ABSTRACT

Environmental Influence on Math Cognitive Ability: A Sibling Study

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Previous research has shown that there is a relationship between speed of information processing, as measured by general reaction time (RT) on various simple tasks, and standard tests of cognitive ability. Moreover, this relationship is partly due to shared genes and partly due to shared environment. When the environmental factors have been further analyzed, it appears that the environmental influences are mostly due to non-shared factors, i.e., the influences that make siblings from the same family different. To date, little has been done to investigate if the same relationships exist for academic achievement domains, such as mathematics. This study compared the relationship between RT and standard tests that measure mathematics. As the sample is comprised of sibling pairs, we were also able to examine the amount of variance due to Between Family (BF) factors (i.e., the environmental factors that make siblings alike) and Within-family (WF) factors (i.e., the environmental factors that make siblings different). This study seeks to examine (a) if there is a relationship between RT and traditional tests of mathematics, and (b), if there is a relationship, how much of the environmental influences are due to BF vs. WF factors.

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ENVIRONMENTAL INFLUENCE ON MATH COGNITIVE ABILITY:
A SIBLING STUDY

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CHAPTER ONE

Review of Literature

While siblings within a family may be very similar in some regards, there are inevitably areas in which they differ. The major goal of this study was to determine whether siblings are more similar to each other than to other people outside of their families in their performance on math-based tasks, in order to draw conclusions about whether the shared environment or unshared environment has a greater influence on math cognitive ability. In addition, as simple reaction time measures have been established as reliable measures for general cognitive ability, we sought to determine whether they are also reliable measures of more complex math cognitive function.

Reaction Time (Speed of Information Processing)

Reaction time (RT) is the time that elapses between the presentation of a stimulus and the detection of a response by the person being tested. Typically, the respondent knows that his or her response is being timed, and that the goal is to be both quick and accurate (Jensen, 2006). RT is the conventional measure for the speed of information processing and is usually measured in association with simple tasks, called elementary cognitive tasks (ECTs). ECTs are a broad category of tasks that includes ‘successful’ or ‘correct’ outcomes or end states that are to be attained through a relatively small number of mental processes or operations, and whose successful outcomes depend on the instructions given to, or the sets or plans adopted by, the person (Carroll, 1993). In other words, ECTs are tasks that are intentionally simple enough that almost anyone can complete them with 100% (or close to 100%) accuracy in a short period of time; thus, the area of interest is rarely whether the respondent answers correctly, but how quickly the respondent completes the task (Jensen, 1982).

ECTs are often subdivided into simple and choice measures, which differ on the amount of information processing the tasks require (i.e. the level of complexity). Simple tasks involve a single stimulus and a single intentional response (Jensen, 2006). For example, the assessment of simple RT involves measuring the time it takes the subject to lift his or her finger from a "home" button after a light goes on directly in front of the subject. In this case, RT is measured from the onset of a light until the subject initiates lifting his or her finger, and movement time (MT) is the time that it takes the subject to move his or her finger from the home button to the button in front of the light that turned on (Vernon, 1987, p. 79). An example of such simple RT apparatus is given in Figure 1.

Choice RT is the time that elapses between the onset of one out of a number of possible stimuli and the subsequent intentional response to that stimulus. Since the subject is unsure as to which of the 2, 4, or 8 lights will go on, there is an element of choice which makes it a more complex measure. Choice RT is measured in the same way as simple RT, with similar definitions (Vernon, 1987, p. 79). The onset of the light (reaction stimulus) for both simple and choice RT measures is preceded by a preparatory stimulus, usually a beep, which sounds at variable intervals ranging from 1 to 5 seconds. An example of such choice RT apparatus is given in Figure 2.

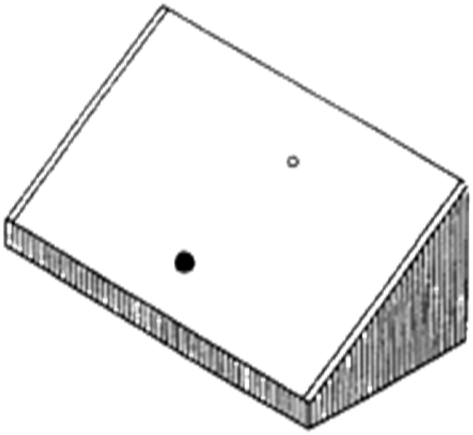


Figure 1. *Simple Reaction Time Button Box.* From Jensen (2006, p. 31)

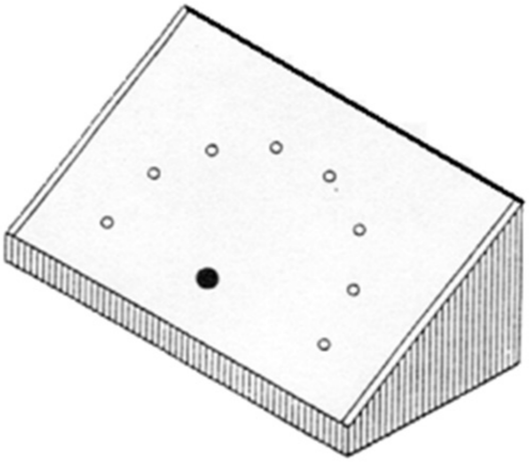


Figure 2. *Choice Reaction Time Button Box.* From Jensen (2006, p. 31)

Speed of Information Processing and Intelligence

Reaction times have been measured for a variety of populations, over a range of cognitive abilities. For example, they have been done with individuals with a severe intellectual disability who had to be placed in an institution (Jensen, Schafer, & Crinella, 1981), individuals with low borderline abilities who were employed in a sheltered workshop (Vernon, 1981), unskilled manual workers (Sen, Jensen, Sen, & Arora, 1983), and vocational college students and university students (Beaujean, Knoop, & Holliday, 2006; Vernon, 1983; Vernon & Jensen, 1984). Similar RT paradigms have also been used with preschool children (Telzrow, 1983) and with school children in different grades (Carlson & Jensen, 1982; Carlson, Jensen, & Widaman, 1983; Cohn, Carlson, & Jensen, 1985; Jensen & Munro, 1979).

These researchers have established the relationship between RT and standard paper-and-pencil tests of cognitive ability (e.g., Eysenck, 1987; Jensen, 1982; Vernon, 1987). Reaction times differ not only between groups that differ in cognitive ability, but also within the same individual measured at different times, called intraindividual variability. Intraindividual variability varies widely between individuals and demonstrates consistent individual differences over a variety of RT paradigms (Jensen, 1992). It is expressed as the standard deviation of a subject's RTs over all trials, or RTSD (Jensen, 2006; Jensen, Cohn, & Cohn, 1989).

The correlation between choice reaction time and cognitive ability increases with the complexity of the choice reaction time task. Simple reaction time correlates weakly (usually around -0.2 to -0.3) with cognitive ability, as measured by standard paper-and-pencil tests of general cognitive ability, but choice reaction time tends to show stronger relationships (-0.3 to -0.9) (Vernon, 1987). Intraindividual variability negatively correlates with cognitive ability; that is, the more inconsistent the RTs for an individual across trials of the same task, the lower the cognitive ability (Eysenck, 1987). For example, Cohn et al. (1985) compared RTs between intellectually gifted and average youths. The differences between the RTs of gifted and non-gifted groups were statistically significant in almost all (11 out of 12) processing tasks. In another example, Jensen et al. (1989) compared RTs of intellectually gifted seventh-grade students to those of their siblings. The gifted students had both faster mean RTs and less intraindividual variability in RT than their siblings.

Reaction Time with Gifted Students

Cohn et al. (1985) compared academically gifted youths of ages 12-14 years old to a group of similar-aged peers in the seventh grade. Gifted status was determined based on the students' success in college-level courses in mathematics and science. This study was distinctive in that it compared those of average intelligence with those considered to have superior intelligence, rather than those of average or superior intelligence with those of sub-average ability, as was done by most previous studies. This addressed the widespread view that RT differs little between those at the average and upper extremes of the intelligence. This view considered the difference between "gifted" and "average" students to be in the "amount of scholastic knowledge and specific high-level problem-solving skills and strategies" that resulted from differences in learning opportunities outside of school, academic interests, and study habits (Cohn et al., 1985, p. 621). Thus, these two groups of youths were similar in their capacities to process basic information and varied only in the special knowledge and high-level skills that they possessed.

Intellectually gifted individuals differed from the average group in speed on RT tasks about as much as average groups differed from the mentally subnormal groups (Baumeister & Kellas, 1968). Furthermore, the difference between the gifted group and their average peers extends past their level of scholastic knowledge, problem-solving strategies, and study habits by measuring the speed of information processing in extremely simple ECTs. The gifted students were faster in completing these tasks, indicating that differences in elementary cognitive processes also play a role in this intelligence difference. In fact, the magnitude of the differences between the gifted and non-gifted groups on processing speed with ECTs was fairly close to that of the differences between the two groups on the regular psychometric tests. Presumably then, differences in elementary cognitive processes play a large role in differences in general cognitive ability (Cohn et al., 1985).

Math-Based Chronometric Assessment

Ashcraft (1982) reviewed the use of chronometric (i.e., reaction time) models and methods of cognitive psychology in the assessment of arithmetic performance in children. He presents RT as a way to view normally unseen mental processes and defines it as a composite, comprising of several stages that occur in a fixed sequence and are independent of one another. These stages include encoding, match/comparison, decision, and response. Sternberg (1966, 1969) proposed this model of RT stages based upon his results and observations from his short-term memory scanning research. Groen and Parkman (1972) changed the match/comparison stage in Sternberg's (1966, 1969) four-stage model to a computing stage in their testing of children's addition performance (Ashcraft, 1982). Ashcraft (1982) proposed a processing model for mental arithmetic which includes declarative and procedural long-term memory components and which has served as the basis for later models. It includes encoding, search/compute, decision, and response stages.

Ashcraft and Fierman (1982), focusing on addition, and Cooney, Swanson, and Ladd (1988), focusing on multiplication, supported a shift in strategy for simple arithmetic problems that occurs some time during third or fourth grade in most children. Whereas children use counting techniques prior to the third or fourth grade, most begin to retrieve simple arithmetic facts from a stored body of memorized facts, which is organized into an interconnected network (Ashcraft, 1982; Geary, 1996). This more efficient memory retrieval strategy is used through adulthood.

Several different models for predicting average RT to simple arithmetic problems, including analog models, counting (digital) models, a direct memory access/counting model, and memory network models (Geary & Widaman, 1987). As stated before, young children use counting processes until around third or fourth grade, and then shift to memory network retrieval. According to Groen and Parkman's model (1972), adults mostly use memory retrieval, turning to counting strategies in instances when retrieval fails; however, subsequent models that only include memory network retrieval are better predictors of adult RT. For example, Miller, Perlmutter, and Keating (1984) found that the correct product of the pair of numbers on which operations were performed (i.e. the addends or the multiplier and multiplicand) best predicted RT on simple addition and multiplication problems. In conjunction with the analysis of errors, this indicated that addition and multiplication facts are retrieved from a similar memory network. Widaman et al. (1989) found that the product of the addends was the best predictor of RT to both simple and complex addition problems. For simple addition problems, the strongest alternative model also supported the use of memory network retrieval. Regardless of the specific model of the memory network for arithmetic facts, research strongly supports the notion that it is a memory retrieval process, rather than a counting (digital) or an analog process, which best accounts for response latencies to simple arithmetic problems (e.g. Ashcraft & Battaglia, 1978; Miller et al., 1984; Widaman et al., 1989).

Sibling Studies

Sibling studies are an often-overlooked type of study which can be very useful in psychological research (Lahey & D'Onofrio, 2010; Olneck, 1977). Jensen (1980) explained some of the benefits of using sibling data, one of which allows investigations of influence of family background. As siblings typically are exposed to many of the same environmental influences, comparing the variability within family (i.e., among siblings) to the variability between families can be informative in the understanding of the influence of shared and non-shared environmental components.

Between- and Within-Family Variance

In behavioral genetics, variability in an outcome is often divided into that due to shared genetics (i.e., heritability) and that due to the environment (Plomin, DeFries, McClearn, & McGuffin, 2008). The environmental factors are further subdivided into shared (within family) and non-shared (between family) factors.

Between-family variance is what is typically thought of when thinking of environmental influence. It is comprised of the environmental influences that are common to all siblings within a family, but that differ between families. Within-family variance, then, is everything else in the environment that cause full siblings who are reared together to differ from one another (Dunn & Plomin, 1992; Turkheimer & Waldron, 2000). Most genetic factors that cause variation in the population have both between- and within-family differences, although there are some exceptions. For example, racial origin typically has between-family variability but seldom has within-family variability. There are no characteristics, however, that differ within families that do not also differ between families (Jensen, 1980).

Univariate Models

When examining a single variable, the sibling correlation is the proportion of the total variance which is attributable to variance between families. For a given variable, *y*, sibling correlations can be estimated using intraclass correlations. Sibling correlations tell the relationship on *y* between two randomly drawn pairs of siblings, and can be interpreted as the influence of the environmental factors that the siblings share (e.g., SES, neighborhood, schools). Theoretically, these shared factors should make individuals who live within a household more similar on a variable than individuals from different households (Lynch & Walsh, 1998)

The situation is similar to the situation with multilevel models. In those types of models, one is often interested in examining the relationship between scores on a variable and the clusters/grouping from to which an individual belongs, and thus decomposes a variable's variance into group and individual level components (Snijders & Bosker, 1999).

To be more explicit, the value on variable of interest, *y*, for individual *i* in group (i.e., family) *j* can be written as

$$y_{ij} = \mu + \varepsilon_{ij} \quad (1)$$

where μ is the population mean and ε_{ij} is an individual's specific deviation from the mean, with variance σ^2_{ε} (Because μ is a constant, $\sigma^2_{\varepsilon} = \sigma^2_{y}$). As a constant can be added or subtracted to a variable without influencing its (co)variance, we can re-write (1) as

$$y_{ij} - \mu = \varepsilon_{ij} \quad (1^*)$$

and σ_{ε}^{2} does not change.

The deviation score, ε_{ij}, can be further decomposed into a family specific component (i.e., common to all siblings within a family) and an individual specific component (i.e., unique to sibling *i* within family *j*): a_i and b_{ij}, respectively:

$$\varepsilon_{ij} = a_j + b_{ij} \qquad (2)$$

This allows us to re-write (1*) as

$$y_{ij} - \mu = a_i + b_{ij} \qquad (3)$$

In (3), a_j is the family-specific deviation from the population mean (i.e., the mean of family *j* on the $y_{ij} - \mu$ variable) and b_{ij} is individual *i*'s deviation from his/her family's mean (i.e., how far *i* deviates from a_j on the $y_{ij} - \mu$ variable). Assuming a_i and b_{ij} are independent, then the variances of a_i and b_{ij} are additive:

$$\sigma_y^2 = \sigma_{y-\mu}^2 = \sigma_{\varepsilon}^2 = \sigma_a^2 + \sigma_b^2 \qquad (4)$$

Equation (4) allows us to calculate the intraclass correlation (ICC) (i.e., the sibling correlation) for variable *y* as

$$\rho_y = \frac{\sigma_b^2}{\sigma_a^2 + \sigma_b^2} \quad (5)$$

Bivariate Models

In addition to examining the BF and WF variation for a single variable, we can also examine how much the co-variation among two or more measures is due to BF and

WF factors (Neale & Maes, 1992). Here, instead of examining variance of a single variable, we examine the covariance among variable. As with the univariate approach, separating the co-variability into BF and WF components separates the influence of macroenvironmental and microenvironmental factors on the relationship between our outcomes of interest. When just examining two variables, researchers typically examine the correlation, and decompose it into a BF component and a WF component (Robinson, 1950). The BF correlation reflects those genetic and environmental factors that differ between families, but not among siblings within families (i.e., the factors that make siblings within a family similar). The WF correlation reflects those factors that differ among siblings (i.e., the factors that make siblings within a family dissimilar) (Jensen, 1980; Plomin et al., 2008).

Jensen (1980) proposed that variables derived from family interests, lifestyles, cultures, or other environmental experiences that are more associated for all siblings of one family than for all siblings of other families will show a much higher BF than WF covariance/correlation. Thus, if the relationship between two variables were mostly attributable to differences in socioeconomic status (SES), cultural background, parental education, and other similar macroenvironmental factors, then the BF relationship should be much higher than the WF relationship. If the BF correlation is not appreciably larger, the main effects of social class and cultural factors do not account for the variables' relationship, and aspects of family background are negligible sources of variance in one or both of the correlated variables (Jensen et al., 1989).

Reaction Time between Siblings

Jensen et al. (1989) compared academically gifted seventh-grade students with their next closest in age full siblings. Giftedness was based upon their performances on the Scholastic Aptitude Test (SAT), as part of their participation in the Center for Talented Youth's (CTY) Talent Searches. Mean RT and the intraindividual variability (SDRT) were both correlated with the general cognitive ability *within* as well as *between* families, and the WF and BF correlations did not differ substantially from each other. This indicates that cultural and socioeconomic sources of variance between families had minimal influence on the relationship between the performance on RT task and the measure of cognitive ability (Jensen et al., 1989).

Current Study

The purpose of the current study is to examine the influence of BF and WF factors on RT to math-based chronometric tasks, as well as their influence on the relationship between math-based chronometric tasks and paper-and-pencil tests of mathematics and general cognitive ability.

CHAPTER TWO

Methods

Participants

Forty adolescents participated in the current study, which was conducted prior to this thesis project. Of the 40 participants, 33 were siblings (15 families with 2 sibling participants, 1 family with 3 sibling participants). Participants came from a group of middle school students attending a math camp held at the University of Missouri. Each participant was asked to participate in the study and to have their closest in age sibling participate as well. Of the 15 two-sibling pairs, 5 were brothers, 3 were sisters, and 6 were brother-sister. The three-sibling family was comprised of two brothers and one sister. The mean age of all participants was 133.28 months (11.10 years), with a variance of 558.38 months (3.88 years).

Psychometric Tests

To measure math ability, we used the Woodcock Johnson-Third Edition Tests of Achievement, form A (WJ-III-A) (Woodcock, McGrew, & Mather, 2001a). The WJ III-A is a standardized battery of individually administered academic achievement tests. It contains three math subtests in its core battery: (a) Applied Problems (i.e., ability to orally answer spoken math word problems); (b) Math Fluency (i.e., ability to answer single-digit addition and subtraction problems within a three minutes); and (c) Calculation (i.e., ability to compute answers to math problems ranging from simple addition to calculus without time restrictions). These three scores comprise the Broad Math score, the variable used for this study. McGrew and Woodcock (Woodcock & McGrew, 2001) estimated the internal consistency of the Broad Math score to be between 0.94 to 0.96 for 11-19 year-olds.

The Woodcock-Johnson III Tests of Cognitive Abilities (Woodcock, McGrew, & Mather, 2001b) provides a brief measure of intelligence with the Brief Intellectual Ability (BIA) score. The BIA score is comprised of three cognitive tests: (a) Verbal Comprehension, (b) Concept Formation, and (c) Visual Matching, measuring Comprehension-Knowledge (G_c), Fluid Reasoning (G_f), and Processing Speed (G_s), respectively. The internal consistency of the BIA score is between 0.95 and 0.96 for 11-19 year-olds.

Speed of Information Processing

We used 6 different math-based chronometric tasks for this project, ranging from single number naming to completing the multiplication of 3 numbers (for a description of the tasks used, see Table 1). For the number naming tasks, the participants were given 2 trials of 10 items, each. For the other tasks, participants were given 3 trials of 20 items, each. The mean RT was calculated as the average time it took for the respondent to answer an item, while the mean intra-individual variability (SDRT) was calculated as the average of the within-person SD across the trials of a task. Only correct answers were used in the calculation of the mean and variation measures.

The chronometric tasks were administered using the Computer-based Academic Assessment System/ Cognitive Aptitude Assessment Software (CAAS) (Cisero, Royer, Marchant, & Jackson, 1997). The CAAS works using a PC, but instead of having a device for respondents to press, respondents wear a headset microphone and say their answer aloud. The CAAS software then calculates the delay from stimulus presentation to first verbal output. After the respondent answers, the task administrator responds using either the keyboard or the mouse whether the response was correct. If for some reason the CAAS calculated the time before the respondent gave an answer (e.g., the respondent coughed), then the task administrator would flush that particular item and it would be administered again later.

Table 1. Description of chronometric tasks

Test	Description
Single number naming	Say the name of a single digit number
Double number naming	Say the name of a double digit number
Single-single addition	Add two single-digit numbers
Single-single subtraction	Subtract two single-digit numbers
Single-single multiplication	Multiply two single-digit numbers
Triple multiplication	Multiply three single-digit numbers

CHAPTER THREE

Results

All data analysis was done in the R statistical program (R Development Core Team, 2011). Table 2 summarizes the results for the psychometric and chronometric tests.

Table 2. Scores for psychometric and chronometric variables

Variable	Mean	Standard Deviation
Brief Intellectual Ability	121.65	15.46
Broad Math	123.88	11.43
Single Number Naming (s)	0.63	0.10
Double Number Naming (s)	0.67	0.13
Single-Single Addition (s)	1.31	0.47
Single-Single Subtraction (s)	1.51	0.49
Single-Single Multiplication (s)	1.33	0.56
Triple Multiplication (s)	3.13	1.83

Note: Two trials each were done for Single Number Naming and Double Number Naming. Three trials each were done for Single Single Addition, Single Single Subtraction, Single Single Multiplication, and Triple Multiplication. The statistics are an average of all the trials for each test.

Psychometric variables

Both the BIA and Broad Math scores are on the typical IQ metric, with a mean of 100 and a standard deviation of 15. The average BIA of these students was 121.65, and the average Broad Math score of these students was 123.88, indicating that both their general cognitive ability and math ability are above average. Moreover, as the SD of the BIA is 15.46 and for the Broad Math is 11.43, it indicates that there is roughly as much variance within the sample as in the general population.

Chronometric variables

As expected, mean RT tended to increase as the task difficulty increased. On average, students required about 0.63 seconds to name single digit numbers and 3.13 seconds to multiply three single digit numbers.

Univariate Analyses

The results from the univariate analyses are given in Table 3, which have the ICC for each of the psychometric and chronometric variables, as well as the 95% confidence interval (McGraw & Wong, 1996). Data from all participants, regardless of whether they had siblings, was used to calculate the ICC. The Broad Math, Single-Single Multiplication RT, and Single-Single Multiplication SD had large ICC coefficients, indicating a substantial contribution of BF factors to the performance variation in these measures. Most of the ICCs, however, are small or negative. This indicates that these variables had as much (or more) variability within families on these variables as between families. Stated differently, the factor that brings the siblings together (i.e., being part of same family) makes them *less* similar than any two randomly chosen members of the whole population (Kenny, Kashy, & Cook, 2006).

Table 3. Intraclass correlation coefficients for psychometric and chronometric variables

Variable	Lower CI	ICC	Upper CI	n
BIA	0.00	0.48	0.75	40
Broad Math	0.44	0.75	0.89	40
Single Number Naming RT	-0.99	-0.64	-0.15	39
Single Number Naming SD	-0.83	-0.38	0.13	39
Double Number Naming RT	-0.81	-0.35	0.17	39
Double Number Naming SD	-0.68	-0.18	0.32	39
Single-Single Addition RT	-0.68	-0.18	0.31	39
Single-Single Addition SD	-0.72	-0.22	0.28	39
Single-Single Subtraction RT	-0.55	0.10	0.56	36
Single-Single Subtraction SD	-0.35	0.28	0.66	36
Single-Single Multiplication RT	0.36	0.80	0.92	31
Single-Single Multiplication SD	0.38	0.80	0.93	31
Triple Multiplication RT	-1.76	0.23	0.74	27
Triple Multiplication SD	-2.04	0.08	0.68	27

Note. RT: Reaction Time. SD: Intraindividual variability.

Bivariate Analyses

Correlations between RT and intraindividual RT variability, as measured by SD, on the chronometric tasks and scores on the psychometric tests are shown in Table 4. Column 2 of Table 4 gives the Pearson correlation between the chronometric and psychometric variables. As expected, the BIA and Broad Math scores displayed a strong positive relationship. In addition, as scores on either psychometric test increased, RT on the chronometric tests tends to decreased, as does intraindividual variability (RTSD). These relationships tend to become stronger as the tasks become more difficult.

When decomposing the Pearson correlation into WF and BF components, the WF correlation was generally as large as, and sometimes larger than, the BF correlations. The only major exception to this pattern is with the BIA-Broad math relationships, where the BF correlation was approximately three-times the magnitude of the WF correlation.

Thus, the factors influencing the relationship between the psychometric and chronometric variables were minimally influenced by BF factors. The relationship between general cognitive ability and general math skills, as measured by paper-and-pencil tests, however, was largely influenced by BF factors.

Table 4. Correlations between performance on BIA and Broad Math tests and chronometric variables for subject group

	Pearson Correlation	WF (Lower CI, Upper CI)	BF (Lower CI, Upper CI)
Correlation of BIA with:			
Broad Math	0.79	0.38 (0.65, 0.9)	0.91 (0.59, 0.9)
Single Number Naming RT	0.06	0.03 (-0.28, 0.39)	0.11 (-0.32, 0.44)
Single Number Naming SD	0.14	0.19 (-0.17, 0.47)	0.13 (-0.22, 0.49)
Double Number Naming RT	-0.04	-0.03 (-0.37, 0.32)	-0.05 (-0.41, 0.35)
Double Number Naming SD	0.05	0.04 (-0.23, 0.39)	0.06 (-0.33, 0.39)
Single-Single Addition RT	-0.20	-0.24 (-0.52, 0.11)	-0.2 (-0.56, 0.19)
Single-Single Addition SD	-0.23	-0.34 (-0.54, 0.12)	-0.18 (-0.59, 0.15)
Single-Single Subtraction RT	-0.18	-0.3 (-0.53, 0.22)	-0.14 (-0.52, 0.19)
Single-Single Subtraction SD	-0.24	-0.25 (-0.57, 0.19)	-0.25 (-0.56, 0.1)
Single-Single Multiplication RT	-0.24	-0.15 (-0.68, 0.37)	-0.26 (-0.53, 0.09)
Single-Single Multiplication SD	-0.27	-0.34 (-0.68, 0.31)	-0.27 (-0.55, 0.08)
Triple Multiplication RT	-0.22	-0.31 (-0.84, 0.67)	-0.2 (-0.48, 0.09)
Triple Multiplication SD	-0.31	-0.43 (-0.86, 0.57)	-0.29 (-0.54, -0.01)
Correlation of Broad Math with:			
Single Number Naming RT	-0.01	-0.05 (-0.36, 0.32)	0.01 (-0.41, 0.42)
Single Number Naming SD	-0.04	0.01 (-0.41, 0.29)	-0.07 (-0.42, 0.4)
Double Number Naming RT	-0.08	-0.05 (-0.42, 0.25)	-0.13 (-0.44, 0.33)
Double Number Naming SD	-0.09	-0.17 (-0.43, 0.24)	-0.07 (-0.46, 0.33)
Single-Single Addition RT	-0.14	-0.28 (-0.45, 0.18)	-0.08 (-0.48, 0.27)
Single-Single Addition SD	-0.12	-0.25 (-0.46, 0.23)	-0.07 (-0.48, 0.29)
Single-Single Subtraction RT	-0.18	-0.5 (-0.54, 0.2)	-0.08 (-0.52, 0.23)
Single-Single Subtraction SD	-0.21	-0.37 (-0.6, 0.2)	-0.17 (-0.54, 0.18)
Single-Single Multiplication RT	-0.35	-0.5 (-0.75, 0.1)	-0.33 (-0.62, 0.06)
Single-Single Multiplication SD	-0.32	-0.42 (-0.73, 0.17)	-0.31 (-0.58, 0.13)
Triple Multiplication RT	-0.32	-0.03 (-0.89, 0.53)	-0.36 (-0.57, 0)
Triple Multiplication SD	-0.30	-0.01 (-0.88, 0.58)	-0.34 (-0.54, 0.09)

CHAPTER FOUR

Discussion

Limitations

One limitation to this study and the conclusions that can be drawn from it may be extracted from the fact that there was a lot of missing data, especially with chronometric tasks. While the exact reason for each missing data point is unknown, one of the most likely reasons for data being absent is technological glitches and/or participants leaving before completing the task, whether because they were tired, could no longer focus after a long day of testing, or for other reasons (the chronometric tasks were often the last test given). We tested the data to see if there any patterns in the missingness using Little's test for missing completely at random ($\chi^2 = 54.22$, df=32, $p = .01$). The results indicated that there might be some slight pattern in the data's missingness (Little, 1988).

Another potential limitation with tasks maybe too difficult (e.g., triple multiplication) is that if participants do answer all of the questions correctly, they may take a long time to do so. RT tasks are designed to be a measure of simple information processing capacity; increased difficulty may require a more complex problem-solving strategy that they have not automatized. The need to employ complex problem-solving strategies would likely increase the range of RTs because it would take some of the participants substantially longer than others (Widaman, Little, Geary, & Cormier, 1992). This could lower the Pearson coefficients and weaken the correlations between psychometric and chronometric variables.

Another limitation that could exist in studies using RT testing is the inclusion of tasks that are not difficult enough (e.g., number naming). Not only would all of the participants answer all of the questions correctly, but those of average cognitive ability might have RTs similar to those of above average cognitive ability. This would likely yield a diminished correlation between psychometric and chronometric variables, as well.

Conclusions

We examined the relationship between paper-and-pencil tests of math and general cognitive ability (using the Woodcock Johnson Tests of Achievement and Cognitive Ability, respectively) and chronometric tasks of math ability. The chronometric tests used were designed to be simple enough that, given no time constraints, the typical child in middle school could complete all of the items without error. Therefore, reaction time (RT), and the intraindividual variability of RT over trials (RTSD), measured not how much the children knew, but how quickly they could retrieve what they knew.

As expected, there was a strong positive correlation between the paper-and-pencil tests of general and math cognitive ability. Moreover, the (Pearson) correlation between the psychometric tests and the RT and RTSD for chronometric tests grew increasingly negative as the chronometric task difficulty increased. This is consistent with other studies that have shown that RT becomes a better indicator of cognitive ability when the tasks become more difficult (as long as they are not overly difficult) (Jensen, 2006).

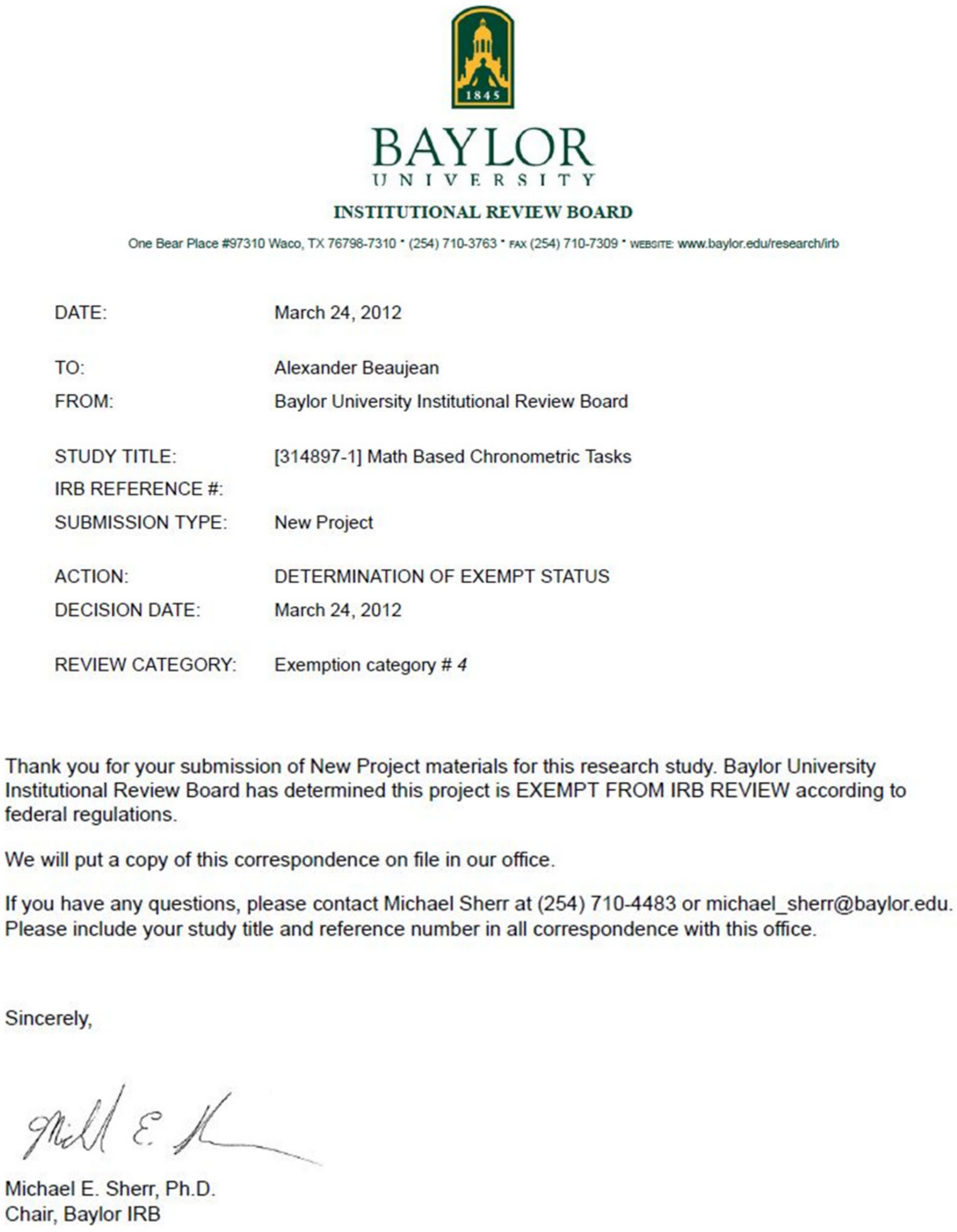
When examining the influence of within family (WF) and between family (BF) factors on the tasks, the WF factors generally played a role that was equal to, or larger than, that of BF factors. This was true for both individual task performance as well as the bivariate relationships between the psychometric and chronometric tasks. The results suggest that unshared environmental factors play more of a role than shared environmental influences. In other words, variance in cognitive ability, as well as RT and RTSD for most of the chronometric tasks, was due to unshared environment, and the relationship between psychometric and chronometric variables that is increasingly negative with increased task difficulty is also due to unshared environmental factors, which falls in line with other studies that have examined chronometric tasks using a genetically informative design (Beaujean, 2005; Jensen et al., 1989).

As with most general patterns, however, there were some exceptions. First, since the relationship between general cognitive ability and general math skills, as measured by paper-and-pencil tests, was largely influenced by BF factors, this relationship is likely due to shared environmental factors. Likewise, BF factors significantly influenced performance variance in Broad Math, Single-Single Multiplication RT, and Single-Single Multiplication RTSD, indicating that much of the variance in these tasks can also be attributed to the shared environment.

APPENDIX

APPENDIX

Exemption from Institutional Review Board



BAYLOR
UNIVERSITY
INSTITUTIONAL REVIEW BOARD
One Bear Place #97310 Waco, TX 76798-7310 • (254) 710-3763 • FAX (254) 710-7309 • WEBSITE: www.baylor.edu/research/irb

DATE: March 24, 2012

TO: Alexander Beaujean
FROM: Baylor University Institutional Review Board

STUDY TITLE: [314897-1] Math Based Chronometric Tasks
IRB REFERENCE #:
SUBMISSION TYPE: New Project

ACTION: DETERMINATION OF EXEMPT STATUS
DECISION DATE: March 24, 2012

REVIEW CATEGORY: Exemption category # *4*

Thank you for your submission of New Project materials for this research study. Baylor University Institutional Review Board has determined this project is EXEMPT FROM IRB REVIEW according to federal regulations.

We will put a copy of this correspondence on file in our office.

If you have any questions, please contact Michael Sherr at (254) 710-4483 or michael_sherr@baylor.edu. Please include your study title and reference number in all correspondence with this office.

Sincerely,

Michael E. Sherr, Ph.D.
Chair, Baylor IRB

BIBLIOGRAPHY

Ashcraft, M. H. (1982). The development of mental arithmetic: A chronometric approach. *Developmental Review*, *2*, 213–236. doi:10.1016/0273-2297(82)90012-0

Ashcraft, M. H., & Battaglia, J. (1978). Cognitive arithmetic: Evidence for retrieval and decision processes in mental addition. *Journal of Experimental Psychology: Human Learning and Memory*, *4*, 527–538. doi:10.1037/0278-7393.4.5.527

Ashcraft, M. H., & Fierman, B. A. (1982). Mental addition in third, fourth, and sixth graders. *Journal of Experimental Child Psychology*, *33*, 216–234. doi:10.1016/0022-0965(82)90017-0

Baumeister, A. A., & Kellas, G. (1968). Reaction time and mental retardation. *International Review of Research in Mental Retardation* (Vol. 3, pp. 163–193). New York: Academic Press. Retrieved from http://www.sciencedirect.com/science/article/pii/S0074775008600117

Beaujean, A. A. (2005). Heritability of cognitive abilities as measured by mental chronometric tasks: A meta-analysis. *Intelligence*, *33*, 187–201. doi:10.1016/j.intell.2004.08.001

Beaujean, A. A., Knoop, A., & Holliday, G. (2006). Does chronometry have a place in assessing math disorders? *Learning Disability Quarterly*, *29*, 32–38.

Carlson, J. S., & Jensen, C. M. (1982). Reaction time, movement time, and intelligence: A replication and extension. *Intelligence*, *6*, 265–274. doi:10.1016/0160-2896(82)90003-4

Carlson, J. S., Jensen, C. M., & Widaman, K. F. (1983). Reaction time, intelligence, and attention. *Intelligence*, *7*, 329–344. doi:10.1016/0160-2896(83)90008-9

Carroll, J. B. (1993). *Human cognitive abilities: a survey of factor-analytic studies*. Cambridge: Cambridge University Press.

Cisero, C. A., Royer, J. M., Marchant, H. G. I., & Jackson, S. J. (1997). Can the computer-based academic assessment system (CAAS) be used to diagnose reading disability in college students? *Journal of Educational Psychology*, *89*, 599–620. doi:10.1037/0022-0663.89.4.599

Cohn, S. J., Carlson, J. S., & Jensen, A. R. (1985). Speed of information processing in academically gifted youths. *Personality and Individual Differences*, *6*, 621–629. doi:10.1016/0191-8869(85)90012-1

Cooney, J. B., Swanson, H. L., & Ladd, S. F. (1988). Acquisition of mental multiplication skill: Evidence for the transition between counting and retrieval strategies. *Cognition and Instruction*, *5*, 323–345. doi:10.1207/s1532690xci0504_5

Dunn, J., & Plomin, R. (1992). *Separate lives: Why siblings are so different*. Basic Books.

Eysenck, H. J. (1987). Intelligence and reaction time: The contribution of Arthur Jensen. *Arthur Jensen: Consensus and controversy* (p. 506). Philadelphia, PA: Psychology Press.

Geary, D. C. (1996). *Children's mathematical development: Research and practical applications* (1st ed.). Washington, D.C.: American Psychological Association.

Geary, D. C., & Widaman, K. F. (1987). Individual differences in cognitive arithmetic. *Journal of Experimental Psychology: General*, *116*, 154–171. doi:10.1037/0096-3445.116.2.154

Groen, G. J., & Parkman, J. M. (1972). A chronometric analysis of simple addition. *Psychological Review*, *79*, 329–343. doi:10.1037/h0032950

Jensen, A. R. (1980). Uses of sibling data in educational and psychological research. *American Educational Research Journal*, *17*, 153–170. doi:10.2307/1162480

Jensen, A. R. (1982). The chronometry of intelligence. In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence* (Vol. 1, pp. 255–310). Hillsdale, NJ: Erlbaum.

Jensen, A. R. (1992). The importance of intraindividual variation in reaction time. *Personality and Individual Differences*, *13*, 869–881. doi:10.1016/0191-8869(92)90004-9

Jensen, A. R. (2006). *Clocking the mind: mental chronometry and individual differences* (1st ed.). Amsterdam; Boston; London: Elsevier.

Jensen, A. R., Cohn, S. J., & Cohn, C. M. (1989). Speed of information processing in academically gifted youths and their siblings. *Personality and Individual Differences*, *10*, 29–33. doi:10.1016/0191-8869(89)90174-8

Jensen, A. R., & Munro, E. (1979). Reaction time, movement time, and intelligence. *Intelligence*, *3*, 121–126. doi:10.1016/0160-2896(79)90010-2

Jensen, A. R., Schafer, E. W. P., & Crinella, F. M. (1981). Reaction time, evoked brain potentials, and psychometric g in the severely retarded. *Intelligence*, *5*, 179–197. doi:10.1016/0160-2896(81)90008-8

Kenny, D. A., Kashy, D. A., & Cook, W. L. (2006). *Dyadic Data Analysis* (1st ed.). New York: The Guilford Press.

Lahey, B. B., & D'Onofrio, B. M. (2010). All in the family: Comparing siblings to test causal hypotheses regarding environmental influences on behavior. *Current Directions in Psychological Science*, *19*, 319–323. doi:10.1177/0963721410383977

Little, R. J. A. (1988). A test of missing completely at random for multivariate data with missing values. *Journal of the American Statistical Association*, *83*, 1198–1202. doi:10.2307/2290157

Lynch, M., & Walsh, B. (1998). *Genetics and analysis of quantitative traits* (1st ed.). Sinauer Associates.

McGraw, K. O., & Wong, S. P. (1996). Forming inferences about some intraclass correlation coefficients. *Psychological Methods*, *1*, 30–46. doi:10.1037/1082-989X.1.1.30

Miller, K., Perlmutter, M., & Keating, D. (1984). Cognitive arithmetic: Comparison of operations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*, 46–60. doi:10.1037/0278-7393.10.1.46

Neale, M. C., & Maes, H. H. M. (1992). *Methodology for genetic studies of twins and families*. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Olneck, M. (1977). On the use of sibling data to estimate the effects of family background, cognitive skills, and schooling: Results from the Kalamazoo Brothers Study. *Kinometrics: Determinants of socioeconomic success within and between families* (pp. 125–162). Amsterdam, North Holland.

Plomin, R., DeFries, J. C., McClearn, G. E., & McGuffin, P. (2008). *Behavioral genetics* (5th ed.). New York: Worth Publishers.

R Development Core Team, R. F. F. S. C. (2011). Official@ R - A Language and Environment for Statistical Computing. *R*.

Robinson, W. S. (1950). Ecological correlations and the behavior of individuals. *American Sociological Review*, *15*, 351–357. doi:10.2307/2087176

Sen, A., Jensen, A. R., Sen, A. K., & Arora, I. (1983). Correlation between reaction time and intelligence in psychometrically similar groups in America and India. *Applied Research in Mental Retardation*, *4*, 139–152. doi:10.1016/0270-3092(83)90006-1

Snijders, T. A. B., & Bosker, R. J. (1999). *Multilevel analysis: An introduction to basic and advanced multilevel modeling*. London; California; New Delhi: SAGE.

Sternberg, S. (1966). High-speed scanning in human memory. *Science*, *153*, 652 –654. doi:10.1126/science.153.3736.652

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. *Acta Psychologica*, *30*, 276–315. doi:10.1016/0001-6918(69)90055-9

Telzrow, C. F. (1983). Making child neuropsychological appraisal appropriate for children: Alternative to downward extension of adult batteries. *Clinical Neuropsychology*, *5*, 136–141.

Turkheimer, E., & Waldron, M. (2000). Nonshared environment: A theoretical, methodological, and quantitative review. *Psychological Bulletin*, *126*, 78–108. doi:10.1037/0033-2909.126.1.78

Vernon, P. A. (1981). Reaction time and intelligence in the mentally retarded. *Intelligence*, *5*, 345–355. doi:10.1016/0160-2896(81)90025-8

Vernon, P. A. (1983). Speed of information processing and general intelligence. *Intelligence*, *7*, 53–70. doi:10.1016/0160-2896(83)90006-5

Vernon, P. A. (1987). *Speed of information-processing and intelligence*. Norwood, N.J.: Ablex.

Vernon, P. A., & Jensen, A. R. (1984). Individual and group differences in intelligence and speed of information processing. *Personality and Individual Differences*, *5*, 411–423. doi:10.1016/0191-8869(84)90006-0

Widaman, K. F., Geary, D. C., Cormier, P., & Little, T. D. (1989). A componential model for mental addition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *15*, 898–919. doi:10.1037/0278-7393.15.5.898

Widaman, K. F., Little, T. D., Geary, D. C., & Cormier, P. (1992). Individual differences in the development of skill in mental addition: Internal and external validation of chronometric models. *Learning and Individual Differences*, *4*, 167–213. doi:10.1016/1041-6080(92)90002-V

Woodcock, R., & McGrew, K. S. (2001). *Woodcock-Johnson III technical manual.* Itasca, IL: Riverside Publishing.

Woodcock, R., McGrew, K. S., & Mather, N. (2001a). *Woodcock-Johnson III Tests of Achievement*. Itasca, IL: Riverside Publishing.

Woodcock, R., McGrew, K. S., & Mather, N. (2001b). *Woodcock-Johnson III Tests of Cognitive Abilities*. Rolling Meadows, IL: Riverside Publishing.