) that the timing of those sequences seem to have a curious parallel in the pattern of brain maturation rate. (p. 3)

Therefore, I am presenting a brief review of the anatomical, developmental, and functional characteristics of the prefrontal lobe as they are thought to relate to inhibition. The following review of the underlying mechanism responsible for inhibition may also explain why other developmental behaviours controlled by the prefrontal lobe (e.g., activity level) are correlated with inhibition.

The Anatomy, Development, and Functioning of the Prefrontal Lobes

Evidence has been presented from a number of sources that indicates that inhibitory ability develops from infancy until adolescence. The development of the prefrontal lobe has been proposed as the neurological basis of this development. This review will demonstrate why this brain region is likely responsible for inhibitory ability and its development.

Anatomy of the Prefrontal Lobes

Two anatomical facts would suggest the prefrontal lobes are an important neurological structure for cognitive functioning. The prefrontal cortex, the most anterior structure of the frontal lobes makes up 29% of the cortex (Brodmann, 1912, cited in Fuster, 1989, p. 3), which is generally thought responsible for higher cognitive functioning. Secondly, the prefrontal lobes have a multitude of reciprocal connections to other brain regions (Fuster, 1989). The connectivity of the prefrontal lobes with other brain regions allows the prefrontal lobes to integrate the information from these other brain regions, and functionally to interact with them (Fuster, 1989; Stuss, 1992). For instance, the many afferent connections to the prefrontal lobes come from both cortical sensory processing areas and non-sensory processing neocortical brain regions

(Fuster, 1989), making it the only brain region connected to four different sensory modalities (Fuster, 1989; Nauta, 1971, 1972, cited in Stuss, 1984). Therefore, the prefrontal cortex may be a cross-modality associational centre (Fuster, 1989) allowing it to act with, as well as react to different brain regions, because it has efferent connections to almost every structure from which it receives connections (Fuster, 1989).

Developmental Progression of the Prefrontal Lobes

As indicated above, Segalowitz and Rose-Krasnor (1992) suggest several reasons for examining the brain's development and its relations with certain cognitive capabilities. The review of inhibitory ability has revealed that it develops gradually, and over a considerable portion of the lifespan. The prefrontal lobes, with a similarly long period of development, have been suggested as the most likely underlying neurological region responsible for the development of inhibition (Dempster, 1992; Fuster, 1989; Goldman-Rakic, 1987; Luria, 1980).

Goldman-Rakic (1987) examined the structural development of the prefrontal lobes in rhesus monkeys. The monkeys' prenatal and postnatal prefrontal lobe development was predicted to be slower than the development of other areas of the neocortex (i.e., visual, somatosensory, motor, and associative cortices). Goldman-Rakic (1987) evaluated the physiological maturation of the brain according to three criteria: the developmental formation of each of the six layers of neocortex, the timing of the formation and location of axonal connectivity, and the periods and locations of synaptogenesis in the different regions of the brain. In contradiction to her prediction, she found that on these three criteria, the neocortex of the brain develops concurrently with the other regions of the brain, not more slowly as she had expected.

Stuss (1992), however, indicated that the development of the prefrontal cortex is not just straightforward biological maturation, but that its development interacts with behaviour. Synapses in the prefrontal lobe are subject to selective survival. If they are not used, they perish (Stuss, 1992). There is an optimal level of synaptic density, and synaptic elimination occurs before certain prefrontal cognitive capacities become functional (Goldman-Rakic, 1987). In other words, structural development precedes functional development.

In addition to an extended period of elimination of the synapses, there are other important physiological developments of the prefrontal cortex that make it especially interesting to developmental researchers. For example, prefrontal ribonucleic acid (RNA) development is not mature until around 9 years of age (Uemura & Hartmann, 1978, cited in Stuss, 1992) and, much later, diminishing RNA levels produce the neuronal involution that occurs in the seventh and eighth decade of life (Uemura & Hartmann, 1978 cited in Fuster, 1989). As well, the prefrontal lobe is the last to achieve electrophysiological maturity (Hudspeth, 1987 cited in Stuss, 1992). Hudspeth's electroencephalography measurements suggest that electrophysiological maturity starts at the back of the brain and moves forward. Lastly, myelinization of the pre-frontal cortex is one of the last maturational processes in the brain's development (Yakovlev & Lecours, 1967, cited in Case, 1985).

Functions of the Prefrontal Lobes: Behaviourial Characteristics

The previous list of anatomical and developmental characteristics of the prefrontal lobes are consistent with the behavioural characteristics that have been attributed to the prefrontal lobes. The relatively large size of the prefrontal cortex in combination with its extensive connectivity make it the most likely candidate responsible for inhibition. Inhibitory ability is most necessary when the habitual, or conditioned, response is not the appropriate response (Goldman-Rakic, 1987). The appropriate response is determined by the present, ever changing conditions. Therefore, the integrative nature of the prefrontal lobes would make it the most able to evaluate the present demands of the situation. As well, the reciprocal nature of the prefrontal lobes' connectivity enables it to act on its evaluation, and initiate the appropriate response pattern (Goldman-Rakic, 1987; Stuss, 1992).

In addition, the several measures of brain maturation previously discussed indicate the prefrontal lobes have a longer functional period of development than the other brain regions. A finding that is consistent with the protracted period of development for inhibition. For example, Diamond (1991) found infants' (monkeys and humans) could perform tasks dependent on the parietal cortex earlier than they could perform very similar tasks, but ones that depended on the prefrontal cortex. In a review of a series of studies, Diamond (1991) concluded that the prefrontal cortex takes longer to reach functional maturity than the other brain regions (e.g., the parietal cortex and the hippocampus). The previous studies of children also suggest that the tasks dependent on the prefrontal cortex are mastered later than tasks dependent on other brain regions.

Furthermore, cognitive inhibition may depend on these maturationally slower physiological developments. For example, Case (1985, chapter 17) proposed that increasing myelinization could be responsible for both cognitive activation and inhibition. Myelin continues to develop in the brain late into adolescence (Yakovlev & Lecours, 1967, cited in Case, 1985), and neuronal myelinization, which insulates the axons, prevents transmission leakage and lateral transmission (Tasaki, 1953, cited in Case, 1985). Case (1985) used these facts in combination with Hebb's Cell Assembly theory to explain how both cognitive activation and inhibition would be more efficient with myelinization. Myelinization would make the chemical-electrical signal transmission at each junction more likely to activate only the correct cell and less likely to activate the adjacent, but incorrect cells. This intuitive theory, however, is only speculative and it is meant to illustrate how physiological maturation of the brain could underlie a cognitive mechanism such as inhibition.

Behaviourial evidence, in addition to these anatomical and developmental facts, support the notion that the prefrontal cortex is responsible for inhibitory ability directly or indirectly (Diamond, 1991; Diamond & Goldman-Rakic, 1989; Diamond, Zola-Morgan, & Squire, 1989; Goldman-Rakic, 1987; Fuster, 1989; Luria, 1973, 1980; Stuss & Benson, 1986; Stuss, 1992). Stuss and his colleagues have gathered evidence from human clinical populations of brain damaged patients that indicate inhibitory ability is dependent on the functioning of the prefrontal lobes. As well, Fuster (1989) concluded that inhibition was one of the main processes served by the prefrontal cortex in his examination of the prefrontal cortex. Studies of rodents, brain-damaged adults and normal children also indicate the prefrontal cortex is responsible for inhibitory ability (Luria, 1973, 1980).

Lastly, some of the strongest evidence for the prefrontal lobe being responsible for the ability to inhibit responses has been provided by Diamond and Goldman-Rakic. Diamond and colleagues (e.g., Diamond, 1991; Diamond & Goldman-Rakic, 1989; Diamond, Zola-Morgan, & Squire, 1989) using human infant, and adult and infant monkey studies have established that inhibition depends on the functioning and development of the prefrontal cortex. Only specific lesions to this frontal lobe area produce the error patterns associated with a lack of inhibitory ability. Lesioning other brain areas, such as the parietal cortex or the hippocampus, did not produce these inhibitory ability error patterns (Diamond, 1991). The combination of human and animal studies using the same behaviourial tasks has provided very convincing evidence for the existence of inhibition, its beginning development in infancy, and its dependence on the prefrontal cortex.

Interestingly, the prefrontal lobes are thought to be responsible for certain types of motor activity as well as inhibition. Humans with prefrontal lobe damage are known to exhibit either hypo- or hyper-kinetic movement disorders (Fuster, 1989; Luria, 1973; Stuss & Benson, 1984). Hypoactive patients generally have large or massive prefrontal lobe damage (Fuster, 1989; Luria, 1973; Stuss & Benson, 1984). Hyperactive patients, on the other hand, usually have more restricted damage to the prefrontal lobe brain region (Fuster, 1989; Luria, 1973; Stuss & Benson, 1984). Functionally, the prefrontal lobes of children are probably most like those patients with restricted prefrontal lobe damage. Children's prefrontal lobes are in the process of developing, so their prefrontal lobes are more likely to have small non-functioning regions, rather than having totally inactive prefrontal lobes. Therefore, younger children with less mature prefrontal lobes could be expected to be more active than those older children with the more fully developed prefrontal lobe brain regions.

Furthermore, the voluntary or organized motor activity is associated with the functioning of the prefrontal lobes (Fuster, 1989; Goldman-Rakic, 1987). Goldman-Rakic (1987) has characterized the prefrontal lobes as regulating motor behaviour through the "initiation, timing, and inhibition of behaviour" (p.605). A connection between hyperactivity from prefrontal lobe damage and lowered inhibitory ability has also been noted by Fuster (1989).

In conclusion, the functioning of the prefrontal lobes seems to be responsible for the ability to inhibit behaviour and for differing levels of motor activity. Thus, a relation between motor activity level and inhibition may exist through this common mechanism. Definitive examination of these relations would require both behaviourial and neurological data. The present proposal, however, is restricted to behaviourial data.

The examination of the theoretical and empirical information about the prefrontal lobes has suggested interesting relations among motor activity level, inhibitory ability, and maturational status. Some of the evidence pertaining to these relations will be examined in the next section on activity level.

Activity Level

The construct of inhibition has been shown to be an important factor in preschoolers' cognitive and behaviourial performance. Motoric activity level (AL) is also a prominent component of preschoolers behaviour, both in terms of their temperament and their cognitive abilities. The previous review of the development of inhibition has demonstrated the prefrontal lobe is likely responsible for preschool children's inhibitory ability. Evidence also has been presented that the prefrontal lobe could play a role in certain types of activity. Across any developmental period examined, a consistent correlation between inhibition and AL would be expected, if the development of the prefrontal lobes is responsible for both of these behaviours. Therefore, motor AL and its developmental characteristics will be identified in order to compare its developmental pattern with that of cognitive inhibition. This is followed by evidence that suggests and supports that there is a relation between children's motor AL and their ability to inhibit.

Definition

Child and infant levels of motor activity have been a core dimension of most child and infant temperament scales (Buss & Plomin, 1984; Goldsmith et al., 1987; Thomas and Chess, 1977), and many different operational definitions have been used to measure it. Behaviour rating scales, observational measures, as well as a variety of more objective measures have served as measures of children's overall levels of activity (Tryon, 1984). In order to encompass all the various operational definitions of AL, and yet still convey the basic meaning of the construct, Eaton and Enns (1986) used a very broad definition of AL. They defined AL as an individual's "customary energy expenditure through movement" (p.19). This definition excludes energy expenditure used for physical growth or system maintenance (Eaton, in press).

Developmental Characteristics. Motoric activity, like inhibition, is a function of both individual differences and developmental maturation (Eaton, in press). Individual differences in AL are expected to remain much the same throughout the whole life, as a constitutionally based trait. Developmental differences in AL, however, are a function of maturational status and so are transitory. Furthermore, these short-term developmental differences likely interact with the individual differences in motor AL, complicating attempts to explicate the children's varying levels of activity. Developmentally infants, children, and adults display different levels of activity (Eaton, in press). Eaton (in press) examined the relation between chronological age and AL and found it to be curvilinear. More specifically, Eaton found that AL increased with age until two years of age, then sometime between two- and five-years of age, it levelled off and began to decrease. After five years of age AL consistently decreased with age. The specific age at which the age-AL relation reverses itself, however, is not known. I am predicting that, between four- and six-years of age, AL will be negatively related to chronological age.

Cognition and Activity Level

Although AL has mostly been studied as a component of childhood personality, some researchers have also examined cognitive-AL correlates (Buss, Block, & Block, 1980; Halverson & Waldrop, 1976; Palisin, 1986). These studies have added weight to the possibility that AL and cognitive inhibition are related. However, research results have not been consistent in determining whether there is a relation between AL and general measures of cognitive performance during the preschool years. Palisin (1986) found significant negative relations between AL and two of her IQ measures, consistent with the Halverson and Waldrop's (1976) findings. Her third IQ measure, however, was not significantly associated with AL, and this result is congruent with Buss, Block, and Block's (1980) findings.

More focused cognitive measures than IQ, however, have demonstrated a more reliable association with level of activity. Impulsivity, cognitive tempo, and behaviourial tempo have been found to be negatively related to AL (Halverson & Waldrop, 1976; Victor, Halverson, & Montague, 1985). Success on these measures generally requires attention, perseverance, and some degree of inhibition. Gender differences, however, moderated these findings (Victor et al., 1985). Halverson and Waldrop found AL was significantly correlated with performance on the Children's Embedded Figures Test at 2 1/2 and 7 1/2 years of age. Dempster (1992) identified the Embedded Figures Test, which measures whether an individual is field dependent or field independent, as a good measure of inhibitory ability. Field dependence is associated with subjects who are more susceptible to interference, while less susceptible individuals use more field-independent strategies. Lastly, Martin (1989) found that AL in school-aged children was consistently associated with distractibility, a behaviour associated with poor inhibitory ability. In sum, there is suggestive evidence in the literature that cognitive performance and AL are associated, especially with more precise measures of cognition. More direct evidence for an association between AL and cognitive inhibition comes from research on hyperactive children.

Hyperactive Children and Inhibition

The focus of this proposal is on the development of normal children; however, certain insights can be obtained by examining a more extreme population, hyperactive children. Hyperactivity (H), rather than Attention Deficit Disorder (ADD), is associated with prefrontal lobe problems, specifically inhibition (Benson, 1991). Hynd, Lorys, Semrud-Clikeman, Nieves, Huettner, and Lahey, (1991) concluded that

ADD without H could be distinguished from ADD with H as qualitatively different disorders, with each disorder having unique types of deficits and distinctively different comorbids. Schachar and Logan (1990) used a more precise measure of inhibitory ability and distinguished ADD with H children into two groups, the situationally versus the pervasively hyperactive. The pervasively hyperactive did significantly worse on the inhibition tasks than all other groups of children including normals, ADD with H and conduct disorder problems, and ADD with situational H.

ADD with H has been firmly connected to the prefrontal lobe dysfunction through anatomical, neurochemical, and behaviourial evidence (Colby, 1991). Furthermore, Benson (1991) has described ADD with H as a result of delayed brain maturation of the prefrontal lobes because these children usually grow out of the disorder. Denckla (1991) and others (e.g., Fischer, Barkley, Edelbrock, & Smallish, 1990) have found some adults do not grow out of their ADD with H problems, and have labelled these adults as ADD with H - Residual Type adults. Denckla (1991), however, agrees these ADD with H - Residual Type adults do seem to be suffering from delayed or relatively weak permanent states of development. Thus, ADD with H would seem to be a disorder that is a result of delayed or arrested development of the prefrontal lobes. Furthermore, hyperactivity, itself, seems most directly related to the reduced ability to inhibit.

The other problems experienced by ADD with H children, such as social relations or reading comprehension, are shared by children with other similar disorders (e.g., learning disabled children, and conduct disordered children). Inhibitory deficits, however, seem more uniquely a problem of hyperkinetic children. In fact, as Schachar and Logan (1990) demonstrated hyperactivity *per se* seems to be most closely associated with poor inhibition.

Therefore, if hyperactivity (H) rather than ADD is associated with inhibitory ability, and if hyperactivity is a result of delayed or arrested maturation, a precise measure of AL may be able to identify normal children of different inhibitory abilities.

Inhibition and Activity Level

Several sources of evidence have been presented for the existence of a relation between AL and cognitive inhibition: the prefrontal lobe's relation with both inhibition and motor AL, the past research connecting AL with general and specific cognitive functioning, and recent research with hyperactive children and cognitive inhibition. This information leads to the prediction that inhibition and activity level will be negatively correlated with each other. That is, more active children will be less able to cognitively inhibit. Two AL measures will be used to test this prediction: a parent-report questionnaire of AL, and an actometer, an objective mechanical AL measure. These measures will be discussed in more detail in the method section.

Because both inhibition and AL are a function of brain maturation, a measure of the children's maturational status could shed some light on the development of each of these two behaviours and any relations that exist between them. Specifically, the developmental trajectory of inhibitory ability and activity level will be traced in four- to six-year-olds using chronological age and another measure of maturational status, *relative maturation.* Therefore, the concept of relative maturation will be described and its potential influence on both inhibition and AL will be discussed next.

Relative Maturity

What is known so far? The functioning of the prefrontal lobes is thought to influence both cognitive inhibition and the motor AL of children. Cognitive inhibition and AL have both been found to display developmental and individual differences. Moreover, there is some evidence that inhibition and AL are related to each other, possibly by the same maturationally determined mechanism. Therefore, a measure of physical maturation could help to disentangle developmental from individual differences influencing these behaviours and could contribute to a more precise understanding of each of these behaviours.

Developmental versus Individual Differences

Individual differences are thought to be stable over time, and are probably attributable to constitutional or genetic differences. Developmental differences, on the other hand, are transitory due to differences in the maturational status of different individuals. Thus, distinguishing between these two sources of differential performance is theoretically interesting. Can the amount of variance accounted for by developmental differences be estimated apart from the amount of variance accounted for by individual differences? The answer would seem simple - yes, but the usual methods for separating them are not necessarily sufficient.

Traditionally, any differences existing after the effects of chronological age have been covaried out are considered individual differences. For example, Reed et al. (1984) found both developmental and individual differences in children's ability to inhibit. They compared three-and-a-half-year-olds to four-year-olds. The older children were better able to inhibit than the younger ones, lending support to the notion that inhibition develops. Reed et al. (1984) also found individual differences in inhibitory ability after controlling for the effects of chronological age. Chronological age, however, has been shown to be a crude measure of maturational status (Eaton & Speed, in press; Ritchot, 1992; Tanner, 1978); so, simply controlling for the chronological age of children will not accurately reflect the full effect maturational differences have on children's cognitive ability. Thus, Reed et al.'s (1984) conclusion that individual differences in inhibition exist, may have been incorrect. The remaining variance in inhibitory performance may have been simply unmeasured developmental differences falsely interpreted as individual differences.

Individual differences in behaviour, however, likely do exist in most cases. An important question is what amount of the variance in performance or behaviour is attributable to maturational influences, and what proportion of the variance is attributable to individual differences in ability or predisposition. Eaton and Yu (1989) answered this question with regard to sex differences in AL. Males are typically more active than females. Eaton and Yu (1989) asked whether the sex difference in AL was due to the sex differences in maturational status or simply constitutionally based sex differences. Using a more precise estimate of physical maturation than chronological age, they found some of the variance normally attributed to sex differences in AL was due to differences in physical maturation. Not all the variance in AL, however, was accounted for by differences in maturational status. Therefore, Eaton and Yu (1989) concluded that were sex differences as well as developmental differences in AL. Such examples suggest examining the effect of maturational status would be informative in better understanding the nature of children's behaviour, specifically the development of inhibition and AL. So, how physical maturation and its relation to inhibition and motor activity will be discussed next with the goal of better understanding these behaviours.

Physical Maturation and Cognition

Physical maturation measures are less expensive and more typical than brain maturation measures in studies of children's cognitive development. Physical maturation measures are assumed to reflect brain maturation, which in turn, is assumed to be related to cognitive ability. Thus, a measure of physical maturation could be used to predict cognitive abilities indirectly. The assumption that brain maturation and cognitive ability are related is a commonly held one, but the indirect assumption that physical maturation and cognitive development are related is less common and mostly untested.

There is, however, some evidence supporting this second assumption. Case (1985) presented data that suggested there was a direct relation between physical growth and cognitive capabilities. He compared the rate of physical development (in terms of growth in height) against the rate of intellectual development, and concluded that "children's intellectual development during this period [of 1 month to 18 years of age] decelerates at approximately the same rate as their physical development" (p. 284). Similarly, Ritchot (1992) found that early maturing boys had faster cognitive processing speeds than late maturing boys, when she used relative stature (the percent of adult stature currently obtained) as her measure of maturational status. Eaton and Speed (in press) also used relative stature as their measure of maturational status, because it is a more precise maturation measure than chronological age. They found that early maturing boys performed better than late maturing boys on a phonological imitation task, even after controlling for the effects of chronological age. Phonological abilities (e.g., articulation rate) have been found to influence short-term memory (Baddeley, 1990; Hitch, Halliday, & Littler, 1989). Eaton and Speed (in press) have speculated that the failure to differentiate early and late maturing girls was because the tasks used were not sensitive to the cognitive differences present in these girls. Because girls mature earlier than boys (Tanner, 1978), they would require more difficult tasks than the boys to fully tax their abilities, and thus reveal the cognitive difference between early and late maturing girls (Eaton & Speed, in press). Tanner took a similar position when he concluded from a review, for both males and females, that more physically advanced children "score on average slightly higher in most tests of mental ability than children of the same [chronological] age who are physically less mature" (p.83). In sum, the assumption that physical maturational status is related to brain maturation (including the prefrontal lobe) and, hence, to cognitive development, is not unreasonable. Thus, physical maturation may be used to predict cognitive development, and more specifically, the development of cognitive inhibition.

Physical Maturation and Activity Level

Eaton and Yu (1989) have shown motor AL and physical maturation to be related. As previously stated, physical maturation is thought to be a more precise measure of maturational status than chronological age. If this is true, then physical maturation would provide a more accurate estimate of the variance due to maturational status differences than would chronological age, and a measure of physical maturation would explain significantly more of the variance in AL than would chronological age. Therefore, physical maturation was used to estimate the variance in AL due to maturational differences, and residual variance in AL would be assumed to represent the variance due to individual differences in AL, which is thought to be constitutionally based and stable. Maturational differences should also exist between males and females, and these gender differences and their effects will be discussed next.

Maturational Gender Differences

Should gender differences in inhibitory ability and/or AL be expected? Tanner (1978) has indicated that at birth girls are 4 to 6 weeks more physically mature than boys, and this difference increases until the beginning of puberty. Females enter puberty on average, 2 years before males and thus, reach adult maturity 2 years earlier than males. Alternatively, the average bone age of males is only 80% of that of females from birth until full maturity (Tanner, 1978). This gender difference in physical maturation is expected to result in gender differences in both motor AL and performance scores on the inhibition tasks.

Given that females are more physically mature than males, and that inhibitory ability increases with maturational status during childhood, it was expected that females would have higher scores of inhibitory ability than would males. Stating the propositions of this prediction more explicitly: 1) physical maturational status is related to the brain's maturational status, 2) the functioning of the prefrontal lobe increases with increases in the brain's maturational status, 3) prefrontal lobe functioning is responsible for inhibitory ability, 4) females advanced physical maturational status would coincide with their more fully functioning prefrontal lobes, 5) the more fully functioning prefrontal lobes of females gives them more fully developed inhibitory abilities than males, and thus, 6) females will be better able to inhibit than males of the same chronological age.

The empirical evidence in support of this prediction, however, is not so consistent. In the studies of older children sometimes females were able to inhibit better than males, sometimes males were better able to inhibit than females, and sometimes there was no difference (Becker et al., 1987; Chelune & Baer, 1986; Passler et al., 1985). Diamond (1985) found female infants to have consistently better inhibitory abilities than the male infants. In the few studies examining younger children (three- to six-year-olds), only Reed et al. (1984) tested for gender differences in inhibition, but did not find a significant gender effect. However, using their data, I estimated the size of the gender difference in inhibitory ability performance to be .37, an effect size which is considered large (Cohen, 1992, p.99). The Reed et al. study, however, did not provide enough information to determine the direction of the effect size (whether males or females performed better). Nonetheless, the results suggest that there is a definite difference between males' and females' inhibitory abilities, and Reed et al.'s (1984) failure to find a difference likely resulted from low power.

As previously mentioned, a gender difference in inhibitory ability is expected because females are more physically mature than males of the same chronological age. Adding a measure of relative maturity as a covariate could indirectly eliminate the gender difference in inhibition. The relative maturity (RM) measure in effect, would statistically remove existing developmental differences in maturational status between males and females, and thus diminish or remove any gender difference in inhibition.

The role of physical maturation in AL and gender differences is more direct. First of all, a meta-analysis by Eaton and Enns (1986) established that there are gender differences in AL. They found males were more active than females, with an effect size of approximately .5 standard deviations. Secondly, Eaton and Yu (1989) demonstrated that the sex difference in AL is partially mediated by physical maturation status, with children between the ages of five and nine-years-old. Thus, examining whether the gender differences in AL are mediated by physical maturational differences, with these younger children, is a simple empirical extension. In the present study, I am using relative stature as a measure of physical maturation, that is, as a more precise estimate of the children's maturational status than chronological age. A description and rationale for using this physical maturation measure is next.

Relative Stature

There are a variety of physical maturation measures available: skeletal maturity, dental maturity, secondary sex characteristics, peak height velocity (PHV), age of menarche (females), and relative stature without skeletal age (Roche, Tyleshevski, & Rogers, 1983; Tanner, 1978). Roche et al. (1983) evaluated these various measures of physical maturation. They indicated that PHV, menarche, and secondary sex characteristics as measures of physical maturation are applicable only to a limited age range, and require serial or long-term data collection across the specified age range. As well, although skeletal and dental maturity measures can be used on a much broader age range, they are expensive and invasive, requiring irradiation (X-rays). Relative maturity (RM) or relative stature without skeletal age, however, is a non-invasive, inexpensive method of measuring physical maturity (Roche et al., 1983). Furthermore, Roche et al. have shown that RM is significantly correlated with these other more invasive measures of physical maturation. Based on such information, they concluded that, if irradiation or invasion of personal privacy cannot be justified, RM is an acceptable alternative measure of physical maturation.

Relative stature is the ratio of a child's current stature divided by that child's predicted adult height. Roche, Wainer, and Thissen (1975) provide a formula for calculating a child's predicted adult height (see the method section for the specific formula). This ratio is then multiplied by 100 to produce a relative maturity (RM) estimate. Relative maturity is interpreted as the percentage of adult maturity that a particular child has currently achieved. For example, a child with a relative maturity score of 50 has achieved 50% of her adult physical maturity. Therefore, RM will serve as my measure of physical maturation. RM will be used to compare the developmental versus individual differences in inhibitory ability and motor AL. As well, RM can be used to determine if gender differences in inhibition are solely a function of maturational differences, or alternatively, to reveal that other factors are acting to produce the gender differences.

General Hypotheses

The preceding review of the literature leads to a number of specific hypotheses. Generally, children from 4- to 6-years-old are expected to be more successful at tasks that do not require inhibition than those that do. Because non-inhibition tasks are believed to be almost fully mastered by age four, a more specific prediction is that performance on inhibition tasks will improve more over age than will performance on tasks not requiring inhibition. A negative relation between AL and inhibition also is anticipated because of the hypothesized influence of the prefrontal lobes on both of these behaviours. AL also should show gender differences, with boys being more active than girls, and more generally, AL is expected to decline across this age range for both males and females. Taken together, these expectations predict that girls will perform better than boys on inhibitory tasks, and will be less motorically active. Physical maturation as measured by RM is predicted to relate to both inhibition and AL, with RM significantly related to inhibitory ability and AL even after statistically adjusting for chronological age effects. In a related prediction, I expect that once adjustments for maturity have been made, gender differences in inhibitory ability will be reduced or disappear. The methods to implement tests of these hypotheses follow.

METHOD

Participants

Recruitment

The 4-, 5-, and 6-year-old participants used in this study were recruited from day care and after school programs. Centres were selected from a complete list of the city's day care and after school child care centres that was obtained from the Manitoba Child Care Program. A centre was selected for recruitment it was relatively close to the University of Manitoba, the Fort Rouge area (near my home), or along the North-South path connecting the two areas. Letters were sent to 19 centre directors, and these letters described the nature of the study and identified what would be required of them and their day care centre (see Appendix A). As well, the directors' letter packages contained a copy of the letter to be distributed to the parents (see Appendices B & C) and a project summary to be posted in the day care (see Appendix D). The project summary reported the purpose of the study and specified the general data collection procedures.

About two-weeks after letters were mailed to the directors, they were telephoned and asked if they would be willing to participate in the study. In total, 12 of the 18 day care directors contacted agreed to participate in the study. For those directors who agreed, the number of 4-, 5-, and 6-year-old children at each centre also was determined so that the correct number of signed parent recruitment letters could be delivered to the child care centre. See Appendix E for the telephone protocol. In total, 213 parent recruitment letters were delivered to the day cares. These letters were distributed to the parents by the day care workers or the directors themselves.

The parent recruitment letters explained the purpose of the study and described what participation would involve for each child. A consent form, a request for each of the biological parent's heights (for the relative stature calculation), and the EAS parent questionnaire (for the parent-rated motor AL measure) were included with the parent letter (see Appendices B & C). Seventy-nine consent forms to participate were returned, a response rate of 37%. Sample size determination determined that a sample size of about 66 would be needed to ensure a minimum level of power=.70 (see Appendix F). Due to scheduling difficulties, however, only 72 of the 79 children participated. Other procedural problems or incomplete responses further reduced the overall sample to 66 children, 59 of whom had complete data for all analytic measures, which are described next.

Measures

Three theoretical constructs were examined in this thesis: cognitive inhibition, AL, and relative maturity (RM). The measures used to estimate each of these constructs are identified and described below.

Cognitive Measures: Control and Inhibition

Six neuropsychological tasks adopted from Llamas and Diamond (1991), Passler, Isaac, and Hynd (1985) and Balamore and Wozniak (1984) were used to measure the children's cognitive abilities and development. These tasks were relatively quick to administer, taking from 15 to 30 minutes to complete. The older children generally completed the tasks in less time than did younger ones.

Each of the six tasks had a control and experimental condition. In the experimental condition the child was required to inhibit a typical response pattern and to produce an alternative response. The control condition was comparable to the experimental condition, except success did not require the child to resist or inhibit an habitual behaviourial tendency. Each child was administered both the control and experimental conditions for each of the tasks.

Dowel Tapping. For this task, the children were required to tap a clear acrylic wand dowel, either synchronously (control condition) or asynchronously (inhibition condition) to the experimenter's tapping pattern. Specifically, for the control condition, the children were instructed to tap once if the experimenter tapped once and to tap twice if the experimenter tapped twice. For the experimental condition, however, the children were required to tap once if the experimenter tapped twice and to tap twice if the experimenter tapped his wand once. There will be 2 practice trials and 12 scored trials for both the experimental and control conditions. Each correct trial earned 1 point, whereas, each failed trial received 0 points with a total possible score of 0 to 12 for each condition.

Marble Sequencing. Twenty-one marbles, 9 black and 12 white, a square plastic dish to hold them, and a small container with a clear plastic tube extending out from its lid were used for this task. Children transferred the marbles from the dish into the container through the plastic tube, one marble at a time. In the control condition 9 black marbles and 9 white marbles were used, and the children were required to deposit a black marble first, then a white marble, and to continue alternating colours until all the marbles were moved. In the experimental condition 6 black marbles and 12 white marbles were used transferred into the container in a repeated black-white-white pattern. A participant received 2 points for each correct sequence and thus, could have obtained a score from 0 to 12 points. Similarly, for the control condition, a participant received two points for each correctly performed sequence of three marbles with a possible scoring range of 0 to 12 points.

Shape Drawing. Children were required to draw three shapes for this next task: a circle, a cross, and a square. Before starting this task, the children were asked to draw these shapes to ensure they were able to identify and draw each one. On occasion the experimenter had to identify and draw one of the three shapes for a child. Such children were given additional shape-drawing practice, and these extra measures usually enabled the child to proceed with the drawing task. For each drawing condition, the children were given a pencil and a sheet of paper containing three rows of boxes with 6 boxes in each row (a total of 18 boxes) and instructed to draw one shape in each box. For the control condition, 6 circles in the first row, 6 crosses in the second row, and 6 squares in the third row was the correct configuration. Alternatively, for the experimental condition the children were required to draw a circle - cross - square pattern for a correct response. Two points were awarded for each correct three figure sequence for both conditions. Therefore, each child received from 0 to 12 points for each condition.

Modified Stroop. This task is similar to the traditional Stroop Colour-Word reading test in concept, but picture cards rather than printed words were used for the young non-readers. A deck of two different cards were used for each task condition. The children were told to say aloud either "day" or "night" depending on which picture card was presented to them. Each card deck included 12 rectangular cards about 10 cm by 14 cm in size. The control condition card deck contained 6 cards with a red squiggly "X" on a white cardboard background and 6 cards with blue and white checkerboard pattern. Labelling of the control condition cards was counterbalanced, so that the children were required to call the red "X" cards "day" or "night" equally as often. The experimental card deck included 6 cards with a yellow 'sun' positioned in a blue 'sky' and 6 cards with yellow 'stars' and a crescent 'moon' on a black 'sky' background. In order to produce a Stroop-like interference effect, the children were instructed to say "day" when flashed the stars and moon card and "night" when shown the card with the sun and blue sky. The first 2 cards of each condition were practice trials and the next 12 cards were scored. Thus, the possible scoring range for both the control and experimental condition was from 0 to 12 points.

Simultaneous Hand Switching. Both conditions of this task required the children to switch the position of their hands at the instruction of the experimenter. For the control condition, each child started with both hands palm down flat on the table, and at the command of the experimenter, he or she lifted his or her hands slightly off the table, curled them into fists, and set them back onto the table. At the next "switch" command, the children's hands were lifted, uncurled, and positioned flat on the table. For the experimental condition, the hand positioning started with one hand palm down flat on the table and the other hand curled into a fist on the table. When the experimenter said "switch" the child lifted both hands off the table simultaneously, uncurled the closed hand and curled up the spread out hand at the same time, and returned her or his hands to the surface of the table. There were four practice trials six and scored trials. The children were given two points for each switch that was correct and simultaneous. One point was given if the hand switch was performed asynchronously. Zero points were awarded when the hand switching was obviously incorrect. The children's performance could be incorrect in two ways. The children may have performed the switch one hand at a time, or they may have placed their hands down onto the table in the wrong position. Once again the range of possible scores for each control and experimental condition of this task was from 0 to 12 points.

Sequential Tapping. This task required the children to tap coloured bowling pins in either a linear consecutive pattern, or in an alternating non-linear order depending on the task condition. Four coloured plastic bowling pins - red, green, yellow and blue, a plastic carrying case for those pins, and a clear acrylic sparkle-filled wand were the materials used for this task. The bowling pins were placed in one of the two configurations depicted in Figure 1. As portrayed in Figure 1, the bowling pins are spaced apart approximately equally, so that both sequential tapping conditions were physically comparable. Before beginning this task, all children were asked to identify and name the colour of each bowling pin to ensure they could distinguish all four colours. Under the control condition, the colour tapping sequence was red, green, and yellow for the three-pin game, and red, green, yellow, and blue for the four-pin component of the control condition. The colour tapping sequence of the experimental condition was red, yellow, and green (three-pin), and red, yellow, blue, and green (four-pin). There were two levels of instructions: verbal instructions, or a demonstration with verbal instructions. Children who accurately performed the task after the first level of instruction received 2 points, those children who required the second level of instruction, a demonstration and verbal

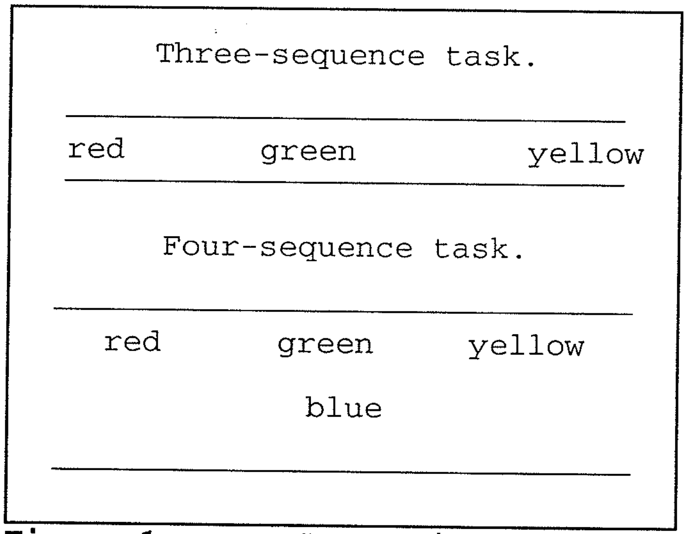

Figure 1. Sequential tapping configuration.

instructions only received 1 points for each correct trial. Of course, those children who were unable to perform the task did not receive any points for a trial. This scoring system applied to both the three- and four-pin sequential tapping tasks. There were three trials for each three- and four-pin task components. Therefore, there was a possible combined score of 0 to 12 for each condition of this colour-sequential tapping task.

Table 1 Task intercorrelations and component-aggregate correlations.

	Stroop	Tap	Marble	Draw	Hand	Colour	Aggreg
Stroop	--	16	-10	-10	6	5	--
Tap	17	--	28	25	13	23	53
Marble	27	52	--	10	25	28	72
Draw	16	60	56	--	29	13	58
Hand	14	27	36	40	--	27	67
Colour	24	43	65	56	41	--	59
Aggregate	--	63	72	69	64	81	--

Aggregation of the Data. Aggregation reduces measurement error and increases generalizability and stability of research results if the combined elements share variance (Epstein, 1986). Therefore, prior to aggregation, the intercorrelations among the scores for the tasks were examined (see Table 1). Because of the modified Stroop task's relatively low or negative correlations with the other tasks it was not included in either of the aggregated scores. The intercorrelations in Table 1 reveal that the control condition of the Stroop task was negatively correlated with two other control condition tasks, as well as having much lower control condition intercorrelations than any of the other control condition tasks. The experimental condition of the Stroop tasks also had relatively low intercorrelations among all of the experimental condition tasks. Thus, the Stroop task was excluded from the composite score for both conditions. The five remaining tasks were positively intercorrelated and they were used to create two aggregated scores for each participant: an inhibition score (IS) and a control score (CS). Standardization of the individual cognitive scores was not necessary prior to aggregation because all individual tasks were significantly and comparably correlated with the aggregated score (see Table 1), and would be equally sensitive to the children's performance in both the control and experimental conditions.

Task Scoring Reliability. Two different data collection assistants provided reliability data for 31, or 48%, of the participants. Basic scoring instructions were provided on the scoring forms and more detailed scoring instructions were discussed with each assistant to maximize scoring reliability. In addition, the principal investigator described and demonstrated various typical responses and suggested how they should be scored before any data collection was begun. Reliability data were collected throughout the data collection period, although the greatest proportion of it was collected at the beginning of study. The reliability scoring was obtained while the children were actually performing the tasks. The children's performance data used in the analysis was scored by the principal investigator both live and off the audio-video tapes. Initially, a two-way Child by Judge ANOVA was used to evaluate scoring reliability separately for the experimental and control condition tasks. The significant Child effect for both the control ($F(60, 31) = 18.21$, $p < .0001$) and experimental conditions ($F(60, 31) = 60.91$, $p < .0001$) confirmed that the measures were consistent in detecting individual differences in the children's performance. The Judge effect, however, was non-significant for both the control ($F(1, 31) = 1.03$, $p < .32$) and experimental ($F(1, 31) = 0.42$, $p < .53$) conditions, indicating an absence of systematic differences between the examiner and reliability scorer. Reliability was then estimated with an intra-class correlation, which takes into account both ordinal ranking and mean level differences among the different judges (Shrout & Fliess, 1977). The reliabilities of the CS and IS scores were .78 and .93, respectively, and was deemed acceptable.

Activity Level

As indicated earlier, two different methods were used to measure the children's level of activity. Actometers were used as an objective measure of physical movement, and the Emotionality Activity Sociability Parent Temperament Survey (EAS [Buss & Plomin, 1984]) served as a parent-report measure.

Actometers

Actometers are modified women's wrist watches that record movement rather than time. They have a watchcase diameter of 25mm and a weight of 10g excluding band (Eaton, McKeen, & Saudino, in press). If this watch is tilted or moved, the hands of the watch will advance and, therefore, the "apparent passage of time (as read by the hands) is proportional to the number of times the recorder is tilted or oscillated" (Eaton et al., in press). Thus, the actometer provides a frequency or count measure of motor activity that is not responsive to the intensity of movement (Eaton et al., in press).

Actometer standardization. The outcome measure of the actometers are Activity Units (AU), which are the "seconds" registered during an interval of real time. A rate measure of Aus per minute was calculated by dividing the total number of AUs by the total number of minutes the actometers were worn. This allows the AL of children with unequal wearing intervals to be compared. Evidence for actometer validity comes from two sources: objective, mechanical experiments, and subjectively based ratings of children's AL. The mechanical experiments provide simple, independent validity that actometers measure physical movement, while the correlations between person-rated AL ratings and actometers assess the convergent validity of actometers. The specific evidence for each of these types of actometer validity follows.

Objective actometer validity. Mechanical experiments have been conducted demonstrating the ability of actometers to measure movement (e.g., Eaton et al., in press; Eaton, McKeen & Lam, 1988; Tryon, 1985). For example, a mechanical, chemical shaker bath was recently used to demonstrate the actometers' ability to validly record and distinguish various levels of movement (Eaton et al., in press). Nineteen actometers were attached to a chemical shaker bath, which was operated at two oscillation rates (170 or 200 cycles per min), and at two time intervals (4- or 8-min sessions). An Actometer (19) X Mins (2) X Rate (2) ANOVA found that the actometers differentiated the different movement conditions. The actometers were found to be sensitive to both different time intervals and different oscillation rates, and there were no interactions between the Actometer and the other two factors, indicating that the instruments were not differentially sensitive to condition differences.

Convergent actometer validity. Evidence for convergent actometer validity among preschool populations is mixed. Several studies have found significant correlations between actometer measures of AL and subjectively rated AL measures with preschoolers (Buss, Block, & Block, 1980; Butcher & Eaton, 1989; Eaton, 1983). For example, Butcher and Eaton (1989) examined the AL of 4.5- to 6-year-olds in nursery school play settings and found the observer-rated measures of AL significantly correlated with the actometer measured values of AL (r =.53, p <.01). Eaton (1983) also found actometer readings, teacher ratings, and parent questionnaires of activity level to have intercorrelations of .69 and higher (Eaton, 1983) with children from 3.5 to 5 years old, who were measured in free play. Buss, Block, and Block (1980) provided further evidence for the convergent validity of actometers. They found actometers and teacher rated Q-sort scores of activity level were significantly correlated at both three- and four-years of age. A study by Saudino and Eaton (in press), however, failed to a find a significant correlation between actometer AL rankings and parent report questionnaire on a sample of 3-year-old twins. The failure in the present study to find a significant correlation between the actometer rated AL and the activity scale of the EAS ($r = .04$, $p < .77$) suggests that this incongruity may not be restricted to unique populations such as twins.

Actometer reliability. A number of studies have shown actometers to be reliable in detecting individual differences among infants, preschoolers, and adults (Buss et al., 1980; Eaton, 1983; Eaton et al., 1988; Eaton et al., in press). Actometer reliability, however, is complicated by the fact that people exhibit inter-limb differences in AL. Therefore, measuring all four limbs of a child produces the most reliable measure of that child's motor AL. When actometer resources are limited, however, different limb attachment combinations produce more or less reliable AL composites (Eaton et al., in press). For example, Eaton et al. (in press) found that combining the activity level of an arm and leg produced the highest reliability coefficient (Spearman-Brown $r = .82$) with only two actometer attachments per infant. This study used only two actometers per child and so used this same-side arm and leg actometer attachment method to maximize reliability. This current study confirmed the general conclusion that actometers are reliable in detecting individual differences in AL with a Spearman-Brown correlation of .55, within the range found by Eaton and his colleagues ($r = .43$ [with adults] to $r = .82$ [with infants]).

Activity Level Questionnaire

The EAS parent questionnaire (Buss & Plomin, 1984) was used as a second measure of AL (see Appendix C). Five of the 20 items on this questionnaire assessed the children's typical levels of motor activity. The average score for these 5 items was used as the parent-report AL measure. This measure of AL has been shown to have good reliability with a test-retest correlation of 0.80 on a sample of 31 three-and-a-half year-olds (Buss & Plomin, 1984). As well, this more general measure of AL circumvents interpretation problems that may arise from using actometers. Namely, actometers, although accurate and reliable, only are able to represent the amount of activity the child exhibited during the time period they are worn, which may be unusually restricted or atypical in some way. Thus, the parent-reported measure of AL, although subjective, offers a more general measure of the child's typical AL.

Relative Maturation

A measure of the children's relative maturational status was the third major data collection task. The calculation of Relative Maturity (RM) requires: 1) a child's current height and weight measurements, 2) the age and sex of the child, and 3) the heights of the child's biological parents. Next, the formula for calculating RM is described.

Relative Maturity Calculation. After the basic information necessary for the maturity calculation is obtained, it is used to estimate each child's predicted adult height. Predicted adult height is accurate to within ± 2.85 cm, 90% of the time. The next step was to determine each child's Relative Maturity (RM), which is equal to a child's current height divided by her or his predicted adult height multiplied by 100 (Roche, Tyleshevski, & Rogers, 1983). The specific formula used to calculate RM is provided in Appendix H.

Questionnaire Form for Relative Stature Estimate. A few brief questions included with the parental consent forms (see Appendix B) provided some of the information necessary for the RM estimate. Specifically, the parent's were asked to indicate their child's birth date and gender, and to provide the biological parent's heights. Using the SAS date function exact age was calculated by subtracting the child's birth date from the date she or he was examined. Although parents tend to slightly overestimate their actual heights (Himes & Roche, 1982), the resulting increase in the child's predicted adult stature is very small. Furthermore, as long as the overestimation occurs across the whole sample, all of the children's RM estimates should be comparably biased.

Summary of Overall Procedure

After the children were recruited and the permission forms and questionnaires were collected, an actometer was attached to each child's non-dominant wrist and ankle. The height and weight of each child was then measured, and he or she was administered the six tasks. The specific details of each of these procedure is provided next.

Actometer attachment procedures. In the daycare, the experimenter attached two actometers to each child, one on a wrist and one on an ankle (maximizing reliability with limited resources). More specifically, the actometer at the wrist was attached on the dorsal aspect of the forearm proximal to the radialcarpal joint. The ankle attachment was superior to the lateral malleoli. The actometers were attached on their non-dominant (left-sided or right-sided) limbs. Dominance was determined by asking the children to draw a circle on a piece of paper, and the hand they used was identified as the dominant one. The children wore the actometers the rest of the day, overnight at home, and the next day until removed. Non-removable bands were used, which required cutting to be detached. The children were told they could carry out their usual activities but that they should not get the actometers wet. As the actometers must be removed for baths, each actometer had an arm or leg label, and a set of extra watch bands were provided to replace those removed for a bath or other purpose. Instructions were included with the extra bands, directing the parents to record the time of day the actometers were removed and reattached, and emphasizing that the actometer should be reattached onto the same limb from which it was removed (see Appendix I). The following day the actometers were removed in the daycare at approximately the same time of day that they were attached on the previous day.

Physical Measurements

A free-standing GPM anthropometer was used to measure the children's height, and a digital scale (a Thinner model HW 105 scale) was used to measure their weight. Both height and weight measurements were made twice and the average of each used in the RM calculation. Standing height rather than recumbent length was measured, so 1.25 cm was added to the averaged height value to estimate recumbent length (Roche et el., 1975). The primary examiner measured both the heights and weights of each child. The children were asked to remove their footwear, stand with their backs toward the anthropometer, heels together, hands at their side, asked to look straight ahead, and take a breath just before their height was measured. Immediately following these measurements, the children were weighed with their shoes still off. The children were instructed to look up and not to touch or lean on anything while the measurements were being taken. As already indicated, each measurement was taken twice in order to ensure accuracy. If the first two measurements (for either height or weight) were discrepant (by more than 1.5 cm in height or by 1 lb in weight), that child was measured a third time. The two measurements closest to each other then were used to calculate the mean value.

Task Administration. The tasks were administered with the experimenter and child sitting across from each other at a small child's table. All the tasks were administered by the principal investigator according to the protocol in Appendix G. To prevent systematic differences due to order of presentation effects, the presentation of the control and inhibition conditions was counterbalanced. Nearby, an 8 mm audio-video recorder was set up to record the children's performance for later scoring. The videos were used mainly by the principal investigator because the nature and pacing of several of the tasks made it impossible to simultaneously administer and score them.

RESULTS

Preliminary Data Assessment

During data collection it was discovered that 2 of the 72 participants were from special populations, one was mentally delayed and the other was on a high drug dose for epilepsy. Data from these two children were not used. Another two children spoke English as their second language, so their inhibition data, which depends on following verbal instructions, was excluded. In addition, missing information from a few of the participants further reduced the sample size for the cognitive hypotheses resulting in a total usable sample size of 64.

For the activity level hypotheses, four children produced unusable actometer activity level data by removing their actometers at either unspecified times of the day or at times highly discrepant with the goal of measuring the children's typical activity over a 24-hour period. Therefore, actometer activity level predictions were based on a sample size of 66. The EAS activity level parent-report questionnaires, however, had

Table 2. Sample sizes by age and gender.

Chronological Age (Years)	Female	Male
4	13	13
5	10	14
6	10	4

data for all 70 participating children. For particular analyses conducted the combination of missing information and unequal sample sizes resulted in further reduced samples sizes that ranged from 59 to 70. The age by gender sample size distribution used for analyzing the cognitive hypotheses is presented in Table 2. The sample size distribution is similar for the AL and RM analyses. The relatively small number of 6-year-old males is the most noteworthy fact of this table, otherwise the sample size distribution among the ages and gender was comparable.

Data manipulation. Prior to testing any of the hypotheses, the distributions of the data were examined for normality and outliers with SAS Univariates and Frequency procedures. The actometer AL data and the cognitive task performance scores had skewed distributions. Thus, the raw data sets were transformed to better meet the assumptions of the statistical analysis (Tukey, 1977). The transformations

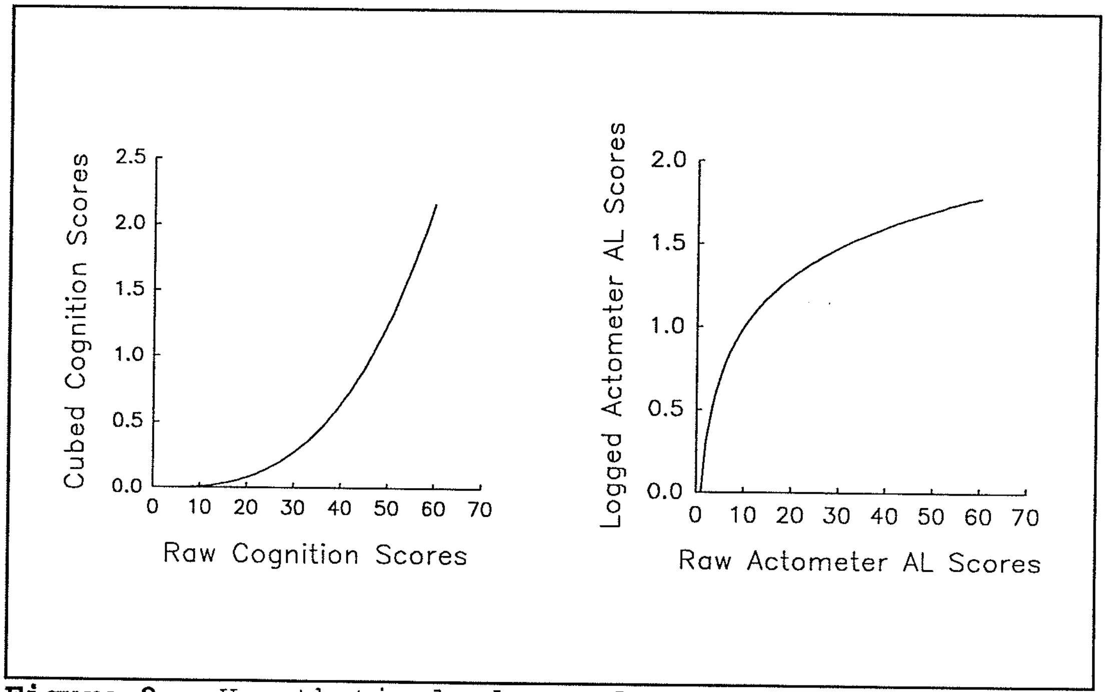

Figure 2. Hypothetical plots of raw by transformed data scores.

used did not alter the relative ranking of individual scores. However, they did stretch or shrink the distance between adjacent data points to normalize the distribution, a key assumption of parametric statistical tests.

The common log transformation was used on the raw actometer activity level data, which is almost always positively skewed. The common log transformation reduces the difference between values at the high end of the distribution, and thus, bring in the skewed tail of the distribution, normalizing it.

Table 3. Descriptive statistics for measured variables.

Descriptive Variable	N	M	SD
Sample Characteristics			
Chronological Age (yrs)	69	5.3	0.8
Height (cm)	69	112.1	6.2
Weight (Kg)	69	20.9	3.5
Relative Maturity	68	64.5	4.2
Cognitive Variables			
Control Score	64	1.7	0.5
Inhibition Score	64	1.0	0.6
Actometer Readings			
Time Worn (hours)	66	23.8	0.9
Actometer AL score	66	2.2	0.1
EAS Scales			
Activity level	70	4.0	0.7
Emotionality	70	2.9	0.7
Sociability	70	3.6	0.7
Shyness	70	2.3	0.7

The cognitive performance data was negatively skewed and the control conditions variances were much smaller than the experimental conditions variances. Therefore, the aggregated raw scores for both the control and experimental conditions were cubed. The cubic conversion produced more normally distributed data, and the variances between the two conditions were much closer in magnitude to each other. Cubed score values, however, are very large in size, so each score was divided by 100,000 to make for a simpler presentation and discussion of the results. Figure 2 shows how the cubic and log transformations redistribute hypothetical raw data.

Table 3 presents the basic descriptive statistics of the measures collected on this sample, including the statistics for transformed variables, cognitive inhibition and AL.

Inhibition Hypotheses

The first set of hypotheses are mainly concerned with children's inhibitory abilities. A 3-Way Mixed Model ANOVA, with Age (3) and Gender (2) as the between-subjects factors and Task (control score vs. inhibition score) as the within-subjects factor, was used to examine the first three hypotheses.

If cognitive inhibition performance is identifiably different from tasks that do not require abandoning previously successful responses, a significant task effect should emerge. It did ($F(1, 58) = 129.67$, $p < .0001$), and the control score mean of 1.66 ($SD = 0.45$) was significantly larger than the mean inhibition score of 1.02 ($SD = 0.59$) and produced an effect size estimate of 0.85, substantially larger than that predicted from the previous research literature.

Significant age effects for the control ($F(2, 64) = 15.11$, $p < .0001$) and inhibition ($F(2, 64) = 24.94$, $p < .0001$) conditions demonstrated that rapid cognitive development occurs within this 4- to 6-year age range, emphasizing the developmental importance of this period. The second hypothesis, that inhibitory ability would show greater improvement with chronological age than would performance on the control tasks, was tested by the Age X Task effect. The significant effect (F(1, 58) = 3.31, *p* <.04), in combination with visual examination of the group means revealed that the inhibition scores did indeed show greater increases than the control scores across this age range. Figure 3, a plot of the control and inhibition scores across age, illustrates the distinctly different developmental trajectories between the two conditions. The different slopes provides further evidence that inhibition is a unique cognitive mechanism, not just a more difficult form of the control tasks.

The third cognitive inhibition prediction forecast a Gender by Task interaction, which was not supported *F*(1, 58) = 0.003, *p* <.96. In fact, there was no main order Sex effect (*F*(1, 58) = 0.00, *p* <.97), signifying that the females' performance did not differ significantly from the males' performance on either task, nor were there any significant three-way Age X Sex X Task interactions. Thus, gender was not an important moderator variable for any of the cognitive inhibition results.

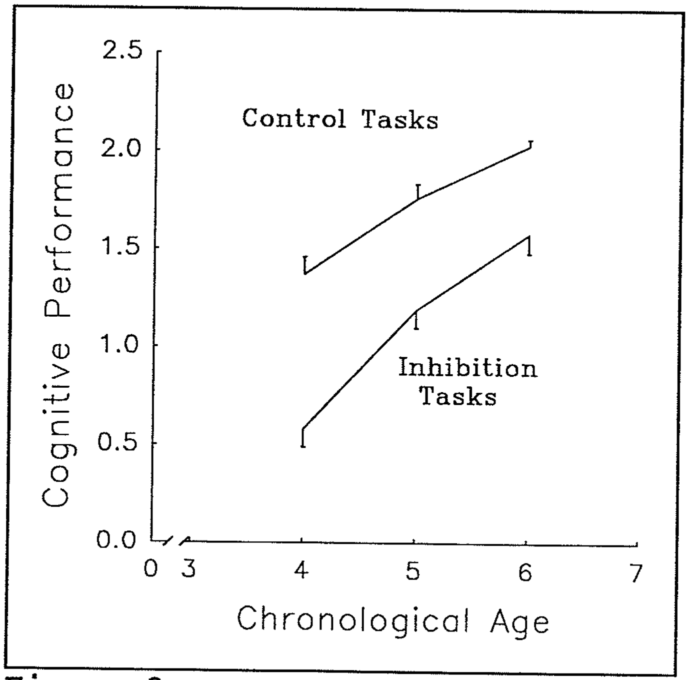

Figure 3. Mean cognitive performance (± 1 SE) by task condition and age.

Activity Level Hypotheses

The role of motor AL in children's development was the focus of the next three hypotheses. The first of these predictions simply tested an expected AL gender effect. Eaton and Enns's (1986) meta-analysis found males to be significantly more active than females throughout childhood. Therefore, the non-significant gender difference between the activity level as measured by actometers ($t(1, 63) = -.30$, $p < .76$) was quite surprising, and the means were virtually identical, male mean = 2.19 ($SD = .11$) and female mean = 2.20 ($SD = .11$). The results of the activity level subscale of the EAS were equally surprising. Females were found to be significantly more active than the males ($t(1, 69) = -2.80$, $p < .01$) with a mean EAS AL rating = 4.28 ($SD = .60$) versus a mean of 3.82 ($SD = .74$) for the males.

The test of the second AL hypothesis was equally surprising. A slightly negative relation between activity level and chronological age was expected based on Eaton's (1994) review of AL - age correlations from infancy to adulthood, but the actometer measured AL - age correlation in this study was significantly positive, $r = .28$ ($p < .05$) while the EAS measured AL-age correlation was non-significant ($r = .09$, $p < .49$). This unexpected relation between actometer measured AL and age provided a possible explanation for the failure to find the expected gender difference in AL: The relatively small number of 6-year-old males may have lead to an underestimated real gender difference in AL (on the assumption that missing 6-year-old males would be quite active). Thus, an actual gender difference could have been hidden due to unequal sample sizes. To test this possibility a *post hoc* t-test for an AL - gender effect was conducted on this sample after excluding all the 6-year-olds. The results, however, were the same as the results based on the whole sample; there was no actometer measured AL gender difference ($t(1, 49) = -.06$, $p < .95$), and the significant EAS AL gender differences with females rated as more than males was still significant ($t(1, 53) = -2.13$, $p < .04$). The relation between chronological age and parent-rated activity, however, was non-significant

The third and last AL hypothesis predicted activity level to be negatively correlated with inhibition. This proposition was based on the underlying assumption that the functioning of the prefrontal lobes influenced both of these behaviours. The hypothesis was also rejected, with a non-significant correlation for both the actometer measured AL ($r = .21$ ($p < .11$)) and the EAS measured AL ($r = .14$ ($p < .28$)). The trend toward a positive relation between AL and inhibition was unanticipated, although it is consistent with the unforeseen positive correlation found between activity level and age. Even though older children demonstrated greater inhibitory ability and displayed higher levels of motor activity than their younger counterparts, AL and cognitive inhibition were not significantly related to each other. Therefore, the prefrontal lobes cannot be said to be influencing both of these childhood behaviours in any unified manner.

Relative Maturity Hypotheses

Relative maturity, a measure of physical maturation, was hypothesized to be a better predictor of maturational effects than chronological age for these last three hypotheses. The first prediction was that relative maturity (RM) would explain more of the variance in inhibitory ability than chronological age (CA). Although RM was significantly related to inhibition ($F(1, 58) = 25.43$, $p < .0001$), it was not significant after the effects of CA had been removed ($F(1, 58) = .42$, $p < .52$). Thus, RM was not a better predictor of the effects of inhibitory ability for this sample of children. In fact, CA, rather than RM, was the better predictor of children's performance levels because it was a significant predictor of inhibition whether entered before ($F(1, 58) = 45.94$, $p < .0001$) or after ($F(1, 58) = 20.93$, $p < .0001$) RM.

Another hypothesis had predicted that an inhibition-gender effect would disappear after statistically eliminating the maturational difference between males and females. However, no gender differences in inhibitory ability were found with this sample, so, the prediction could not be tested. Nonetheless, it is unlikely RM would have had such an effect given the failure to find support for the first RM prediction between inhibition and RM.

The third RM prediction, that AL would correlate significantly with RM independent of chronological age, also was rejected. Both the actometer measured AL model (*F*(3, 58) = 1.78, *ns*), and the EAS measure of AL model (*F*(3, 62) = 2.16, *ns*) were non-significant. This result, in combination with the other RM results, suggests that age rather than RM is the better measure of physical maturation, at least as it relates to inhibition and activity for 4- to 6-year-olds. Therefore, chronological age (CA), rather than RM, was used to estimate the maturational nature of both inhibition and AL. CA accounted for 51% of the variance in cognitive inhibition performance scores, while CA only accounted for 7% of the variance in AL.

DISCUSSION

The relations among cognitive inhibition, motor activity level (AL), and physical maturity were examined on a cross-sectional sample of 4- to 6-years-old children. This age range was chosen because rapid physical and cognitive development during this time make it likely to find transition points in cognitive and physical domains. The goal of this study was to examine whether a cognitive mechanism such as inhibition can be distinguished from other cognitive behaviours and how such a mechanism changes with age. As well, the development of motor activity level was examined because of its potential association with this cognitive mechanism. The developmental nature of both of these constructs led to the use of a second maturational measure, relative maturity, which was examined to determine whether it was a better predictor of performance than chronological age.

Cognitive Inhibition

The results of the current study support the conclusion that cognitive inhibition is a measurable cognitive behaviour that can be differentiated from non-inhibition cognitive tasks in 4- to 6- year-olds. Inhibition is somewhat difficult for these children, and their performance on the control condition tasks was 0.85 standard deviations greater than their performance on the inhibition tasks, a large effect size by current psychological standards (Cohen, 1992). The only other study that has examined inhibitory development on this age range of children was conducted by Llamas and Diamond (1991). They also found inhibitory ability improved across this age range, and this current study adds support to their conclusion. In addition, this current study found neuropsychological tasks, previously used only with older children, were also sensitive to differences in these younger children's inhibitory abilities. A finding that increases the generalizability of Llamas et al.'s (1991) conclusions.

The strong Age and Age X Task effects that indicate the developmental improvements in cognitive inhibitory ability across this age range support the conclusions of researchers such as Bjorklund and Harnishfeger (1990) and Dempster (1992) that cognitive inhibition is an important mechanism in children's cognitive development. Furthermore, the magnitude of the effect size difference between control and inhibition condition performance scores is considerably larger than that calculated from Passler et al.'s (1985) findings (effect size = 0.35), which were based on a slightly older sample of children, 6- to 8-years of age. One possible explanation for this difference in effect size may be that inhibition is changing or developing more rapidly in this younger age range of 4- to 6-years. Therefore, although there is strong evidence that cognitive inhibition improves with age throughout childhood as evidenced by the finding of this study and many other studies (e.g., Becker et al., 1987; Comalli et al., 1962; Doyle, 1973; Llamas at al., 1991; Reed et al., 1984; Tipper et al., 1989), the rate at which inhibitory ability of improves may vary according to the particular age range studied.

In order to more precisely track the development of cognitive inhibition and evaluate the rate at which it changes with age, a specific parameter estimates was calculated. This tentative but testable estimate of the development of cognitive inhibition is offered for this 4- to 6-year age range in Figure 4. It presents the theoretical developmental trajectory of cognitive inhibition for this age. The developmental function is described by the mathematical equation Y = -4.8 + 0.9 X; where 'Y' is the inhibition score, and 'X' is the age of the child in years. Gender was not included as one of the predictor variables because the gender effect was non-significant.

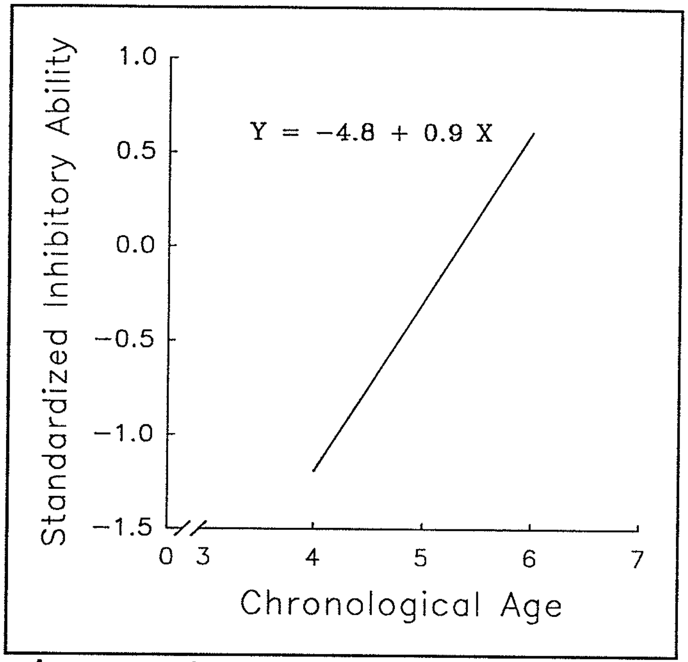

Figure 4. Hypothesized developmental trajectory of cognitive inhibition.

One might be tempted to argue that the inhibition condition tasks are just a more difficult form of the control condition tasks, and that the lower overall inhibition performance scores would be expected. The age by task interaction, however, makes this interpretation unlikely because inhibition performance changed more across this age range than did control condition performance. Presumably, two behaviours cannot represent the same underlying mechanism and change at different rates. Thus, the age by task effect is important in that it implies that inhibition performance is not based on the same underlying mechanism that determines control condition performance.

One might ask if the interaction is simply due to the cubic transformation used on these cognitive performance scores. The effect of this transformation is to differentially increase the magnitude of all values; higher values are increased a greater amount than low ones. Therefore, the difference between two large values is greater than the difference between two small values. The significant interaction between the control and experimental conditions found in this study was due to the decreasing size of the difference between the two conditions as the values increased. Thus, the cubic transformation made this particular disordinal interaction less likely, not more likely.

Although gender differences in cognitive inhibition were predicted, the failure to find a significant gender difference is consistent with much of the inhibition research to date (Becker et al., 1987; Chelune & Baer, 1986; Passler et al., 1985; Reed et al., 1984). I originally thought these failures to obtain a significant gender effect were due to studies with low power, but the current study failed to find a gender effect, even after a predetermined acceptable level of power was achieved. Furthermore, the difference between females and males performance levels was so small, that the effect size was virtually zero.

Activity Level

The non-significant correlation between the EAS parent-report measure of activity and the actometer measure of AL raises the question of which one of the AL measures were valid. Either measure may be valid because it depends on what the AL measure is representing. Actometers undeniably measure children's amount of physical movement, but they do not necessarily measure children's level of activity as perceived by others. For instance, Mintz and Collins (1985) demonstrated that both parents and teachers rated children as more active when they exhibited socially inappropriate behaviours as compared to when they exhibited socially appropriate actions, regardless of their real levels of motor activity. This bias in observer perceptions and rating of children's level of activity, however, may not be problematic. If AL is studied as a component of childhood temperament, then the children's perceived AL may be more important than their actual, objective level of AL. The child's perceived levels of activity rather than the child's actual level of activity may be inducing the particular social consequences associated with different levels of activity. The role of AL in this study was not concerned with AL as temperamental trait but rather as a biological outcome of physical maturation. Therefore, the actometer measure is the more appropriate and relevant AL measure, and the lack of convergence with the EAS does not really pose much of a problem for the conclusions of this study. Nonetheless, the results of the EAS measured AL may be offer some interesting differences in parent's perceptions of their children's levels of activity.

Overall, the AL results were unexpected. The failure to find the anticipated gender effect in AL was most surprising. The prediction that males would be more active than females was based on a meta-analysis of 127 studies with an estimated effect size of 0.5 standard deviations (Eaton & Enns, 1986). In the present study, the difference between male and female actometer measured AL is negligible (even when the 6-year-old data was removed to eliminate potential error due to the small number of 6-year-old males). A result that is simply unexplainable. The most direct path to clarifying this perplexing finding is to further sample the AL of females and males to determine whether this non-significant gender effect is replicated.

The significant gender difference found with the EAS measured AL indicates that parent's perceive female children to be more active than male children, in spite of the fact that objectively the females and males were no different in their levels of motor activity. One possible reason for this gender observer bias may be that the girls were engaging in more socially inappropriate behaviour, and so they were rated as more active than the boys. A second possible reason could be that the parent's were aware of the general finding that in the past parent's have rated boys more active than girls simply because they were boys not because of any actual gender differences in AL. Therefore, the parents, in guarding against this bias, may have overcompensated and rated the females as more active than the males unjustifiably. Nonetheless, both measures of AL failed to support the predicted gender difference in AL.

The positive correlation between actometer-measured motor AL and age also was unanticipated. However, unlike the AL-gender effect, the prediction of a negative correlation between age and AL was tentative because of the inconsistency of AL data within this age range. In fact, this study was done in part to clarify the direction of the AL-age relation. The original prediction was based on Eaton's (1994) hypothesized curvilinear relation between age and AL. Eaton (1994) suggested the peak of this curve to be located within the 2- to 5- year age range. The data from this study, however, indicate that the peak of the AL-age curve probably occurs after age 6.

The non-significant correlation found between age and EAS-measured activity level suggests that the EAS may not be a very sensitive measure of children's objective AL. From an parent's perspective, a four-year-old may seem as active as a five- or six-year-old child, especially if the absolute age differences in AL are not very large. The following actometer-measured AL-Age developmental relation illustrates these relatively small age differences in AL.

A more precise estimate of the development of AL is presented in the form of a theoretical equation. Figure 5 illustrates this theoretical developmental function with an equation of Y = -1.8 + 0.3 X, where 'Y' refers to the children's level of activity and 'X' is chronological age. This equation indicates that AL increases 0.3 standard deviations units with each additional year increase in chronological age. Such an increase is not very large and suggests AL is not changing very rapidly across this age range. This developmental equation of AL also illustrates how producing specific developmental estimates allows researchers to generate more exact conclusions about their data. This developmental function, like the theoretical developmental function for cognitive inhibition, provides a specific prediction that can be tested and modified with the accumulation of additional information from actometer studies. However, this equation would not be expected to hold indefinitely as age increases. If AL peaks after 6 years, as expected, a curvilinear model would have to be developed.

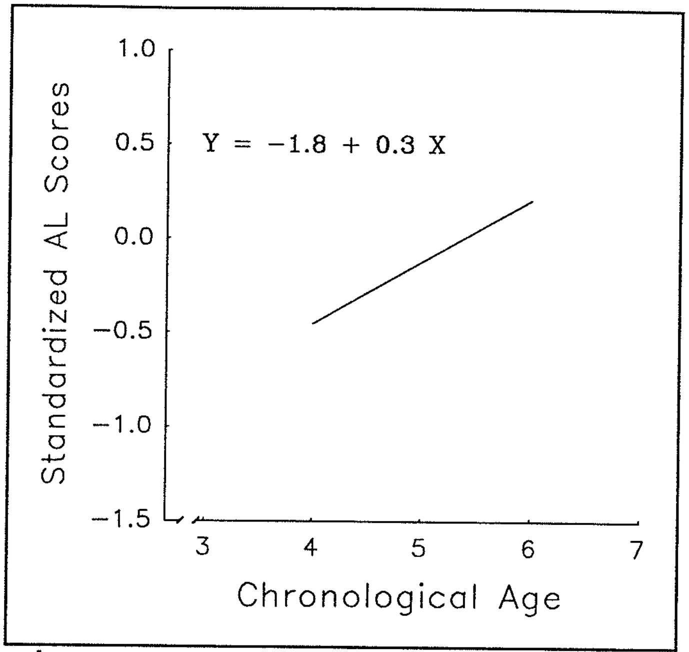

Figure 5. Hypothesized developmental trajectory for 4- to 6-year activity level.

The correlation between cognitive inhibition and AL (both actometer-measured AL and EAS-measured AL) was tested and found to be non-significant. This finding is inconsistent with much of the literature described earlier. Studies from several different domains were presented that suggested AL and cognitive inhibition would be negatively related, however, no actual study had been conducted directly testing whether there was a relation between cognitive inhibition and motor AL. One reasonable explanation for this inconsistency is that support for the negative relation between motor activity and inhibition was not clearly interpretable from the available literature. For example, the underlying reasons for the general hyperactivity found in clinical populations of both adults (Luria, 1980) and children (Schachar, & Logan, 1990) with prefrontal lobe deficits may be qualitatively different from those reasons normal human populations exhibit high levels of activity. Similarly, the negative correlations found between specific cognitive functions and AL (e.g., Halverson et al., 1976; Victor et al., 1985) may have represented a relation between attention and AL rather than inhibition and AL.

However, before the hypothesized relation between motor AL and cognitive inhibition is completely dismissed, more particular types of motor behaviours should be examined to determine whether they are related to children's cognitive inhibition performance. The nature of the AL measures may not have been appropriate for testing the hypothesized relation between AL and cognitive inhibition. Both the actometers and the EAS provide a very general measure of children's AL, but according to Goldman-Rakic (1987) the prefrontal lobes are responsible for "voluntary motor behavior" (p. 605), not all types of motor activity. Originally, it was thought a general decrease in motor activity would be indicative of a general increase in children's control of their motor behaviour, which the actometers and EAS would be able to measure reliably. The children's general motor activity, however, increased with age, as did the functioning of the prefrontal lobes. Thus, the improved functioning of the prefrontal lobes may not produce a general decline in motor activity, and likely has a more focused effect on certain types of motor movement.

The positive trend in the relation between AL and cognitive inhibition, however, encouraged a *post hoc* examination of the arm and leg AL data separately. Correlations between each of these AL scores and inhibitory ability were calculated. As expected neither correlation was significant, but the arm AL did have a slightly higher non-significant correlation with inhibition (*r* = .22, [*p* <.09]) than leg AL (*r* = .13 [*p* <.32]). This suggests that arm activity may be composed of a greater amount of directed and cortically controlled activity than leg activity, and that therefore, arm movements would be more likely than leg movements to correlate with other behaviours that depend on the functioning of the prefrontal lobes.

Relative Maturity

An additional component of this study, was its examination of relative maturity (RM) as a measure of maturation. RM was hypothesized to be a better predictor than chronological age of maturational effects on both cognitive performance and motor AL. Disappointingly, none of the predicted RM relations were significant. In fact, chronological age was the better predictor of both cognitive inhibition and AL. Two explanations are offered which may explain the failure of RM to account for more of the variance than age. First, chronological age and RM appear to be highly redundant (*r* = .81, *p* <.0001), sharing 66% of their variance. The variance in cognitive inhibition accounted for by RM can be accounted for by chronological age, but the reverse is not true. This indicates that RM is redundant with chronological age (CA), but that CA contributes uniquely to inhibition variance.

A second possible reason for the non-significance of RM is that there may be mediating variables that make it too "noisy." For example, individual differences in adult or endpoint cognitive ability could undermine the accuracy of the RM predictions. In the case of predicting children's current cognitive performance from their RM status, two key assumption are made. The most basic assumption is that relative physical maturation is related to cognitive ability, and ultimately, IQ. An equally important assumption is that the children will reach the same cognitive endpoint, or in the case of IQ, all the children will eventually attain the same adult IQ.

This second assumption is untenable given the known variation in adult IQ scores. Therefore, individual differences in IQ may confound the RM predictions based on maturational timing differences.

For instance, two 5-year-old girls are measured and their RM status is estimated. One of the girls has attained 70% of her physical maturational status and the other has only attained 50% of her physical maturational status. Assume that the more mature girl will have an adult IQ of 100, so it is predicted that she has 70% of her adult IQ or 70 adult IQ points. The second, less mature girl will have an adult IQ of 150, so it is predicted that she has 50% of her adult IQ or 75 adult IQ points. Thus, the less mature girl actually has a higher current IQ. If it was assumed that the two girls would attain the same adult IQ of 100, according to the RM prediction the more mature girl would have a higher child IQ and be cognitively advanced relative to her less mature same age mate. In conclusion, mediating variables such as IQ can cloud or interfere with the accuracy of RM. The detrimental effect of some of these mediating variables could be controlled statistically, were they measured.

Relative maturity, however, was not a significant predictor of maturational differences in these behaviours so chronological age (CA) was used to estimate the effects of developmental differences on both cognitive inhibition and motor AL. CA accounted for 51% of the variance in cognitive inhibitory ability. A magnitude that indicates that the transitory effects of developmental differences are more important than the stable individual differences in cognitive performance because the remaining 49% of the variance in performance is accounted for by both measurement error and individual differences in the children's cognitive abilities. The distribution of the variance in AL is reversed in its relations with maturational and individual differences. CA only accounted for 7% of the variance in AL. Thus, the vast majority of the variance in AL would be due to stable individual differences in AL rather than due to temporary developmental differences in AL.

Concerns and Issues

Why did the Stroop task have low or negative correlations with the other tasks? It was the only verbal task used, and thus may rely on separate cognitive factors. Another possibility is that the results of the Stroop performance were obscured by methodological problems of the task. Some children appeared to misunderstand the task instructions, and despite careful instructions, simply repeated "day", then "night," regardless of what card was shown. It was as if they thought the instructions were to say "day" for the first card shown, and "night" for the second card, rather than understanding that each different cards was being given a specific label of "day" or "night". This behaviour was not the norm, however, and many of the children demonstrated their understanding of the instructions by self-correcting immediately after misnaming one of the cards.

Another scoring difficulty with the Stroop task was that the control and experimental conditions may not have been comparable in terms of the memory capacity required for successful performance. This conclusions is based on the observation that during testing of the control condition some of the children appeared to reverse the associated "day" and "night" labels after only a few trials so that all of their following responses were incorrect. The children were actually performing correctly, they had just rearranged the label association. The experimental tasks did not seem to suffer from the same problem because the experimental cards have an inherent meaningful association attached to them. Therefore, the children only had to retain the idea that they must give the opposite name to the picture. The control cards however, depicted a neutral, meaningless stimulus, and so the children had to maintain an association between the neutral stimulus and its label. These problems may explain why the Stroop tasks had lower intercorrelations with the other tasks.

A third concern identified during the process of data collection was the noticeable difference in how long the children took to perform the tasks. Often a child would perform the control tasks with ease and fluidity, but when asked to do the experimental tasks their performance would be slow and laborious, even when successful. This obvious phenomenological difference, however, was not captured by the scoring system in the current study. Timing the children's performance would have allowed response latency to act as an additional dependent variable.

Future Directions

In conclusion, a number of interesting questions were answered and generated from the findings of this study. Evidence for a cognitive inhibitory mechanism was found and its development with age corresponded to the findings of other developmental researchers (e.g., Becker et al., 1987; Chelune & Baer, 1986; Doyle, 1973; Llamas & Diamond, 1991). Furthermore, inhibition and control tasks displayed different developmental trajectories, which implies the presence of distinct underlying mechanisms. These results, however, do not answer all the questions but in fact lead to more questions.

Do other tasks from more diverse behavioural domains also require cognitive inhibition for successful performance (e.g., additional verbal tasks)? Would response latencies provide a representative measure of inhibitory ability given the phenomenologically perceived greater response latencies for the inhibition condition tasks? Could IQ help disentangle developmental differences in cognitive inhibition from individual differences? IQ is recognised as a stable measure of individual differences in cognitive performance (McCall & Carriger, 1993). Therefore, the children's individual differences in IQ could be co-varied statistically from the children's cognitive inhibition performance scores to produce a purer estimate of the maturational differences in inhibitory ability. As well, the relation between cognitive inhibition and IQ could also be examined.

Developmentally, a wider age range of children could be examined to include both older and younger children. This would allow both developmental trajectories of cognitive inhibition and AL to be extended and further tested. Sampling the AL of older children would extend the developmental function of AL and may act to pinpoint the apex of the curvilinear developmental trajectory of AL across age. This additional sample of children could be used to further test whether males were more active than females, and if the actometers were attached to both of the children's arms rather than to one arm and one leg, the relation between AL and cognitive inhibition could be better tested.

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APPENDICES

Appendix A

Director Contact Letter

March 15, 1991

Director of Waverly Heights School Age Program
1885 Chancellor Drive
Winnipeg, Man.

Dear Director:

Mr. Darren Campbell, a graduate student in developmental psychology, and I are conducting a research project on the possible relation between children's cognitive ability to stay focused on tasks, their level of motor activity, and their level of physical maturity. This research requires the participation of children from four to six years old, and we are writing to request your daycare's cooperation. Cooperation would involve providing us with parent and child names so that we could send each parent a letters that describes the nature of their participation, a short questionnaire about their child's behaviour, and a consent form to participate. We have appended a summary of the project, and a copy of the letter to be sent to the parents.

One of us will call you in the near future to see if your centre might participate. In the meantime, either Mr. Campbell or I can be reached at 474-6955, and we would be happy to answer any questions. If it would be helpful, either or both of us would be willing to attend a meeting concerning this request.

Yours truly,

Warren O. Eaton, PhD.
Professor

Appendix B

Parent Recruitment Letter, Consent Form, and Relative Maturity Questions

December 16, 1994

Dear Parent:

We are conducting research on children's motor activity levels and their ability to perform six game-like tasks. We also are wondering if physical maturity is related to activity level and these tasks. Your child's daycare/afterschool program has kindly agreed to cooperate, and I am writing to request your permission to allow your daughter or son to participate.

If you agree that your child can participate, please complete the enclosed form and return it to the daycare/afterschool program. Your information will allow us to estimate your child's level of physical maturity and typical level of motor activity. Each participating child would wear two modified wrist watches that measure movement over a 24-hour period. One watch would be worn on the wrist and other on the ankle. We have successfully used these watches before on many infants and children without problems. Incidentally, these watches are not waterproof, so they must be taken off for baths or other water events. Also, the height and weight of each child would be measured so that we can predict adult height, and we would provide you with your child's predicted adult height. Lastly, your child would play six simple games, which require tapping in different patterns, drawing various shapes, sorting and dropping marbles into a small can, and naming a few pictures. In order to accurately record and score your child's performance, we need to video tape your child playing these six games. These video tapes would only be used for scoring purposes. This would all take no more than 30 minutes of your child's time. For you and your child's participation, your child also will receive a *Bachelor of Activity* (B.A.) certificate.

If you are willing to have your child participate, please complete the attached form and return it to the centre as soon as possible. All obtained information will be used only for research purposes and will remain confidential. As well, only group data will be used in any publications resulting from this data. A summary of the results of the study will be sent to the program director.

If you have any questions or want more details, please feel free to call me or my graduate student, Darren Campbell, at 474-6955.

Yours truly,

Warren O. Eaton, PhD.
Professor

Darren Campbell
Graduate Student

Consent Form

Dear Parents/Guardians: **Please complete the following and return it to the centre.**

Child's name: ______________________________
(first name) (surname)

_____ I **do** consent to let my child participate in Dr. Eaton's study.

_____ I **do not** consent to let my child participate in Dr. Eaton's study.

Parent or guardian signature:_____________________ Date:___________

The following information is necessary for us to predict your child's adult height.

Child's birth date: _____/_____/_____. Child's sex: ______ (F or M).
Day Month Year

Height of child's biological father: _____________ (in feet and inches).

Adult height is influenced by factors such as nutrition and disease during the growing years. Therefore, it would be helpful (*though not crucial*) if you could answer the following questions for us.

Has your child ever been diagnosed as having any persistent, chronic disease (for example, a disease of the heart, digestive system, kidney, liver, central nervous system, or skeleton)?	Yes ___ No ___
Prior to reaching adult height, did the child's biological mother have any persistent, chronic disease?	Yes ___ No ___
Prior to reaching adult height, did the child's biological father have any persistent, chronic disease?	Yes ___ No ___

Appendix C
Parent Report Activity Level Questionnaire

Rate each of the items for your child on a scale of **1** (*not characteristic or typical of your child*) to **5** (*very characteristic or typical of your child*) by circling the most appropriate number following the item.

1.	Child tends to be shy.	1	2	3	4	5
2.	Child cries easily.	1	2	3	4	5
3.	Child likes to be with people.	1	2	3	4	5
4.	Child is always on the go.	1	2	3	4	5
5.	Child prefers playing with others rather than alone.	1	2	3	4	5
6.	Child tends to be somewhat emotional.	1	2	3	4	5
7.	When child moves about, he or she usually moves slowly.	1	2	3	4	5
8.	Child makes friend easily.	1	2	3	4	5
9.	Child is off and running as soon as she or he wakes up in the morning.	1	2	3	4	5
10.	Child finds people more stimulating than anything else.	1	2	3	4	5
11.	Child often fusses and cries.	1	2	3	4	5
12.	Child is very sociable.	1	2	3	4	5
13.	Child is very energetic.	1	2	3	4	5
14.	Child takes a long time to warm up to strangers.	1	2	3	4	5
15.	Child gets upset easily.	1	2	3	4	5
16.	Child is something of a loner.	1	2	3	4	5
17.	Child prefers quiet, inactive games to more active ones.	1	2	3	4	5
18.	When alone, child feels isolated.	1	2	3	4	5
19.	Child reacts intensely when upset.	1	2	3	4	5
20.	Child is very friendly with strangers.	1	2	3	4	5

Appendix D

Project Summary

This research project asks several basic questions about four- to six-year-old children. Are children's motor activity levels related to their ability to perform six game-like tasks? How does activity level and task performance change across this age range? Is physical maturity related to activity level and task performance?

The information from parent questionnaires coupled with height and weight measures of the child will allow us to estimate each child's level of physical maturity and his or her typical level of motor activity. As well, each participating child would wear two modified wrist watches that measure movement over a 24-hour period. One watch would be worn on the wrist and the other on the ankle. We have successfully used these watches before on many infants and children without problems. Incidentally, the watches are not waterproof, so they must be taken off for baths or other water events, and the parent's participation in this respect would be required. The two watches would be put on the children's limbs at the centre, worn at home overnight, and removed the next day at the centre at approximately the same time they were attached. Lastly, each child would play six simple games, which require tapping in different patterns, drawing various shapes, sorting and dropping marbles into a small can, and naming a few pictures. All six games are a bit like the children's game Simon Says because they require the child to vary his/her actions in response to different instructions. The six games will be video taped for later scoring purposes. This would all take no more than 30 minutes of the child's time.

All obtained information will be used only for research purposes and will remain confidential. A summary of the overall results (only group data presented) will be sent to the program director. By way of thanks, the child's predicted adult height will be given to the parent of any participant and a *Bachelor of Activity* (B.A.) certificate given to each child.

Appendix E

Telephone Director Protocol

Director
Telephone number
Daycare address

Centre I.D. ______________________
Date/Time ________________________

Hello ... Darren Campbell U of M. Calling about research project?
letter sent ..received ? This research is for my master thesis in development psychology.
What it would involve for you?
    Distribute letters to the parents
    Provide a small place in your centre where I could set up a small child's table, a few materials and a recorder.
Describe study:
There would be 2 visits:
    First day: put the watches on the children's limbs, and administer the games to each child individually.
    Second Day: Remove the watches and administer the games to any children who could not be tested on the first day.
As well, I would gladly visit the centre before any testing began to make myself known to the children so they would not be nervous with me.
Interested?

YN

Thank you very much for your time.

Do you have any questions?

How many 4, 5, & 6-year-olds do you have? and How many letters would you need?

Directions: Is your centre easy to find (e.g. is it in a school or other non-obvious location?).

Work: 474-6955 or Home: 284-3066 - answering machine at both numbers.

Appendix F

Sample Size Determination

Two types of errors can result from using inferential statistics: a null hypothesis can be falsely rejected (a Type I error) or a failure to reject the null, even though the alternative hypothesis is true, can occur (a Type II error) (Cohen, 1969, 1992). The probability of incurring a Type II error was set at .30 for each of the hypotheses. Or, in other words, the chance of rejecting the null hypothesis and detecting a true alternative hypothesis for each of the hypotheses was 70%. The alpha level for each of the hypotheses varied according to the specificity of the information available for each prediction and the importance of that hypothesis overall. Sample size determination estimates were calculated for each of the nine hypotheses and are summarized in Table A. For each of the hypotheses, the type of analysis planned, the effect size estimated from the literature, and the alpha level and specificity of the test (i.e., one- or two-tailed test) were required and are listed in Table A. This information in combination with Cohen's power analysis tables (1969) was used to determine the sample sizes necessary to achieve a 70% chance of detecting a true alternative hypothesis for each of the hypotheses. Table A indicated that the sample sizes necessary to maintain a 70% chance of detecting a true alternative hypothesis ranged from 23 to 66. However, all of the hypotheses depended on the same data and so, to ensure a minimum power level of 70% a minimum of sample size of 66 was to be collected. Overall, however, power will range from .70 to .99.

Table A
Sample Size Determination with a Power = .70

Hypotheses	Statistical Analysis	Effect size (statistic)	Alpha (tailed)	N of Groups	N per Group	Total N
Task Effect	ANOVA	.30 (f)[a]	.05 (2)	2	25	**50**
Age X Task	ANOVA	.50 (f)[b]	.05 (2)	6	11	**66**
Sex X Task	ANOVA	.40 (f)[c]	.10 (2)	4	15	**60**
Sex X AL	t-test	.50 (d)[d]	.10 (1)	2	27	**54**
Age-AL	Correlation	.50 (r)[e]	.05 (2)	--	--	**23**
IS-AL	Correlation	.35 (r)[f]	.05 (2)	--	--	**52**
IS-RM	Regression	.30 (r)[g]	.05 (2)	--	--	**66**
IS-RM-Sex	Regression	.30 (r)[h]	.10 (2)	--	--	**51**
AL-RM	Regression	.45 (r)[i]	.05 (2)	--	--	**30**

Note. Gender hypotheses were secondary and so their alpha levels were set at .10. As well, the previous effect sizes estimates were calculated from various sources identified below.

[a]Passler et al., (1985). [b]Llamas et al, (1991); Reed et al., (1984). [c]Reed et al., (1984). [d]Eaton and Enns, (1986). [e]Eaton, (1983). [f]Halverson and Waldrop, (1976). [g,h]Assumed a medium effect size (Cohen, 1969). [i]Eaton and Yu, (1989).

Appendix G

Task Administration and Scoring

Experimental Procedures and Instructions

Actometer Recording Sheet

ID _______ Interviewer ________

Day Care Centre _________________________

Begin (DDMMMYY:hh:mm) __ __ __ __ __ __ __: __ __: __ __

End (DDMMMYY:hh:mm) __ __ __ __ __ __ __: __ __: __ __

Set ___	Acto #	Acto Start (hh:mm:ss)	Acto Stop
Arm ___	_____	__ __: __ __: __ __	__: __ __: __
Leg ___	_____	__ __: __ __: __ __	__: __ __: __

Start data entered? ____ checked? ____
End data entered? ____ checked? ____

Height and Weight Measurements

Height 1: __ __ __. __ cm Height 2: __ __ __. __ cm.
Weight 1: __ __.__ lbs Weight 2: __ __.__ lbs

Administration and Instructions for the Cognitive Tasks

"Hi ..NAME... Now I would like you to play a few games with me. I 'll sit here and you sit here O.K.. I think they are really fun and I hope you like them". Video Camera ? It's so we don't forget what we did for the games.

Dowel Tapping Task Procedures

Introduction and Practice for Control Condition.

"For this first game, I get a special wand and you get a special wand. When I tap my wand once, I want you to tap your wand once. And if I tap my wand two times, then you tap your wand two times. Do you understand? Y/N ...

"Ok, now let's try it".
Experimenter taps once. ... child's turn.
Experimenter taps twice. ... child's turn.
If correct, then say "that's right, Very Good!".

Repeat this practice trial once more.
"Let's try that again".
Experimenter taps once. child's turn. ...
Experimenter taps twice. child's turn.

If correct, then say "Very good! Now, let's see how many we can do without stopping or making any mistakes."

Go onto the 12 scored trials.

If incorrect the first time, then say "That was close, but let's try it again. Remember, if I tap once, then you tap once. And if I tap twice, then you taps twice. Ok?"

Repeat this practice trial once more.

Experimenter taps once. child's turn ....
Experimenter taps twice. child's turn.

If correct, then say "very good". And go onto the 12 scored trials.

If incorrect, say "That was very good. But, remember, if I tap once, then you tap once. And if I tap two times, then you taps two times. Ok?"

Now, let's see how many we can do without stopping or making any mistakes."

Control Condition:

Experimenter's Tapping Sequence:

1 2 2 1 1 2 1 1 2 1 2 2 2 1 1 2

Introduction and Practice for Inhibition Condition.

"For this first game, I get a special wand and you get a special wand. When I tap my wand once, I want you to tap your wand once. And if I tap my wand two times, then you tap your wand two times. Do you understand? Y/N ...

"Ok, now let's try it".

Experimenter taps once. ... child's turn.
Experimenter taps twice. ... child's turn.

If correct, then say "that's right, Very Good!".

Repeat this practice trial once more.

"Let's try that again".
Experimenter taps once. child's turn ....
Experimenter taps twice. child's turn.

If correct, then say "Very good! Now, let's see how many we can do without stopping or making any mistakes."

Go onto the 12 scored trials.

If incorrect the first time, then say "That was close, but let's try it again. Remember, if I tap once, then you tap twice. And if I tap twice, then you tap only once. Ok?"

Repeat this practice trial once more.

Experimenter taps once. child's turn ....
Experimenter taps twice. child's turn.

If correct, then say "very good". And go onto the 12 scored trials.

If incorrect, say "That was very good. But, remember, if I tap once, then you tap twice. And if I tap two times, then you tap only once. Ok?"

Now, let's see how many we can do without stopping or making any mistakes."

Inhibition Condition:

Experimenter's Tapping sequence:

1 2 2 1 1 2 1 1 2 1 2 2 2 1 1 2

Marble Sequencing Task Procedures

Materials. Twenty-one marbles: 9 black and 12 white, a plastic dish to hold the marbles, and a container with a plastic lid and a clear plstic tube extending out from it. The only one marble at a time can be placed in the container through the clear tube.

Instructions: The children are instructed to pick up one marble at a time and place it in the container until all the marbles have been placed in the container.

Control Condition:

"For this game, pick up one marble at a time. Put a black marble into this can first (physically pointing to the container), then a white marble, then another black marble and then a white marble. (Pause) So, you need to put a black marble then a white marble. Black-white, black-white, black-white, until all the marbles are in the can".

Inhibition Condition:

"For this game, pick up one marble at a time. Put a black marble in the can, then a white marble, another white, then a black marble, a white one and another white one. That is black, white, white, black, white, white in that order. Do you understand? O.K. Go-a-head!"

Shape Drawing Task Procedures

Practice Test

OK ..NAME.. For this game, you will be drawing a circle, a cross, and a square.

Do you know what a circle is? Y/N?
If Y, then " Show me how you draw a circle in this first box (experimenter pointing to the box)". ... "Very Good!"
If N, then "That's OK, I will draw a circle for you to look at. ... See how it looks. ... Now, can you draw a circle in first box (experimenter pointing to the box) ?

If Y, then continue by moving onto the next shape, a cross.

Do you know what a cross is? Y/N?
If Yes, then " Show me how you draw a cross in this next box (experimenter pointing to the next practice box)". ... "Very Good!"
If N, then "That's OK, I'll draw a circle for you to look at. ... See how it looks. ... Now, can you draw a circle in the first box now?
If Y, then continue onto to the shape of a cross.

Do you know what a square is? Y/N?
If Yes, then " Show me how you draw a square in last box (experimenter pointing to the last practice box)". ... "Very Good!"
If N, then "That's OK, I'll draw a square for you to look at. ... See how it looks. ... Now, can you draw a square circle in the last box now?
If Y, then continue onto to the scored portion of the shape drawing task.

If N on any of the shapes, then move onto the next **task**!

Control Condition

For this game I want you to draw circles, crosses, and squares. You need to draw one in each box in this row (physically pointing to the first row of boxes), one cross in each box in this row (physically pointing to the first row of boxes), and one square in each box in this row (physically pointing to the first row of boxes). So draw circles, crosses, and squares (physically pointing at the appropriate row as you say name the shape.

Inhibition Condition

For this game I want you to draw circles, crosses, and squares. You need to draw a circle in the first box, then a cross in the next box, and a square in the empty box next to the box with the cross. So, to play this game, you draw a circle, a cross, and then a square, and keep doing this until all the boxes on the page have been filled with one of the shapes.

Modified Stroop Task

Materials: Two sets of cards, 12 in each set. The experimental card deck has 6 cards with pictures of a blue sky and a sun, and 6 cards with a black sky, yellow stars, and a yellow moon. The control card deck has 6 cards with a blue background with red squiggles forming an "X" on them, and 6 cards with a blue checkerboard pattern on them.

The task requires the children to look at a card and say aloud either "day" or "night."

Experimental condition:

When you see this card (showing them the "day" card) say the word "night". And when you see this card (pointing to the night card) say "day".

O.K. let's try a couple. Experimenter tries two practice cards, one for each card. If correct, then say "very good". Now let's start the game.

Control Condition:

For this condition, half of the participants are instructed to say "day" upon seeing the "X" card, and they are instructed to say "night" upon seeing the checkerboard card. For the other half of the participants, the children are instructed to say "day" for the checkerboard card and "night for the "X" card.

Simultaneous Hand Switching: Scoring Form

There will be 4 practices and 6 scored experimental trials for each condition. Two demonstrated practices where the experimenter did it together with the child, and two practices the child tried switching her or his hands on her or his own. Some children needed to practice all of their practices together with the experimenter.

2 if totally correct
If correct and simultaneous.

1 if partially correct
If correct, but not simultaneous.
If correctly switched, but not set back down onto the table.

0 if totally wrong
Not switched,
Only one hand switched,

Experimental Condition:

"Now for this game, put one hand flat on the table and the other hand curled into a fist on top of the table - like this (demonstrate it). And when I say **switch** lift both hands off the table at the same time. Curl the flat hand into a fist and uncurl the fisted hand out flat at the same time - like this (demonstrate it)! Then set your hand back down onto the table. O.K. Now you try it. "
Very Good!
So you want to lift your hands off the table switched them and put them back down every time when I say **switch**. O.K.?

Switch Switch Switch Switch Switch Switch

Control Condition:

"Now for this time, put both of your hands flat on top of the table - like this (demonstrate it). And when I say **switch** lift both hands off the table at the same time, curl them into fists, and set them back down onto the table at the same time - like this (demonstrate it)! O.K. Now you try it. "
Very Good!
So you want to lift your hands off the table switched them and put them back down every time when I say **switch**. O.K.?

Switch Switch Switch Switch Switch Switch

Sequential Tapping Task

Can you tell me what colour are these bowling pins (pointing at the bowling pins)?

Red? _____ Green? _____ Yellow? _____ Blue? _____

If all the colours are named correctly, then proceed with the game!

Score: Only verbal instructions - 2
demo - 1
fail all - 0

Control Condition:

Three Pegs:

"Now, take this wand and tap the Red pin, then the Green one, and the Yellow one last. So tap red, green, and yellow in that order. O.K. now try it. Very Good. Now try it again. O.K. One more time. Very good."

Four Pegs:

"This time we 'll use four coloured pins. Take this wand and tap the Red pin, then the Green one, the Yellow one and the Blue pin last. So tap red, green, yellow and blue in that order. O.K. now **try it**. Very Good. Now **try it again**. O.K. **One more time**. Very good."

Experimental Condition:

Three Pegs:

"(This is a little different than the last time) Now, take this wand and tap the Red pin, then the Yellow one, and then green one last. So tap red, yellow, and green in that order. O.K. now try it. Very Good. Now try it again. O.K. One more time. Very good."

Four pegs:

"This time we 'll use four coloured pins. Take this wand and tap the Red pin, then the Yellow one, the Blue one and the Green pin last. So tap red, yellow, blue, and green in that order. O.K. now **try it**. Very Good. Now **try it again**. O.K. **One more time**. Very good."

Demo

If they do not understand it or cannot do it properly with the purely verbal instructions repeat the instructions and then give them a non-verbal demonstration.

Appendix H

Relative Maturity Calculation

Ritchot (1992) provides a very succinct description of Roche, Wainer, and Thissen's formula (R-W-T formula) (1975) for predicted adult stature. Her description follows.

> The Roche, Wainer, and Thissen formula (R-W-T formula) (Roche et al., 1975) for predicting adult stature is as follows:
>
> $PS = \beta o + \beta rl(RL) + \beta w(W) + \beta mps(MPS) + \beta sa(SA)$,
>
> where PS = predicted adult stature in cm, β = beta coefficients, βo = a constant for each sex for each month of age, RL = recumbent length in cm, W = child weight in kilograms, MPS = mid-parent stature in centimetres, and SA = skeletal age and was used to calculate relative stature. Chronological age was substituted for skeletal age, a procedure that is acceptable when X-ray determination of skeletal age can not be justified (Roche et al., 1983). Tables XXVII and XXVIII in Roche et al. (1975) provided the beta coefficients (βo, βrl, βw, βmps and βsa) for boys and girls separately for each month of age.

Appendix I

Instructions for Actometer Removal

Actometer Instructions

A. Please leave the recorders on child as much as possible. It may be necessary to remove one or more of the recorders for dressing and undressing child. The recorders aren't waterproof, so be sure to remove them for baths. It is also very important for us to know of times when a recorder is off each child, so if you find it necessary to remove one or more of the recorders:

1) On the attached sheet note the time of day (not the time on the recorder itself) when each recorder is removed and re-attached.

2) Be sure to re-attach each recorder on the arm or leg from which it was removed. They are color-coded so you can check the attached sheet to see which recorder goes on which limb.

3) Be sure the recorder is snugly fastened on the <u>outside</u> of the wrist or ankle just above the wrist joint or ankle bone.

B. The recorders aren't fragile so you can treat your child as you normally do.

C. If your child is unable to attend daycare or his or her afterschool program for the 24-hour watch removal, we would like you to remove the recorders at the suggested time listed on the attached sheet (or as close to this time as practical). Record the actual time of removal and store the recorders in a place where they won't be disturbed until we can collect them.

If you are uncertain about what to do, please call us at 474-6955.

or

Darren Campbell at Home: 284-3066

If You Remove a Watch, Record the Times on This Sheet

Make a check mark in the column for any watch removed		Time of day in hours and mins		Date	Comments *Remember to return the watch to the same limb (the colored circle on the watch matches the labels to the left).*
Arm	Leg	Removed at (hh:mm)	Replaced at (hh:mm)		

In case your child is unable to return to the daycare/afterschool program within 24 hours.

Remove the Watches for the Final Time

If possible, try to remove the watches at ____________ on ______________.

If you forget or if that time is inconvenient, remove the watches as close to that time as possible.

Actual time of final removal: _____:_____ am/pm (circle one).

Once the watches are removed, keep them where they will be undisturbed.