Physical Maturity and Information Processing Speed in Middle Childhood

by

Kathryn F. M. Ritchot

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PHYSICAL MATURITY AND INFORMATION PROCESSING SPEED IN MIDDLE CHILDHOOD

BY

KATHRYN F.M. RITCHOT

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

MASTER OF ARTS

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ABSTRACT

As children grow older, the speed with which they process information increases. This increase in speed has been demonstrated on a number of tasks, such as simple classification (e.g., Akhtar & Enns, 1989), mental rotation (e.g., Kail, Pellegrino & Carter, 1980), reading (e.g., Lorch, Lorch, Gretter, & Horn, 1987), visual search (e.g., Gitomer, Pellegrino & Bisanz, 1983), and picture and name matching (e.g., Bisanz, Danner, & Resnick, 1979), and is constant across tasks that have little in common (Kail, 1991). It has been proposed that this developmental increase in processing speed may reflect underlying maturational changes (e.g., Kail, 1986; 1988; 1991; Hale, 1990). To test whether greater physical maturity would covary with greater processing speed, relative stature (an index of general physical maturity) was determined for 66 female and 68 male 10-year-olds, and the early and late maturers (the upper and lower quartiles of the maturity distribution) were tested individually on 4 information processing speed tasks. Although there were no differences in performance between the early and late maturing females, the early maturing males outperformed their less mature agemates, and the hypothesis of a maturity-speed association received partial support.

INTRODUCTION

Information processing speed is generally considered an index of efficiency of mental processing because, presumably, those persons who can process information more rapidly will process, and thus acquire, more information in a given time period (Bjorklund & Harnishfeger, 1990). In fact, it has been suggested by Vernon (1983) that differences in IQ result from differences in information processing speed. As children grow older, the speed with which they process information increases. This increase in speed has been demonstrated on a number of tasks, such as simple classification (e.g., Akhtar & Enns, 1989), mental rotation (e.g., Kail, Pellegrino & Carter, 1980), reading (e.g., Lorch, Lorch, Gretter, & Horn, 1987), visual search (e.g., Gitomer, Pellegrino & Bisanz, 1983), and picture and name matching (e.g., Bisanz, Danner, & Resnick, 1979). A recent meta-analytic review by Kail (1991), has established that this increase in speed is constant across tasks that have little in common.

Two specific studies will be examined here as examples of this phenomenon. First, Kail (1986) tested a sample of 12 different age groups, ranging from 8 to 21 years. The participants performed two information processing speed tasks, mental rotation and name retrieval. With increasing age, speed increased on both tasks at a similar rate. Further, the 14-year-old group performed at a similar rate to the adult group. This result suggested that

asymptotic levels of performance may be reached at or about the age of 14 years.

A second example of this phenomenon comes from Hale (1990). In her study, 4 age groups (10-, 12-, 15-, and 19-year-olds) were tested on four speeded tasks: 1) letter matching - on the basis of name identity, 2) two-choice alternative reaction time, 3) abstract matching, and 4) mental rotation. It was found that processing speed increased across all of the tasks at a constant rate up to the age of 15 years. Hale considered this increase in speed lawful and she found that, "By plotting each child group's performance on ell four tasks as a function of the young adult group's performance in the corresponding task condition, precise linear functions were revealed..." (p. 653). The 12-year-olds were two thirds as fast as the 19-year-olds and the 10-year-olds were half as fast as the 19-year-olds. There were no differences between the 15- and 19-year-olds. Thus, Hale's (1990) data confirmed Kail's (1986) data in two ways. First, that lawful increases in speed occur with age across multiple tasks and, second, that asymptotic levels of performance were reached at or about the age of 14 years. In fact, Hale concluded that with age differences of this consistency, age-specific null hypotheses of the expected size of differences in reaction times could replace null hypotheses of no age difference.

These two studies are of importance because both found that information processing speed not only increased with age, but that speed increased at a constant rate across a variety of tasks. To explain the constant rate of

improvement in performance, these two researchers argued that there must be an underlying mechanism, or some general (i.e., not task specific) factor that is responsible for increases in processing speed. Following these two studies, Kail (1991) performed a meta-analysis "... to provide a more robust test of this claim..." (p. 491). The results of this meta-analysis were consistent with the view that a general factor underlies developmental changes. That is, children and adolescents' reaction times became faster as a function of age across a variety of tasks. Further, the results showed that speed increased substantially in early and middle childhood and more slowly thereafter (Kail, 1991).

This general speed factor, which has been proposed to be responsible for lawful age-related increases in speed, might be explained in terms of an absolute increase in the quantity of processing resources available to execute speeded tasks (Kail, 1991). Such an increase in the quantity of resources might occur in one of two ways. First, a functional increase in resources, would occur if the absolute quantity of resources remains constant throughout development, but as increased automaticity develops with age, more resources are available for non-automatic processes. Second, "... the absolute quantity of resources increases with age, reflecting underlying maturational change (Kail, 1991, p. 498). Developmental increases in processing speed have been linked to maturational changes by others, such as Wickens (1974), who reviewed several studies of age differences in speeded performance and, "...tentatively

concluded that some irreducible maturational differences in processing rate are present..." (p. 739).

When Kail (1991) suggested that an absolute increase in processing resources might occur with increasing maturity, he did not specify what these maturational changes might be. However, increasing maturity might cause structural change within the brain. This structural change might be of the sort Bjorklund and Harnishfeger (1990) have suggested, namely, that greater processing speed might be due to myelinization. Myelinization, they argue, is "... a good candidate for mediating changes in speed of processing....The evidence of a relation between myelinization and speed of processing is correlational, but, we believe, compelling" (Bjorklund & Harnishfeger, 1990, p. 60-61). Thus, myelinization, or other structural changes that occur within the brain could be responsible for a general factor that underlies age-related changes in speed of processing.

Similarly, but from a broader perspective, Miller (1989) has linked physical maturation and cognitive developmental changes. She suggested that there is an implicit belief amongst information-processing theorists that nature and nurture are both responsible for developmental change in humans. On the nature side, she has suggested that "...neurological development increases the efficiency of the transmission of neuronal impulses..." (p. 320). She goes on to state that, "There has not been much interest, however, in studying the role of

physical maturation in information processing" (Miller, 1989, p. 320). This lack of attention to maturation is illustrated in the case of processing speed.

Though research on this hypothesis in the information processing tradition has been minimal, research in the individual differences and psychometric tradition has linked maturation to cognitive performance. For example, several studies have found that individuals who are more physically mature for their chronological age are likely to perform better on mental ability tests than are their less mature agemates. This link has been detected from early ages through to puberty. After reviewing several studies, Tanner (1962) concluded that:

> Children who are physically advanced for their age do in fact score higher in mental ability tests than those who are less mature, but of the same chronological age. The difference is not great, but it is consistent, and occurs at all ages that have been studied; that is as far back as 6.5 years. (p. 211)

The relation between individual differences in physical maturity and cognitive ability has also been detected in children prior to the age of 7 years. In a study by Pollit, Mueller, and Liebel (1982), a group of 3- to 6-year-olds, (mean age 49 months) who were more physiologically mature, as defined by weight-for-height criteria (the percentage of weight for a given height percentile) were also more advanced in mental development. In a similar vein, Bayley (1956), in the Berkeley Growth Study Data, found the correlation between

skeletal maturation and intelligence scores tended to be positive from about the age of 10 years until skeletal maturity was reached, a period encompassing the major events of puberty.

The relation between timing of puberty and cognitive abilities was assessed more recently with a meta-analytic procedure by Newcombe and Dubas (1987). In the studies surveyed, several different measures were used to assess physical maturity, and these included: menarcheal age, peak height velocity (PHV), skeletal age, and pubic hair development. Cognitive abilities were assessed on a wide assortment of mental ability tests, including the WISC-R, Raven matrices, Binet, Otis, and the Stanford-Binet. This meta-analysis revealed a small (effect size between .22 and .24) but reliable advantage for early maturers on general mental ability. Although the focus of the Newcombe and Dubas study was on timing of puberty, the advantage was apparent before puberty in some of the studies surveyed. Thus, a consistent positive relation between maturational status and performance emerges on tests of general cognitive ability.

The linkage of individual differences in maturational level to differential performance on general measures of cognitive performance is consistent with the hypothesis that maturation is a 'general factor' that underlies age-related improvement in cognitive performance. More specifically, these findings suggest that structural changes within the brain that are linked to maturity might also account for increases in speed of processing.

This is not to say that physical maturation is the only factor involved in differences in cognitive performance. Kail's (1991) functional increase in resources explanation (that with increasing experience comes greater automaticity causing an increase in the absolute quantity of processing resources) may be another contributing factor to age-related increases in processing speed. It is interesting to note that Case (1978) has suggested that either general experience or maturation might be responsible for increases in automaticity. These two variations of an increase in absolute quantity of resources explanation could work together. That is, at some points in development, and with certain cognitive tasks and/or abilities, biological changes might play a dominant role in accounting for age-related changes, while at other points in development, experiential factors might be more dominant. These experiential factors could account for age differences in terms of a functional explanation or in terms of differences between age groups in strategy use.

Although a recent study by Eaton and Speed did not look specifically at processing speed, their results have a bearing on this issue (Eaton & Speed, 1990). They examined the relationship between physical maturity and performance on two tests related to verbal ability. They tested a group of prepubertal children to examine whether physical maturity would be related to sex differences on two tests related to verbal skills, a Sound Mimicry test and a Reading of Symbols test. In the Sound Mimicry test, the participant was

required to repeat recorded nonsense words, which were used to simulate hearing a new word for the first time. The second test, Reading of Symbols, is a test of word attack skills. In this case the participant was presented with nonsense words printed on cards and was required to read the words aloud.

Eaton & Speed (1990) found that maturation was related to Sound Mimicry test performance even after the effects of chronological age on performance had been removed. However, for the Reading of Symbols test, chronological age predicted performance though relative physical maturity differences did not. These data provide evidence that performance on the two tasks reflect different underlying processes. Sound Mimicry test performance was linked to maturational differences, but Reading of Symbols task performance was linked to an experiential factor that accompanies chronological age, that is, years in school. Because relative stature was not related to performance for the Reading of Symbols task, performance on this task might better be explained in terms of Kail's (1991) 'functional' increase in processing resources. The 'functional' explanation suggests that with sufficient experience, some components of a task, like reading nonsense words may be executed automatically. On the other hand, Sound Mimicry performance might be best explained in terms of a 'structural' increase in processing resources explanation. In any case, the Eaton and Speed results provide evidence for a maturation-performance link in middle childhood.

A general developmental process such as maturation cannot be experimentally manipulated to test a hypothesis. However, individuals vary considerably in 'tempo of growth,' or rate of maturation, and variability in level of maturation could be compared to variability in cognitive performance to see if the hypothesized covariance between maturation and performance exists. This covariance strategy is used in the present study.

Some children have an accelerated growth rate when compared to the norms at any given chronological age, while others have a retarded growth rate. Generally, after about the age of three years, a child's rate of growth will remain either retarded or accelerated throughout their growth process (Tanner, 1978). Thus, at any given age level, children whose development is accelerated are closer to their adult statures than normal children are to their adult statures, and these accelerated children are considered relatively more physically mature. Likewise, those children with a retarded growth rate, at any given CA, are further away from their adult statures than the norm and are considered less physically mature. If physical and cognitive development share underlying processes, children who are delayed in physical development may be those who are delayed in cognitive development.

Because a link has been detected between physical maturity and performance on the Sound Mimicry task and more global cognitive measures, and because a general factor, linked to maturation, might be responsible for lawful age-related increases in information processing speed, the present study

was designed to examine specifically whether a link exists between maturation and processing speed. Thus, the present research examined whether the general factor proposed by many information processing theorists (e.g., Kail, 1986; 1991; Hale, 1990) to account for increases in processing speed across tasks, is related to underlying maturational changes. The relation between information processing speed and relative physical maturity was examined by testing early- and late-maturing children on information processing speed tasks and comparing their performance. To minimize the confounding of physical maturity and chronological age, the sample of children was limited to those who were all in the same grade in school. Thus, the very general experiential factor, school exposure, which was predictive of performance on the Reading of Symbols test in the Eaton and Speed (1990) study, was held constant.

Ten-year-old children, all in the fourth grade, who were the most physically mature *[earlies]* and the least physically mature *[lates]* as determined by relative stature (an index of physical maturity from Roche, Wainer, & Thissen, 1975), performed four information processing speed tasks adapted from Hale's (1990) study. Hale's (1990) tasks were selected, and are described in the Method section, because they sampled a broad range of latencies. The tasks included: 1) abstract matching, 2) letter matching, 3) mental rotation, and 4) choice reaction. Although all of these tasks contain a time component, each taps unique cognitive abilities. For example, the abstract matching task is a concept formation task which can be solved with one display, and was adapted

from Hoyer, Rebok and Sved (1979), and was designed to measure selective attention. The letter matching task was designed to study the cognitive processes involved in simple classification, and task performance has been linked to individual differences in reading (e.g., Jackson & McClelland, 1979). Mental rotation task performance is considered a measure of spatial ability (e.g., Linn & Petersen, 1985), and according to Hale (1990), the choice reaction time task was selected to extend the range of information processing latencies sampled.

The major purpose of the present paper was to determine whether children who are early maturers will perform more quickly on four information processing tasks than those children who are late maturers. If the early maturers perform more quickly than late maturers, it will provide support for the idea that the general factor that has been proposed to explain age-related increases in information processing speed is linked to physical maturation. Because females have a more rapid 'tempo of growth' or rate of maturation than males (Tanner, 1978), separate analyses by sex were necessary. Adults also performed the information processing speed tasks in order to compare their performance to that of the children. Such a comparison contrasts the children with a group that has presumably reached asymptotic levels of cognitive processing speed.

METHOD

Child Participants

Recruitment. After obtaining ethical approval from the University of Manitoba and the Lord Selkirk School Division, 203 Letters to Parents, Consent Forms, and Questionnaires (see Appendices A, B, and C) were sent to the parents of grade 4 students in 4 schools: Happy Thought (n = 66), St. Andrews (n = 87), Daerwood (n = 32), and Mapleton (n = 18). Follow-up contacts with the parents of students who did not return the consent form, were not made because school principals did not want the parents inconvenienced.

Permission and group membership summary. Of the 203 Letters that went out to the parents, 155 forms (76%) were returned, and of these, 144 (93%) of the parents granted permission for participation. Table 1 shows the permission summary by school.

Table 1. Permission Summary by School

School	(n) Sent	% Returned	% of "yes" of Returns
Happy Thought	66	67	89
St. Andrews	87	78	99
Daerwood	32	91	86
Mapleton	18	78	93
Total	203	76	93

The mean CA for the base sample (n = 144) was 9.9 years (SD = 0.3). The mean CA in years for the males (n = 75) was 10.0 years (SD = 0.3), and the mean for the females (n = 69) was 9.8 (SD = 0.3). Relative stature was estimated for 134 (66 girls and 68 boys) of the 144 students in the base sample. Of the other ten, seven were absent on the day of measurement and three had missing data for biological parents' statures.

Once the children were weighed and measured, relative stature was estimated. From that estimate, the *maturity groups* were established by selecting the extreme quartiles. Children in these extreme groups then individually performed the computer tasks in their schools.

Adult Participants

After obtaining ethical approval, a group of 16 female and 17 male University of Manitoba undergraduate psychology students participated for course credit.

Equipment and Materials for Children

Scale and anthropometer. Heights were measured using a free-standing GPM anthropometer. Participants were weighed on a digital scale (Thinner model HW 105). The heights were measured by the primary examiner, and most of the weights were taken by an assistant.

Handedness/computer game exposure questionnaire. A Handedness Questionnaire and questions about the amount of time participants spend playing video and computer games (Appendix C) was included on the reverse

side of the Consent Form (Appendix B). The Handedness Questionnaire information was used to determine whether a left-handed letter matching task or a right-handed letter matching task would be used (the difference in the tasks will be clarified in the Letter Matching Task section). Data on the participants' video/computer game exposure, which was also included on the questionnaire, was gathered to determine if prior exposure to video games would covary with information processing speed.

Materials for Adults

The adults were also asked about their hand preferences (see Appendix D), but were not asked about video and computer game exposure.

Tasks for all Participants

Computer programs. Stimuli for each of the four computer tasks were presented on an IBM-compatible microcomputer running MEL (Micro Experimental Laboratory) programs, a system marketed by Psychology Software Tools, Inc., and used to create experiments to be run on computers. These MEL programs were constructed based on Hale's (1990) computer tasks and were used to display the information processing tasks and to record response accuracy and latencies (1 ms accuracy). The response panel consisted of a standard Qwerty computer keyboard. The *m* key was marked with a red tab and was considered the right response key. The *z* key, located just above the left end of the space bar, was marked with a blue tab and was

considered the left response key. The space bar was used by the participant to signal the program to move from one trial to the next.

Information processing tasks order. Hale (1990), administered the four computer tasks in the following order: 1) letter matching task; 2) mental rotation task; 3) two-alternative choice reaction time task; and 4) abstract matching task. Hale (1990) used this order so that the participants would not proceed from the easiest to the most difficult. She suggested that this order minimized any biases due to factors such as practice and fatigue. However, for this study, the tasks were presented in all possible orders to guard against the possibility of one predetermined task order differentially effecting the maturity groups. Thus, any given participant was exposed to one of the 24 possible task orders. For all tasks, practice trials occurred prior to the experimental trials to familiarize the participant with the procedure. The mental rotation and the abstract matching tasks had training trials prior to the practice session so that the examiner could ascertain whether the participants understood the tasks.

In all four tasks, the left and right responses were counterbalanced. Stimuli in each task were presented in pseudo-random sequence with the provision that there were no more than three consecutive trials of any one response type. The four tasks were comparable to, but not identical with, the ones used in Hale (1990), and are described in the following sections.

Letter Matching (Letters)

The stimuli for this task consisted of five letters (*Jj, Dd, Ff, Rr, Hh*) displayed two at a time in either upper or lower case. Each letter presentation consisted of simultaneous presentation of two forms of the same letter or of two different letters. If the participant was right-handed (91% of children and 82% of adults), he or she was required to press the right response key if the letters were the same letter of the alphabet (whether or not they were both in the same case) or the left response key if the letters were different (whether or not they were both in the same case). If the participant was left-handed, he or she was required to press the left response key if the letters were the same and the right response key if the two letters were different.

Each participant performed six practice trials and 80 experimental trials which consisted of 20 pairs of identical letters (counterbalanced across letters and upper/lower case combinations), 20 pairs of the same letter in different cases (10 pairs with upper case first and 10 with lower case first), and 40 non-identical letter pairs (10 consisted of two upper case letters, 10 of two lower case letters, 10 with the upper case letter first, and 10 with the lower case letter first).

Mental Rotation (Flags)

In this task, the participants were presented with one of two schematic flags (see Figure 1). One flag had asterisks in the upper right-hand corner (right flag) and the other had asterisks in the upper left-hand corner (left flag).

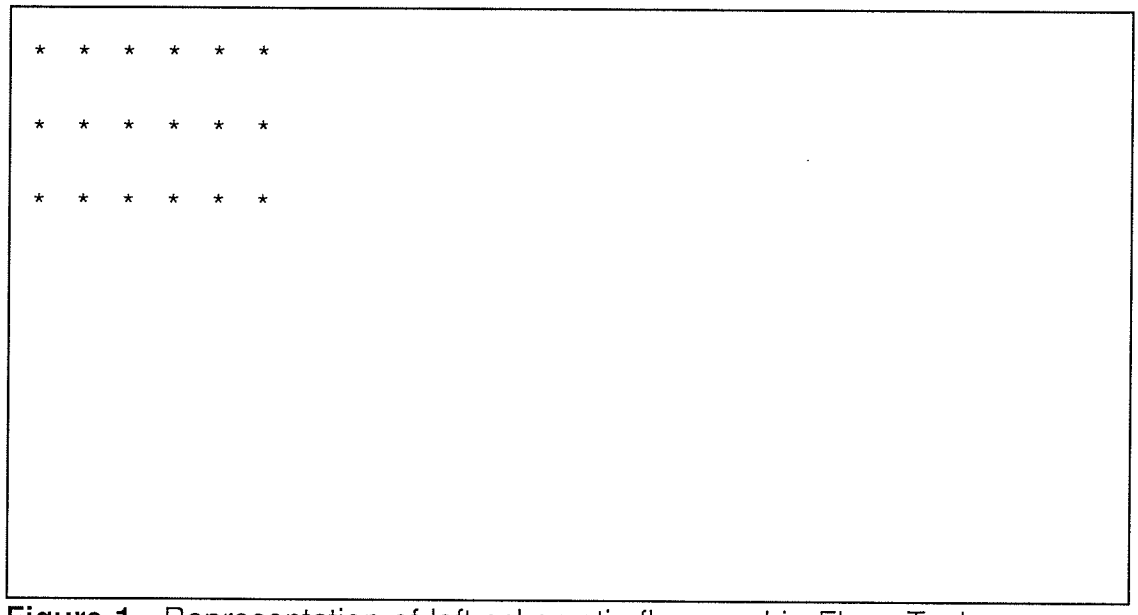

Figure 1. Representation of left schematic flag used in Flags Task.

Each of these flags was presented in one of three orientations: a) upright (i.e., turned 0° clockwise), b) turned 90° clockwise or, c) turned 180° clockwise. The participants were required to determine whether the right flag or the left flag was presented. If the left flag was presented they were required to press the left response key. If the right flag was presented they were required to press the right key.

This task was the same as Hale's (1990) rotation task except that Hale's 270° orientation was omitted. Hale (1990) found that responses to the 90° and 270° presentations were very similar, which suggested that subjects were using counter-clockwise rather than clockwise rotations when confronting the 270° problem. Thus, the 270° presentation was uninformative and was omitted.

There were several training trials prior to the practice trials: The experimenter had a card with the left flag on it and a card with the right flag on

it. These flags were first shown to the participant in their upright position.Next the left flag was displayed upright and alone, and the examiner said, "sometimes you will see the flags in their normal position, but sometimes they will be on their side, and sometimes upside down." The flag was rotated and shown to the participant in both the 90° and 180° positions. The examiner then returned the card to its upright orientation by reversing the rotation and suggested that the participant had to rotate the flag but "in your head, without moving your head", to facilitate correct responding.

The participant was given several training trials (three training trials were intended, but training was given until the participant could correctly respond to three in a row). In the training trials the examiner held up the flags (one at a time) in three different orientations and asked which key was required for each orientation. Following the training trials, there were six practice trials and sixty experimental trials (10 trials of each flag type in each of the three orientations).

The data from each rotation condition (0°, 90°, and 180°) were intended to be analyzed separately for both the left and right handed responses. However, an error in the computer program for this task prevented the identification of the rotation condition on each trial. Without information on degree of rotation it was impossible to calculate speed of mental rotation by comparing latencies for different rotations. Nevertheless, the program did accurately log the reaction times for left and right flags individually. Thus, these

flags data, although not as informative as intended, acted as another measure of choice reaction time.

Choice Reaction (Arrows)

As in the Hale (1990) choice reaction time task, one of two "arrows" [<,>] was presented to the participant, who was required to press the right response key if the arrow pointed to the right and the left response key if the arrow pointed to the left. There were a total of four practice trials and forty experimental trials (consisting of 20 arrows pointed in each direction).

Abstract Matching Task (Matching)

This task is a concept formation task that can be solved in one screen. Like the other tasks, it was a replication of one used by Hale (1990), who adapted it from Hoyer et al. (1979). The stimuli for this task consisted of three different displays of letters, two comparison displays and one standard display. Three dimensions could be varied in these three displays: 1) shape, that is, the actual letter presented [*o*, *v*, or *x*], 2) number of letters presented [2, 3, or 4], and 3) orientation [vertical, horizontal, or diagonal]. The participant was required to compare the right display and the left display with the standard display, centered below, to choose the best match to the standard.

In any given problem, only one of the three dimensions was relevant to the solution of the problem. The participant was required to scan the displays to determine which of the dimensions was relevant to determining the best match. Two types of problems were presented: In Level 1 problems, one of

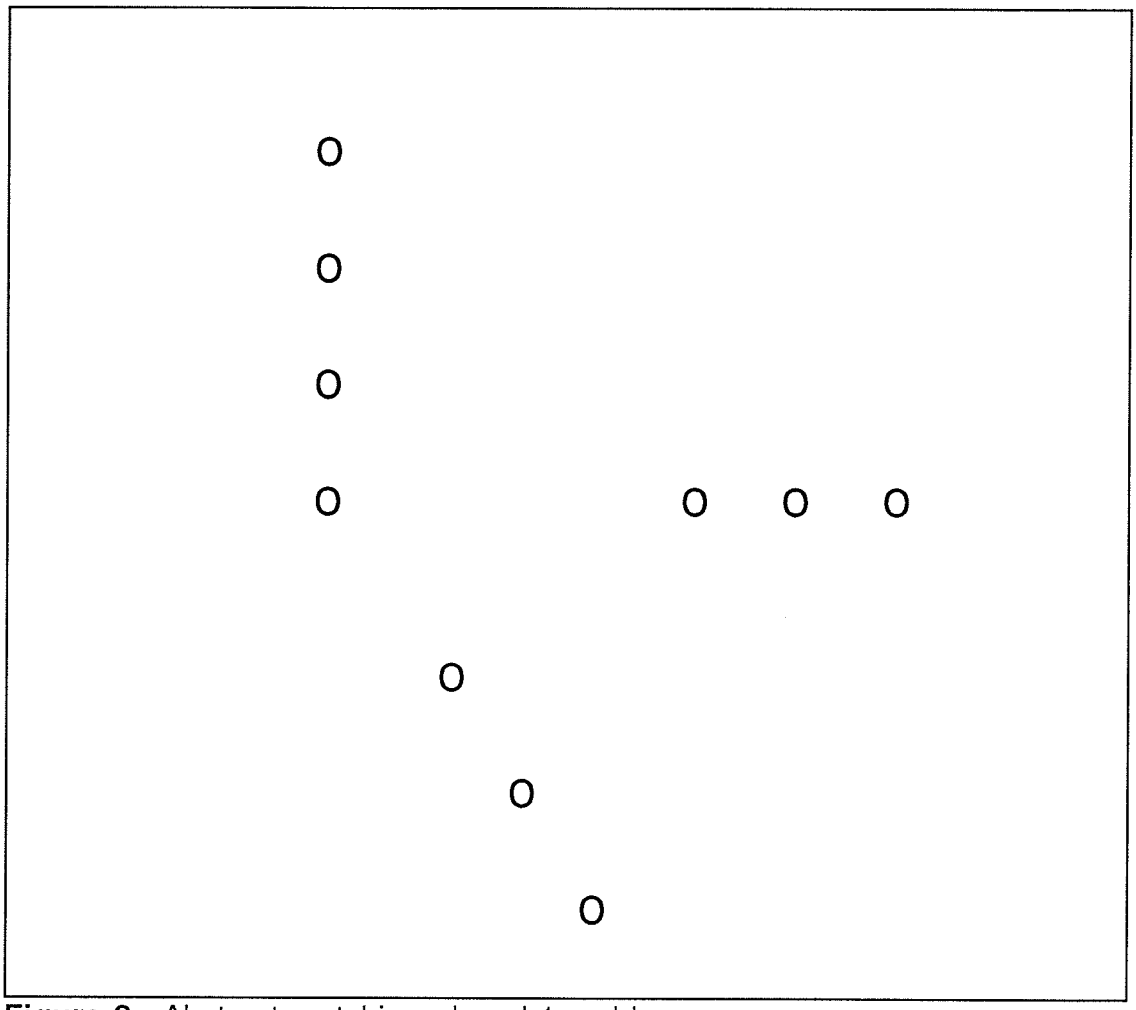

Figure 2. Abstract matching: Level 1 problem

the irrelevant dimensions is held constant across all displays and the other irrelevant dimension is varied (see Figure 2). Here, shape is held constant (all display the letter o), orientation is varied, and the correct match is made on the basis of number. Another example of a Level 1 problem can be seen in Appendix E. In the Appendix E example, orientation is held constant and the best match is made on the basis of shape. In Level 2 problems, both irrelevant dimensions are varied (see Figure 3). Here both the irrelevant dimensions, shape and number, are varied and the correct response is made based on

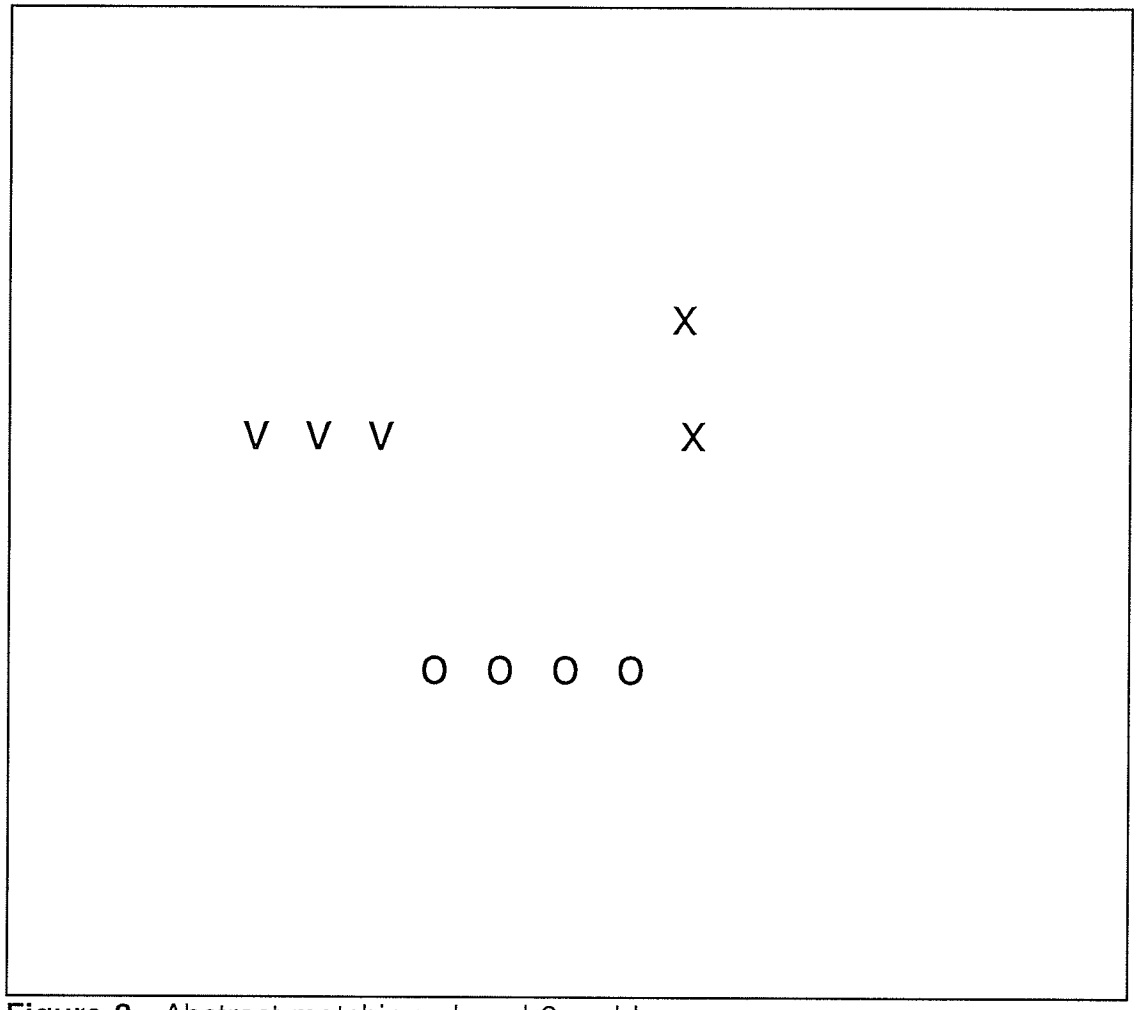

Figure 3. Abstract matching: Level 2 problem orientation.

The participant was required to determine whether the left display or the right display was the most similar, or the best match, to the display appearing at the bottom of the screen. They pressed the right response key if the right display was the most similar to the bottom pattern or the left response key if the left display was the most similar to the bottom pattern. In the Level 1 (Figure 2) example, the correct answer is the right response, and for the Level 2 (Figure 3) problem, the correct answer is the left response.

The participants were told that, in this task, decisions had to be made on the basis of either the shape of the characters (the letter itself), the orientation of the characters, or the number of characters in any presentation (see Appendix F for specific instructions). The examiner began by showing the subject the first problem on a piece of paper (see Appendix E). The participants were asked which pattern (right or left) was the most similar to the bottom one. They were required to explain their decision and were told whether their answer was correct or incorrect. The examiner then explained why one alternative was correct and the other was wrong. Next, participants performed six training trials on the computer. They were required to explain their reasons for each choice to the examiner. If the participants had any problems with reasoning, the examiner corrected this in an attempt to ensure the participants' understanding. Following this, each participant performed 4 practice trials and 36 experimental trials (18 trials of Level 1 and 18 of Level 2).

PROCEDURE

Children's Physical Measurements

To estimate relative stature, each child's height and weight were measured during the physical education class of each participating classroom. The examiner went into the 30-minute physical education class of the first participating classroom and was only able to weigh and measure 10 children. Because the other classes were too large to measure in a 30-minute period, an assistant was enlisted to speed the procedure.

For the remaining eight classes, anthropometric measurements were taken during each class's physical education period by the primary examiner, and weights were taken by an assistant. For the anthropometric measurements, the participants were instructed to remove their footwear and stand with their backs toward the anthropometer, heels together, hands at their sides. They were told to look straight ahead and to take a deep breath just before the measurement reading.

Each participant's weight was measured directly after the height readings were taken, so each participant had already removed his or her footwear. The assistant touched the scale with her foot and then advised the participant to get on the scale when it showed "0000". The participants were instructed to look up and not to touch the wall while the measurement was being taken. Both the height and weight measurements were taken twice in order to ensure accuracy. If the first two measurements (for either the height or weight) were highly discrepant, the child was asked to be measured a third time, and the two measurements closest to each other were used.

Children's Relative Stature Estimates

Relative stature (RS) as an index of physical maturity is the ratio of a child's current stature to predicted adult stature, as described by the following formula:

$$RS = 100 \times (\text{current stature} / \text{adult stature}).$$

The Roche, Wainer, and Thissen formula (R-W-T formula) (Roche et al., 1975) for predicting adult stature is as follows:

$$PS = \beta_0 + \beta_{rl}(RL) + \beta_w(W) + \beta_{mps}(MPS) + \beta_{sa}(SA),$$

where PS = predicted adult stature in cm, β = beta coefficients, β_0 = the intercept, 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. Recumbent length was not taken, therefore, it was estimated by adding 1.25 cm to stature (Roche et al., 1975). Chronological age was substituted for skeletal age, a procedure that is acceptable when X-ray determination of skeletal age can not be justified (Roche, Tyleshevski, & Rogers, 1983). Tables 27 and 28 in Roche et al. (1975) provided the beta coefficients (β_0, β_{rl}, β_w, β_{mps} and β_{sa}) for boys and girls separately for each month of age.

Each child's height and weight were combined with the information obtained from the Consent Form (Appendix B), which includes the following: the child's birth date, sex, and biological parents' statures. According to Himes and Roche (1982), parents tend to slightly overestimate their actual heights, but the resulting increase in the child's predicted adult stature is very small (approximately 2 mm for a 10-year-old girl). Presumably, any overestimation would have occurred across the sample and, therefore, should not effect the hypotheses regarding the relationship between relative stature and information processing speed.

Maturity Group Assignment

Once the relative stature of each participant was estimated using the R-W-T (Roche et al., 1975) formula, the *early* and *late* maturity groups (the top and bottom quartiles respectively) for each sex were identified. For the female distribution, 16 girls fell into the upper quartile and 16 into the lower. For the males, 17 boys fell into the upper quartile and 17 into the lower. Once the maturity group assignment was completed, the members of the maturity groups (earlies and lates) performed the information processing tasks individually in their schools during a second session. As will be discussed in the next section, a pilot group and some other participants performed the information processing speed tasks as well. However, only the data from students within the extreme quartiles were used in the analyses.

Computer Tasks

Child pilot group. Four children who were in neither extreme quartile of the relative stature distribution were run as a pilot group on the first day of testing. This was done to give the examiner practice with the procedure and instructions, to estimate the amount of time each participant would take to complete the tasks, and to ensure that the computer programs were running as they should.

Other participants who performed the computer tasks. Because the relative stature distribution and the computer tasks were completed in the first two schools (Happy Thought and St. Andrews) before students' relative stature

from the third and fourth schools (Daerwood and Mapleton) were available, the cutoffs for the quartiles changed slightly. Therefore, students who were ultimately outside of$the upper and lower quartiles performed the computer tasks as well. Their participation ensured that the addition of new students from subsequent schools would not force us to retest in schools where the school administration had been told that the study was completed.

Data collection. The participants who had fallen into the upper and lower quartiles were listed alphabetically by name and classroom only. Thus, the examiner did not know the maturity group membership of the child at the time of task administration. This procedure was a sufficient safeguard for most of the children, with the exception of a few extremely small or extremely large participants. For these children, the examiner was able to guess, probably with reasonable accuracy, the individual's group membership and, therefore, was not always blind to maturity group membership.

The general procedure for the computer tasks began with the assistant escorting the participant to the computer room. The examiner then gave the participant basic instructions on the computer program, including instructions that speed and accuracy were both important. Specific task instructions were given prior to each individual task. Between the practice and the experimental trials for each task, the examiner re-emphasized the importance of both speed and accuracy (see Appendix F for examiner script).

All of the computer tasks began with the presentation of an asterisk in the centre of the screen as a fixation point. When the participant was ready to begin a trial, she or he was required to press the space bar, which resulted in the immediate presentation of the next trial. The correct response in all task conditions was either depression of the right or the left response key. For the Matching task, if the participant took longer than 20 seconds to respond, the asterisk reappeared on the screen. For the other three tasks, there was no time limit on the stimulus presentation. Once the participant solved each problem on the screen, the asterisk returned to the screen, and the participant began the next trial by pressing the space bar. For all four tasks, there was no limit on the length of time the asterisk would remain on the screen between trials, the intertrial interval was determined by the participant.

During the practice trials the participant was presented with either a *Correct* or *Wrong* message on the screen for 2 seconds after each response and before the fixation point returned. During the experimental trials, the subject received a *Wrong* message for 2 seconds when the answer was incorrect. If the answer was correct, however, the fixation point reappeared on the screen, until the participant initiated the next trial. The entire session took approximately 18-22 minutes for each child.

Procedure for Adults

The procedure for the adults was very similar to that for the children, with the following exceptions: 1) relative stature was not estimated on adults

because they were assumed to have attained physical maturity; 2) the adults completed their questionnaires just prior to performing the computer tasks; 3) after completing the computer tasks, they were given a debriefing form (Appendix G); 4) the adults performed the information processing tasks individually in a laboratory at the University of Manitoba; 5) the entire session for the undergraduates took approximately 15-18 minutes.

RESULTS

Participant Exclusion

In order to remain consistent with Hale's (1990) analyses, participants who had an error rate of over 30% in any given task (n = 3) were excluded from the statistical analyses. Two participants were excluded because their data was incomplete (data from one of the four tasks was missing due to a computer glitch). Because the modal age for the adult sample was 19 years (M = 21.6, SD = 4.4), two outliers on the age distribution (CAs of 37 and 36 years) were excluded from all of the tasks. Thus, for the adults, the final sample consisted of 15 males and 15 females. For the 10-year-olds, Table 2 summarizes the means and standard deviations for CA and relative stature. In order to assess the within-sex differences on relative stature, a t test was performed for each sex, on this variable. For both the males [$t(28) = -14.85$, $p<.0001$], and females [$t(28) = -14.68$, $p<.0001$], earlies were significantly different from the lates on relative stature.

Table 2. Mean Chronological Age and Relative Stature for the Final Sample -- Children Only

Maturity Group	n	CA	Relative Stature
		Males	
Earlies	15	10.2 (0.2)	79.6 (0.7)
Lates	15	9.6 (0.2)	75.9 (0.6)
		Females	
Earlies	16	10.0 (0.2)	85.9 (1.1)
Lates	14	9.5 (0.1)	80.8 (0.7)

Note: Standard deviations are in parentheses.

Data Preparation

Trials data. The correct and incorrect experimental trial data, [reaction time (RT) in ms], for each task, were initially examined for outliers. Some of the RT values were implausible. For example, a value of 32 ms (for Matching, M = 2599 ms) seemed too short to have occurred, except by accident. Similarly, an isolated RT of 5577 ms, which was 15.6 standard deviations from the mean for Arrows (M = 668 ms) suggested that the participant was not attending to the task during that trial. Therefore, the outlying values were truncated to the ninety-ninth and first percentiles, which meant that all values above the ninety-ninth percentile were given the value of the ninety-ninth value.

Similarly, all values below the first percentile were given the value of the first percentile. With this treatment, the outliers remained on the tails of the distribution but their distorting influence on mean values was reduced [see Eaton & Enns, (1986), for an application of this procedure].

After the outliers had been treated, the data were plotted and found to be quite skewed. Therefore the data were transformed to better meet the assumptions of normality. Each trial RT value was normalized by calculating the common (base 10) logarithm (Tabachnick & Fidell, 1989). Treated RTs were used in all further analyses.

Subject data. For each subject, a mean RT was calculated, from the accurate trials only, for each task. Then, for each task a grand mean RT was calculated from all of the subjects' mean RTs.

Relations Among the Dependent Variables

Between task correlations. Correlations between RTs on the four tasks were very high and are shown in Table 3. This level of intercorrelation is consistent with the contention that a general speed factor can account for much of the developmental increase in information processing speed.

Speed/accuracy tradeoff. Because the speed-accuracy relation is often examined in the information processing speed literature (eg, Kail, 1985), the correlations between speed and accuracy for each of the tasks were calculated to determine whether participants might have been trading off speed for accuracy. For each of the tasks, the correlation between RT and accuracy

Table 3. Task Intercorrelations

	Letters	Flags	Matching
Arrows	.81*	.84*	.70*
Letters		.84*	.74*
Flags			.82*

*$p<.0001$.

$N = 90$.

(number of trials correct) was calculated. In general, the correlations were quite low: .00, .05, -.22, and -.13, for arrows, letters, flags, and matching tasks, respectively, and the Flags task was the only one in which the correlation between speed and accuracy was significant ($p<.05$). Thus, in three of the four tasks, the relations between speed and accuracy indicated that, in general, under the instructional conditions of this study, speed was little influenced by strategy choices regarding accuracy and attention was directed at speed, the major focus of this research.

Other correlates. To assess whether exposure to video or computer games was related to speed of information processing, two indices of the 10-year-old participants' exposure to video games were taken and correlated with speed on all four tasks. The first was the parent-reported length of computer task exposure (measured in the number of years that had elapsed since an individual had begun to play video or computer games). Video exposure (in years) was nonsignificantly related to RTs for all of the tasks. The second

video measure was parent-reported amount of weekly exposure to computer games in hours. These weekly exposure data were initially skewed, and therefore the natural logarithms (base 2.72) of the data were used (Tabachnick & Fidell, 1989). Correlations between this variable and RTs were also nonsignificant. Thus, speed in these tasks was uncorrelated to amount of parent-reported child exposure to computer or video games.

Tests of the Hypotheses

Two orthogonal a priori contrasts were performed for each sex separately, using a multivariate analysis of variance procedure. The first compared the adults vs. the children (from both maturity groups), the second compared the earlies vs. the lates. For a graphic representation of the mean RTs for males, see Figure 4, and for females, see Figure 5.

The multivariate and univariate *F* statistics for all contrasts are shown in Table 4. For both males and females, adult performance was faster than 10-year-old performance generally, as well as on all four tasks considered individually. For male children, early maturers differed from late maturers, in general and on the arrows and letters tasks considered individually, where earlies performed faster than lates. Female early maturers did not differ from female late maturers either in general or on any individual task.

Supplementary Analysis of CA as a Covariate

Although the potential confounding of CA and relative stature was minimized procedurally by studying children in the same school grade and

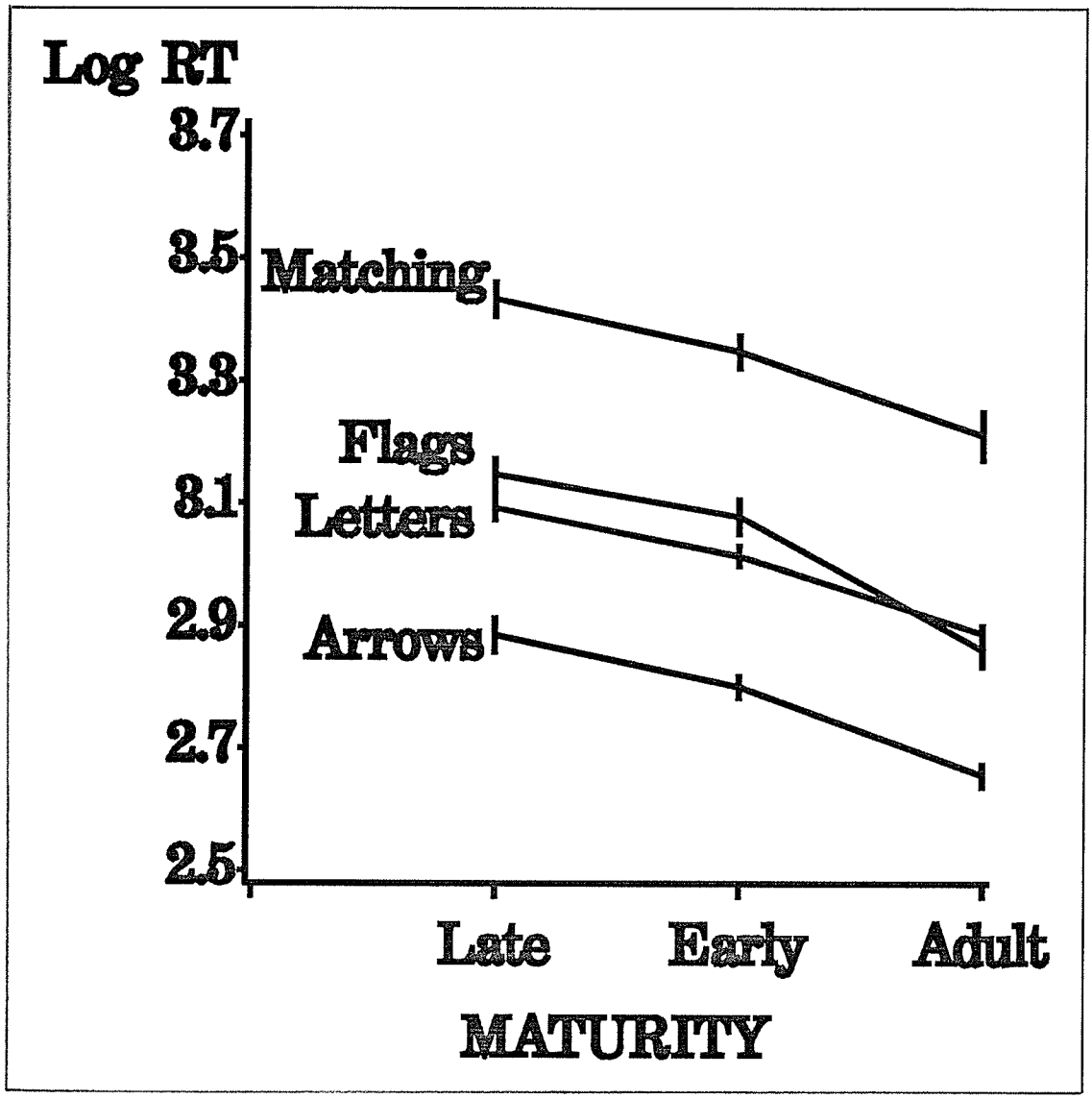

Figure 4. Mean RT (± SE) for each task by male maturity group.

within one year of age (Range = 1.08), the results of two t tests comparing the earlies and lates, for males [t(28) = -7.06, p<.0001] and for females [t(28) = -6.30, p<.0001] showed that, within each sex, the groups differed on CA. Thus, a concern arose that the RT differences might be due to differences in CA. Therefore, a multivariate analysis of covariance, with CA as the covariate, was

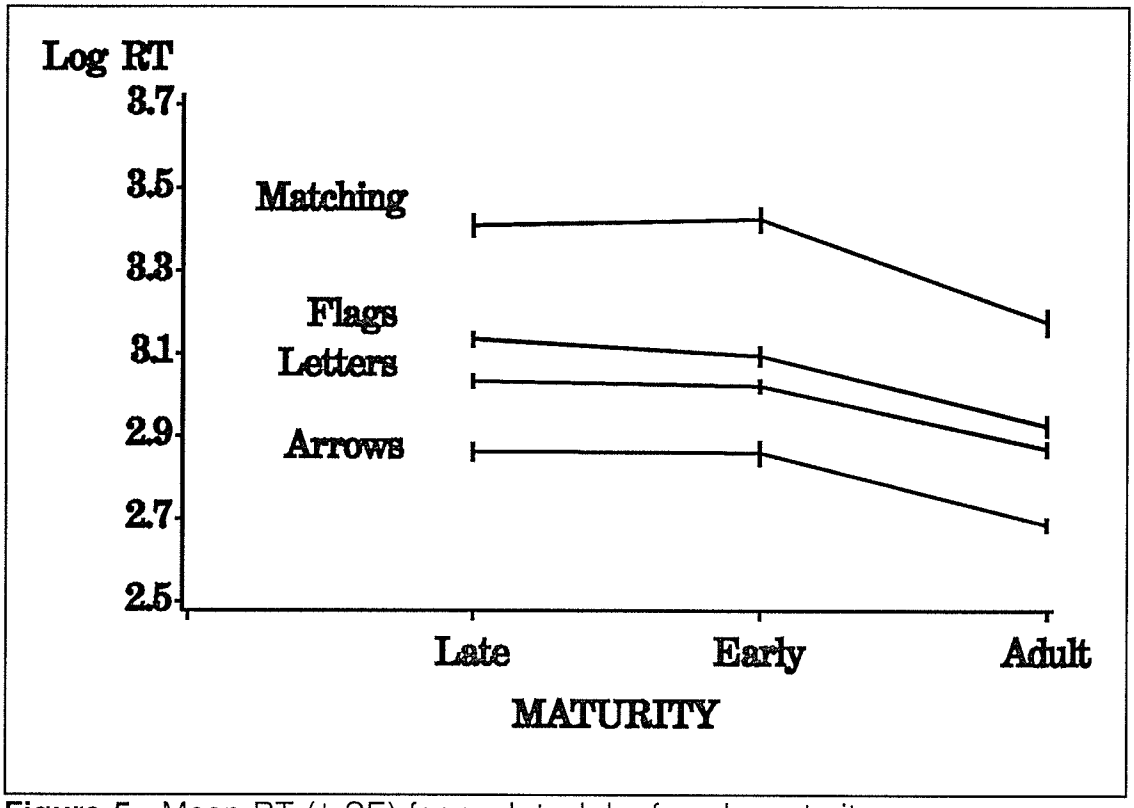

Figure 5. Mean RT (± SE) for each task by female maturity group.

performed on the RTs for the 10-year-old sample as a check of the main analysis. The F statistics are reported in Table 5 for this analysis, and the CA-adjusted means are presented in Table 6.

After CA was covaried for the males, the multivariate F approached significance ($p<.12$), with the earlies' adjusted RTs being faster than the lates' RTs. The univariate F statistics remained significant for the Arrows ($p<.01$), Letters ($p<.05$), and became significant for the Flags ($p<.05$) task. The early and late maturing females differed in general on age-adjusted reaction time. However, although the overall difference between the early and late maturing females is significant, all individual tasks were nonsignificant and an inspection

Table 4. F Statistics for Planned Maturity Group Comparisons by Task

Contrast	Multivariate[a]	Univariate[b]
	Males	
Adults vs. Kids	16.72***	
Arrows		46.12***
Letters		58.70***
Flags		55.47***
Matching		20.58***
Earlies vs. Lates	2.84*	
Arrows		6.96*
Letters		9.84**
Flags		3.08
Matching		3.45
	Females	
Adults vs. Kids	18.40***	
Arrows		40.48***
Letters		63.16***
Flags		52.25***
Matching		46.90***
Earlies vs. Lates	1.70	
Arrows		0.01
Letters		0.27
Flags		1.81
Matching		0.13

*$p<.05$. **$p<.01$. ***$p<.0001$.

[a]df = (4, 39). [b]df = (1, 42).

Table 5. F Statistics for Maturity Effect by Task with CA as a Covariate -- Children Only

Comparison	Multivariate[a]	Univariate[b]
	Males	
Earlies vs. Lates	2.07	
Arrows		7.38*
Letters		6.37*
Flags		5.69*
Matching		2.45
	Females	
Earlies vs. Lates	3.93*	
Arrows		2.19
Letters		0.15
Flags		0.64
Matching		0.30

*$p<.05$.

[a]df = (4, 24). [b]df = (1, 27).

of the means in Table 6 shows that the direction of the effect was inconsistent across the tasks. Thus, the overall picture remains the same after covarying CA -- the early males are faster than the late males, but there are no consistent differences in RT between the two maturity groups for the females.

Heuristic Analysis with Composite Reaction Time

This last analysis of the data was intended to help with hypothesis generation. Because the four tasks were so highly intercorrelated, the four RT

Table 6. CA-Adjusted RT Means and Standard Errors of Maturity Groups for all Four Tasks

Maturity Group	Task			
	Arrows	Letters	Flags	Matching
		Males		
Earlies	2.77 (0.03)	3.00 (0.03)	3.04 (0.04)	3.34 (0.04)
Lates	2.92 (0.03)	3.11 (0.03)	3.19 (0.04)	3.44 (0.04)
		Females		
Earlies	2.89 (0.03)	3.03 (0.02)	3.09 (0.02)	3.43 (0.04)
Lates	2.82 (0.03)	3.02 (0.02)	3.13 (0.03)	3.40 (0.04)

Note: Standard errors are in parentheses.

scores were summed using a unit weighting procedure. This procedure involves simply adding the RTs on all four tasks together (see Cohen, 1990). Thus, to aid in understanding the results of this study, a composite RT score was created for this analysis to examine the relation between relative stature and information processing speed. Orthogonal a priori contrasts were performed for each sex separately, using an ANOVA procedure. The first contrast compared the adults to the children from both maturity groups and the second contrast compared the early and late children. The adults performed faster than the children, $F(1, 42) = 58.26$, $p<.0001$, for males, and $F(1, 42) =$

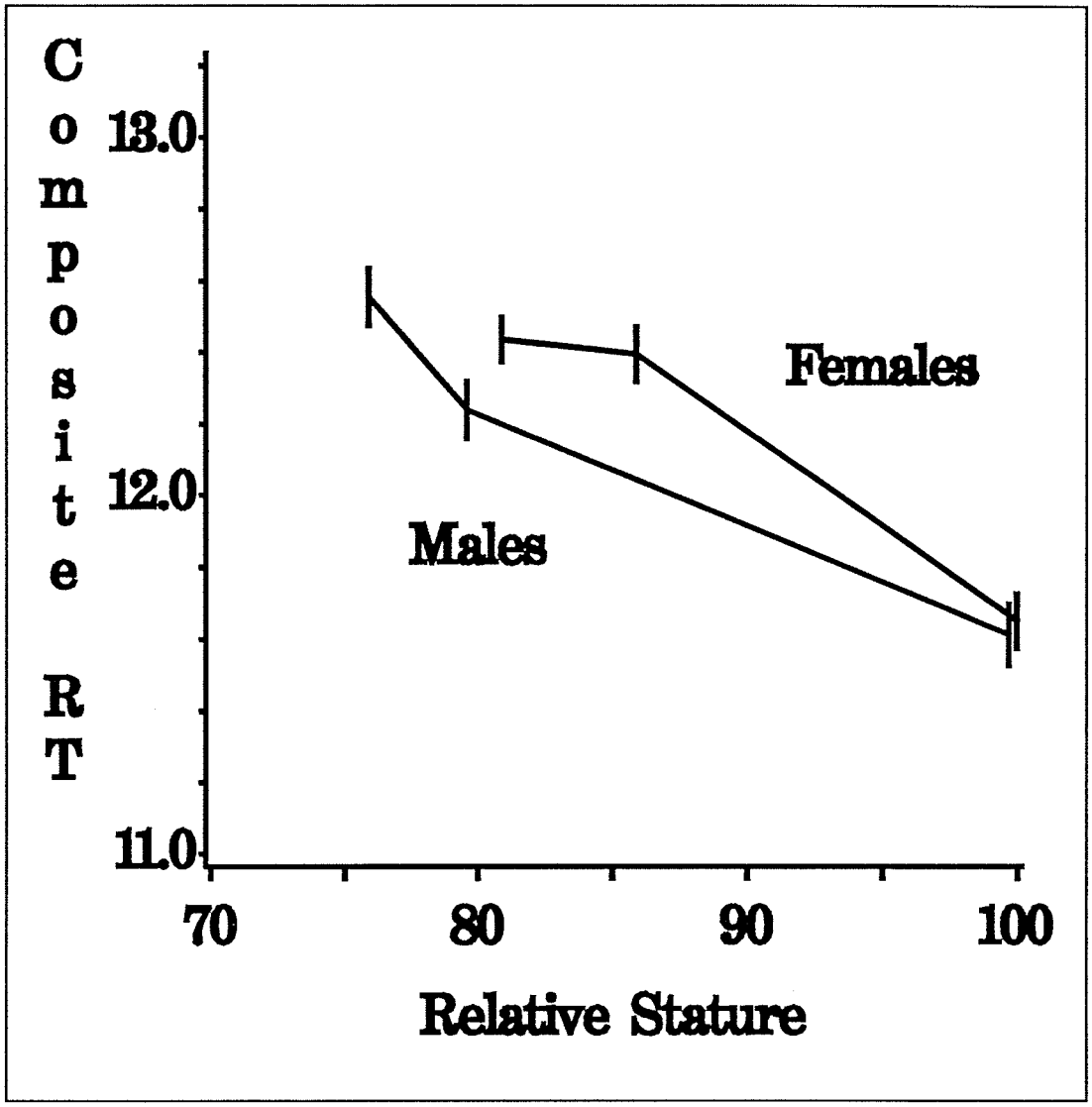

Figure 6. Mean composite reaction time (±1 SE) by mean relative stature for maturity groups by sex.

70.44, $p<.0001$, for females, respectively. Early males performed faster than late maturing males, $F(1, 42) = 7.09$, $p<.05$, but the early maturing females did not differ significantly from the late maturing females, $F(1, 42) = 0.15$. The mean reaction times from the preceding analyses are presented in Figure 6. Each child group has been plotted using the group's mean relative stature value for the horizontal axis position. Adult groups were assumed to have reached

their full statures and were assigned a relative stature score of 100. Such plotting reveals the greater maturity of the female children, the faster performance of the adults, and the male-specific maturity group effect.

DISCUSSION

There are several findings from this study that are worthy of discussion. First, the main hypothesis was that early maturers would perform faster than late maturers on the information processing speed tasks sampled. A brief summary of evidence for this link follows. First, lawful age-related increases in information processing speed, across a variety of tasks, occur during childhood and adolescence (e.g., Kail, 1986; 1991; Hale, 1990). Several theorists have proposed that a general factor which may be linked to maturation is responsible for this increase in information processing speed. Second, maturational differences have been linked to differential performance on many global or omnibus IQ tests, with a tendency for those with greater physical maturity to perform better than their less mature age-mates (e.g., Tanner, 1962; Newcombe & Dubas, 1987). Third, Jensen (1981) found that IQ correlates with reaction times on information processing tasks. Fourth, and last, Vernon (1983) has proposed that differences in intelligence result from differences in information processing speed because an individual who processes information rapidly will acquire more knowledge in a given time frame than an individual who processes information slowly.

Such correlational evidence implicates the existence of a link between maturational factors and information processing speed. Thus, if physical maturity is predictive of reaction time, early maturers should perform faster than late maturers, a prediction that was tested by comparing the early and late maturers of the same chronological age and gender.

Results from the main analysis showed that the hypothesis was confirmed for males, but not females. The male maturity differences were significant, overall and for two specific tasks, the two-choice reaction time task and the letter matching task. Moreover, when the reaction times from all tasks were summed into a composite reaction time, the early maturing males performed more quickly than the late maturing males. For the females, there were no significant differences between early maturers and late maturers on individual tasks or with the composite reaction time measure. Further, an inspection of Figure 6 reveals that in terms of composite speed, the early maturing boys were the fastest, followed by the early maturing girls, the late maturing girls and, the late maturing boys. This pattern suggests that physical maturity does affect information processing speed but does so differently for each sex. Such an outcome may be partially due to the substantial maturational differences between boys and girls at this age level. Results from a study by Duke et al. (1982) were similar to those of the present study with respect to sex as a moderating variable. Duke et al. (1982) compared early and late maturers to other youths of comparable age (12 to 17 years) and sex

on eight education-related measures. They found that early maturing males outperformed mid maturing males, who outperformed late maturing males. No maturity differences were found for females. Their results combined with the results of this study, suggest, for the moment, that the link between maturation and performance in middle childhood is present for males but not for females.

Ten-year-old males, whether early or late maturing, are less physically mature than 10-year-old females, whether early or late maturing. However, early males are faster than early and late females, who are, in turn, faster than late males. This pattern could be related to Kail's (1991) assertion that processing speed changes substantially in early and middle childhood and more slowly thereafter. That is, because females mature earlier than males, they may have already undergone the developmental improvement in speed by age 10. The males, on the other hand, reach the same level of physical status much later, and may still be in a rapid phase of reaction time development at age 10. Therefore, the differences between the two male groups is great and will continue to be so until the developmental gap between the early maturers and late maturers closes. One of the implications of this tentative explanation is that, in a younger group of children, significant differences between the early and late maturing females should be found.

A second finding from the present study is that these results are consistent with results from other studies that analyze child and adult reaction times (see Kail, 1991): Across all tasks and for both sexes, the adults

performed faster than the children. Thus, the present study confirms a key assumption of developmental change that occurs between middle childhood and adulthood.

A third important and expected finding from this research is that the boys and girls differed substantially on relative stature, the measure of physical maturity used in this study. A difference of 1.5 standard deviations in physical maturity between boys and girls at this age level is substantial, particularly in light of sex difference magnitudes in other, related literature (see Eaton, 1989), but this difference is almost always ignored when comparing boys and girls. Given this large difference between the two groups on this variable it was necessary to look within each sex for any covariance between physical maturity and information processing speed. If this within-group tack had not been taken, all the 10-year-olds selected for the early-maturing quartile would have been girls, and all the late maturers would have been boys. Because the differences in levels of physical maturation are so great between boys and girls at this age level, researchers would be well-advised to consider maturity as a confound when comparing the two groups.

Related to this point is the finding that relative stature (from Roche et al., 1975) as a measure of physical maturation is a practical, relatively inexpensive means of determining a child's maturational status. It has the advantage of positively correlating with accepted, traditional methods of assessing maturity, such as, skeletal age of the left hand-wrist, peak height velocity, and age at

menarche. The R-W-T method is also advantageous because it does not rely on retrospective indicators of maturation, which are often used in older samples. Thus, by using this index of physical maturation, a researcher is capable of assessing a pre-pubescent child's current maturational status in a non-invasive manner.

Fifth, information processing speed on all of the four tasks was highly correlated. In light of the fact that the four tasks sampled a broad range of reaction times (for a visual inspection of task differences on reaction time, see Figures 4 and 5), this finding replicates Hale's (1990) findings and bolsters her contention that information processing speed changes in concert across tasks.

A sixth finding of this study also lends support to Hale's (1990) findings in that, although the range of reaction times sampled is broad, the between-task performance in both studies is comparable. The mean reaction times for the 10-year-old and adult groups, from the present study and from Hale (1990) are presented in Table 7 [The tabled reaction times for the latter study were adapted from Hale (1990, Table 1) by averaging and taking the common logrithm value of the appropriate values]. Inspection of Table 7 reveals the same pattern of reaction times across tasks, with the shortest latencies for Arrows and the longest for Matching. Moreover, despite differences between the studies, (eg., the present study used only early and late maturers) the mean reaction times are very similar, and therefore, the present results act as an extended replication of her study.

Table 7. A comparison of mean RTs: The present study and Hale (1990)

		Task			
	n	Arrows	Letters	Flags	Matching
10-year-olds					
Present study	60	2.85	3.04	3.11	3.40
Hale (1990)	16	2.80	3.05	3.22	3.49
Adults					
Present study	30	2.67	2.88	2.89	3.19
Hale (1990)	16	2.61	2.82	2.70	3.24

Seventh, the correlation between information processing speed and the experiential factor, exposure to video and computer games, was examined in this study to assess a possible relation between these two variables. The results of this analysis were nonsignificant, which suggest that individual differences in parent-reported exposure to video and computer games do not account for individual differences in processing speed.

The eighth and last point to note is that, even though all the participants were drawn from the same school grade, the early and late maturers still differed on chronological age (see Table 2). For this reason analyses were conducted with CA as a covariate. The covariance results showed that the early maturing boys were faster than the late maturing boys on each task except the abstract matching task; and these adjusted maturity group differences cannot be attributed to differences in CA. In contrast, covariate-

adjusted differences between early and late maturing girls were non-significant and in different directions on individual tasks. Thus, with or without CA covaried, the relation between maturational status and processing speed is clearer for boys than for girls at this age (10-year-olds).

In conclusion, the results from this study are an important step in answering the question of whether maturity is related to speed of processing. The answer is more blurred than was expected because the maturity-speed relation was found for males only, and more research with younger age groups, is necessary to clarify the specific circumstances in which greater physical maturity is related to greater information processing speed.

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APPENDIX A

Letter to Parents

Dear Parent:

My graduate student, Kathryn Ritchot, and I are conducting research on a possible relation between a child's physical maturity and his or her reaction time on four computer tasks. Your child's school has kindly agreed to cooperate, and I am writing to request your permission to allow your daughter or son to participate in this research in the near future.

In order to determine whether your child will participate, we will be taking height and weight measurements. From this information we will determine how physically mature your child is relative to his or her predicted adult height. About one half of the students who are measured will be asked to play some computer games. We will be measuring how quickly they react while playing these games. The whole session will take approximately 20 minutes. My own children have tried these tasks and found them to be quite intriguing and fun.

If you are willing to have your child participate, please complete the attached form and return it to the school by _____. All obtained information will be used only for research purposes and will remain confidential. However, a summary of the results of the study findings will be sent to the school next fall.

By way of thanks for your participation, we will send you your child's current height and weight, and estimated age 18 height. If you have any questions, please call me or my student (Kathryn Ritchot) collect at 1- or 1-

Yours truly,

Warren O. Eaton, PhD.
Professor

APPENDIX B

Consent Form

Dear Parent:

Please complete the following and return it to the school by _____.

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

Teacher: _____

_____I **do** consent to let my child participate in Dr. Eaton's study on maturity and reaction time.

_____I **do not** consent to let my child participate in Dr. Eaton's study on maturity and reaction time.

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).

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

Height of child's biological mother._____(in feet and inches).

APPENDIX C

Parent Questionnaires

If you would take the time to answer the following questions, as well, it would be most helpful to us.

Does your child ever play video or computer games? _____ (yes/no)

If the answer is **yes** please try to estimate the following:

Do you recall at what age she or he began to play video games? (Please be as specific as possible) _____ years _____ months

Approximately how much time does your child spend playing video/computer games in a **typical week**? _____ hours _____ minutes

Approximately how much time did your child spend playing video/computer games during this **past week**? _____ hours _____ minutes

Hand-Use Questions:

Please answer the following questions by circling the most correct answer.

With which hand does your child:	Always left	Usually left but sometimes right	Either right or left	Usually right but sometimes left	Always right
Eat with a fork?	1	2	3	4	5
Throw a ball?	1	2	3	4	5
Use scissors?	1	2	3	4	5
Write a letter?	1	2	3	4	5
Pick up a glass of water?	1	2	3	4	5

Thank-you very much for your time and cooperation!

APPENDIX D

Adult Handedness and General Information Questionnaire

Please answer the following questions to the best of your ability:

Hand-Use Questions:

(answer the following questions by circling the most correct answer)

With which hand do you:	Always left	Usually left but sometimes right	Either right or left	Usually right but sometimes left	Always right
Eat with a fork?	1	2	3	4	5
Throw a ball?	1	2	3	4	5
Use scissors?	1	2	3	4	5
Write a letter?	1	2	3	4	5
Pick up a glass of water?	1	2	3	4	5

Your age: _____

Gender (sex): _____

First Language:_____

Thank you very much for your cooperation!

The following question was asked aloud after the session:

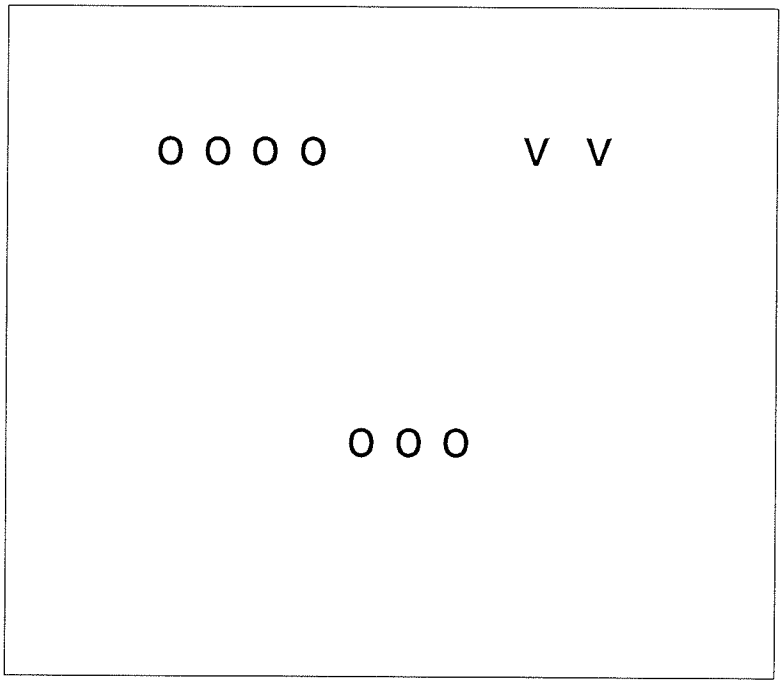
If you were to compare your physical maturity with that of your peers, while you were growing up would you say that you were an

_____early _____average or _____late maturer?

APPENDIX E

Sample Problem for the Letter Matching Task

Here is a Sample problem:



Which of the two patterns on top (the left one or the right one) is most like the pattern on the bottom? Why?

APPENDIX F

Examiner's Script

General Instructions

Today you will be playing four computer games. In order to play these games, you need to know about three of the buttons on the keyboard: The one with the blue dot is the left-hand key, the one with the red dot is the right-hand key, and this is the space bar. {I pointed to each key and then had the participant place his or her fingers and thumb appropriately}. If you press the space bar once you will see what it does {the asterisk appeared on the screen}.

So when ever you press the space bar it moves you from one screen to the next. OK? When the star is on the screen we are not timing you. The rest of the time we are. So if you need to take a quick little break to scratch your nose or something, do it when the star is on the screen.

There is one other thing you should know before I explain to you how to play the first game. While you are practicing you will be given a "Correct" message when your answers are correct and a "Wrong" message when your answers are wrong. During the real game you will only be told when you are wrong. This is because the messages slow you down too much. An important thing to know is that the object of these games is to be as CORRECT as you can be and as FAST as you can be. OK? I am going to watch you while you practice but I will just sit over here {I pointed to a chair close by but facing the

other way} while you are actually playing so I don't make you nervous. Any Questions?

{During all of the practice trials I watched the participants, gave positive reinforcement for all correct responses, and tried to clear up any difficulties with incorrect responses}.

After the practice trials for each task, I told each participant: "REMEMBER, THE OBJECT OF THIS GAME IS TO BE AS CORRECT AS YOU CAN BE AND AS FAST AS YOU CAN BE.

Specific Task Instructions

Letters

This game is called Letters. In this game you will see two letters on the screen at one time. For example, you might see AA or Aa or AB. If the two letters are the same letter of the alphabet -- even if one letter is a capital letter and one is a small letter -- you should press the right key, the red one. {If the participant was left-handed I told them they had to press the left key if the letters were the same}. If the two letters are different letters of the alphabet, you should press the left key, the blue one {the right key for different letters for the left-handed participants}. OK? {I then had them begin with the practice trials}

Whenever you are ready you can start by pressing the space bar.

Flags

This game is called Flags. {I held up cardboard facsimiles of the two flags and pointed appropriately}. You will see one of two flags on your screen. These flags are very similar to each other but one flag has stars in the upper left-hand corner and the other has stars in the upper-right hand corner. If you see the flag with the stars in the upper-right hand corner you will press the red - the right hand key. And if you see the flag with the stars in the upper-left hand corner you will press the blue key (the left hand key). OK?

But it gets more complicated than that because sometimes you will see the flag in its normal position, sometimes you will see the flag turned on its side, and sometimes you will see it upside down {turning the flags appropriately as I spoke} Your job is to turn the flag in your head, without moving your head, until you can see where the stars would be if the flag is in its normal position {I turned the flag back slowly to upright as I spoke}.

Training Trials. {For these trials, I held one of the flags up at a time - in different orientations}. Which key would you press if you saw this flag? {I continued to do this until they were able to respond correctly to three flags in a row. I then had them begin with the practice trials.}

Whenever you are ready, you can begin by pressing the space bar.

Arrows

This game is called Arrows. You will see one of two arrows on the screen. One of the arrows points to the right and the other points to the left. If you see

the arrow that points to the left you must press the blue key but if you see the arrow that points to the right you press the red key. OK? {I then had them begin with the practice trials.}

Whenever you are ready, you can begin by pressing the space bar.

Matching

This game is called Matching. It is kind of tough at first but I am sure you will get the hang of it before long. {I held up Appendix E and pointed, appropriately}. Each problem has 3 patterns - 2 on the top - the right pattern and the left pattern - and one on the bottom. Each pattern is made up of one of three letters: o, v, or x. There can be 2, 3, or 4 letters in each pattern. And each pattern can appear in one of three directions: sideways, up and down, or at an angle.

Your job is to decide which of the two patterns on the top is most like, or the best match, to the one on the bottom. If the left pattern is the 'best match', you should press the blue key and if the right pattern is the 'best match' you should press the red key. Which key do you think you would press if you saw this problem?

{After the participant answered, I gave them feedback and then asked for their reasoning in solving the problem. I corrected any problems the participant had with reasoning}

Training Trials. For the first six problems, I would like you to decide which pattern is the best match and tell me the answer before you press the button.

{For all of the training trials, if the student indicated the correct choice, I gave positive reinforcement and asked why they made their choice. If they made an incorrect choice, I asked why they made their choice. In all cases, if their reasoning was faulty, I explained why the correct choice was correct.} {I then had them perform the practice trials.}

You can begin by pressing the space bar.

APPENDIX G

Debriefing

We'd like to thank-you for participating in this study and take this opportunity to explain to you a little bit about this research. Several studies have found that children who are advanced physically for their chronological age are also likely to perform better on mental ability tests than their less mature agemates. This study seeks to discover whether such a link exists between relative physical maturity and a specific cognitive component, information processing speed. Relative physical maturity was determined for 66 female and 68 male 10-year-olds. These groups were divided into upper and lower quartiles (early and late maturers) and the members of each extreme maturity group were tested individually on the following information processing tasks: mental rotation; letter matching; choice reaction; and abstract matching. You and the other undergraduates who participate in this research will act as an adult control group. We will compare the 10-year-olds results with your results. We expect that the adult group will have faster reaction times than the most mature 10-year-old group, who will, in turn, have faster reaction times that the least mature group. This research is intended to help determine whether greater relative physical maturity is associated with greater information processing speed.

Again, thanks for participating!