A Retrospective Investigation of Sex Differences in Cognition in Children and Young Adults

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The present study is a retrospective analysis to determine whether sex differences in cognition exist in children and young adults (i.e., those between 4 and 18 years of age) and to further identify when these differences emerge across cognitive development. A cross-sectional research design was used to analyze data previously collected by a third-party collaborator. Data (N = 8,184) was collected using the Cambridge Brain Science cognitive test battery, followed by a demographic questionnaire completed by participants' parents or guardians. Data were analyzed using factorial analysis of variance with age and gender as fixed factors. The results demonstrate that females score higher in verbal and reasoning domains as well as in tasks measuring deductive reasoning and attention. Males score higher in the short-term memory domain and in tasks measuring their spatial short-term memory. The emergence of sex differences in cognition varied across tasks, either appearing at the elementary (4 to 9 years), middle (10 to 13 years), or high school (14 to 18 years) levels. The effect of sex was absent when controlling for cofounding variables. The findings demonstrate that females and males are more similar than different from a cognitive perspective.

Keywords: sex differences, cognitive functioning, cognitive development, neurocognitive test battery

A topic of great interest to many psychological researchers is whether there are differences between males and females (Jäncke, 2018). An area that frequently demonstrates sex-based differences is cognitive functioning, which includes abilities like reasoning, planning, attention, problem solving, and processing complex ideas (Gottfredson, 1997). These abilities are vital to everyday functioning and are of particular importance to academic achievement (Nesayan et al., 2019). Recently, researchers have emphasized a need for a re-evaluation of the literature regarding sex-based differences in cognition (Miller & Halpern, 2014).

Miller and Halpern (2014), in particular, note how more recent findings related to cognitive sex differences expose the inextricable and intertwined relationship between biology and environment in determining one's cognitive capabilities. Wade (2013) further notes the widespread abandonment of the "nature/nurture dichotomy" in academia and even acknowledges the potential impacts society may have on our biology (p.278). Furthermore, since the 2000s, scholars have noted the impacts that social progress has had on the activities and tasks boys and girls partake in. For instance, a larger number of young girls are expressing interest in subjects like science and math than ever before (Charlesworth & Banaji, 2019), while the proportions of young males entering into artistic disciplines like cheerleading and dance have substantially increased (Kim & Kwon, 2020). Thus, there is a need to conduct research that reflects these changes in societal norms and expectations, while also considering how these socio-environmental changes intertwine with biological factors in determining sex differences in cognition.

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The present study will determine whether there are cognitive sex differences in male and female children and young adults and, more importantly, it will identify precisely *when* these differences can be seen across development. Although the literature often uses the terms gender and sex interchangeably, they in fact communicate very different things (Jäncke, 2018). While gender is the identity a person assumes themselves throughout their life, biological sex is assigned to an individual at birth and groups individuals into categories based on their primary reproductive system and secondary sex characteristics (Miller & Halpern, 2014).

An extensive amount of research demonstrates that males and females differ in their cognitive performance. For instance, females tend to score higher than males on tasks of memory, verbal fluency, and nonverbal reasoning, while males outperform females on visuospatial, sensorimotor, and motor tasks (Barel, 2018; Bell et al., 2006; Gur et al., 2012; Kraft & Nickel, 1995; Miller & Halpern, 2014; Satterthwaite et al., 2015). These patterns have been found consistently across a wide variety of research studies. However, findings pertaining to sex differences in cognition are limited as they have focused primarily on the performance of adult individuals. While several studies have researched sex differences in the academic performance of children and young adults between the ages of 4 and 18 (Wai et al., 2010), these studies do not speak to potential sex differences in children's and young adults' performance of specific cognitive domains such as verbal, memory, and sensorimotor tasks.

In addition, the studies that have been conducted with children and young adult participants merely postulate how established sex differences in areas such as brain anatomy or hormonal levels may contribute to sex differences in the performance of cognitive tasks (Raznahan, 2010; Waber, 1977). However, an established consensus on whether there are defined differences in cognitive performance between male and female children and young adults has yet to be reached. Understanding the development of cognitive skills and the sex differences that may exist in these skills is important, as studies have consistently shown how cognitive challenges developed during childhood and young adulthood may extend into adulthood (Nesayan et al., 2019). These cognitive challenges have been found to impact academic achievement (Nesayan et al., 2019) and future career status and success (Feinstein & Bynner, 2004). Thus, examining these cognitive abilities early on in an individual's life is important for mitigating the difficulties in vocational and economic outcomes that may arise as they enter adulthood.

The lack of attention paid to sex differences in the cognitive abilities of males and females under the age of 18 means that we also do not know precisely when these differences emerge in development. Past research contains mixed findings with respect to the appearance of sex-based cognitive differences throughout childhood and young adulthood. The limited studies that have investigated these sex-based cognitive differences in children and young adults have concluded that sex differences appear in childhood and persist into adulthood (Barel, 2018; Kraft & Nickel, 1995; Miller & Halpern, 2014; Satterthwaite et al., 2015). However, contradictory findings from recent studies have found fewer sex differences in cognitive performance due to the progression of societal gender norms and expectations (Miller & Halpern, 2014). Thus, it is still not evident when the sex-based differences in cognitive abilities emerge during development.

In addition, studies that have investigated the emergence of sex-based differences in cognition suffer from significant shortcomings like relatively small sample sizes and the use of simple tasks such as the Weschler Adult Intelligence Scale (WAIS; Wechsler, 1981). While WAIS offers a breadth of cognitive tasks suitable for measuring a wide range of cognitive abilities, the lack of complexity in the nature of the tasks themselves limits a study's overall findings since they fail to fully grasp and measure the depth and complexity of the cognitive ability being measured. Furthermore, these previous studies fail to capture a thorough understanding of cognitive functioning since they focus on one specific cognitive ability rather than exploring a wider range of abilities and tasks which would contribute to a broader understanding of cognitive functioning. Therefore, there is a strong need for research on sex-based differences in cognitive performance that employs a large sample size and makes use of more complex, thorough cognitive tasks.

The current study will answer two fundamental questions with respect to sex differences in cognition. First, this study explores whether sex-based differences exist in children and young adults (i.e., individuals between the ages of 4 and 18) and secondly, when these differences emerge throughout development.

Before presenting the current study, a review of the established literature surrounding child and young adult sex differences in cognition is provided. First, an analysis of the limited studies that have investigated sex differences in cognition using child and young adult participants is presented, followed by an outline of the literature on the emergence of sex differences in cognition across development.

Sex Differences in Cognition

While some researchers have focused on cognitive sex differences using child and young adult participants, their findings merely propose explanations for why differences *may* exist in child and young adult individuals rather than establishing a clear consensus on whether males and females differ in cognitive abilities. Nonetheless, these findings indicate a significant potential for sex differences in the cognitive performance of children and young adults.

In a 2012 study, Gur and colleagues focused on both age and sex-related differences in participants' performance on a series of neurocognitive tasks. They studied a large sample size of 3,500 youths, aged 8 to 21, who completed the Penn Computerized Neurocognitive Battery (Penn CNB), a battery consisting of 14 tests exploring many aspects of cognition (e.g., sensorimotor speed, spatial ability, attention, working, spatial and verbal memory). Gur and colleagues (2012) found substantial age-related improvements across cognitive domains such as memory, attention, and motor speed, with moderate to large effect sizes. Furthermore, they found sex differences in both overall performance and age-related variation. Specifically, the results demonstrated that females were more accurate and faster than males on tests of social cognition and face and verbal memory. Females were less accurate and slower than males on tests of attention and spatial and working memory. On the other hand, males were more accurate and faster than females on tests of spatial abilities, sensorimotor speed, and motor speed. The authors noted that the effects of sex were much smaller than the effects of age. Gur and colleagues (2012) further emphasized that the sex differences found were more pronounced after mid-adolescence and that females usually plateau in abilities before males.

While Gur and colleagues' (2012) study contributes significantly to what we know about sex differences in child and young adult participants, it has limitations regarding participant selection and methodology. First, during the recruitment of participants, the authors failed to exclude individuals with medical diagnoses that may have impaired cognitive functioning, thereby impacting their performance on cognitive tests. In addition, the study's sample of participants was biased toward individuals of late adolescence since the youngest participant was already 9 years of age. Therefore, it is unknown whether the effects would apply to children younger than 9 years old. Second, while the Penn CNB battery has been validated (Moore et al., 2015), the number of test items in each domain have been found to not entirely capture the depth nor complexity of the cognitive abilities being measured. The authors themselves thereby emphasized that future research should use a greater number of more complex tasks, as well as tasks that reflect the neurocognitive domain being measured, to fully gauge whether there are sex differences in adolescent cognitive performance.

Ardila and colleagues (2011) conducted a study to assess whether the sex differences in cognition (i.e., verbal, spatial, and arithmetic abilities) that exist in adult participants can be seen in younger participants. The authors sampled 788 monolingual Spanish speakers, aged 5 to 16 years old. The sample consisted of 350 males and 438 females. To assess cognitive abilities, participants completed several subtests of the Child Neuropsychological Assessment (CNA) assessing 7 different cognitive domains including: memory, sensory perception, attentional abilities, oral language abilities, metalinguistic awareness, and visuospatial and visuomotor processing. To analyze the results, the authors conducted seven two-way analyses of variance using sex as the independent variable. Only three domains displayed significant results. In all three domains (language, spatial and sensory-perceptual abilities), males outperformed females. The authors concluded that sex differences could only be found in a small number of cognitive tests and that these differences accounted for a small proportion of the total variance in scores. Thus, Ardila and colleagues (2011) found only minimal sex differences in cognition during development.

There are two fundamental limitations in Ardila and colleagues' 2011 study. First, the participants were non-English speaking and completed a Spanish translation of the CNA. Therefore, the results of the study cannot be generalized to an English-speaking population. The authors also noted how cultural factors may have influenced the results of the study, thereby further limiting the study's validity. Second, as outlined by the authors themselves, the dependent measures used to assess cognitive performance cannot be considered as individual constructs. Therefore, the authors recommend that future studies make use of cognitive tasks with unique underlying cognitive processes to fully assess the depth and complexity of the cognitive abilities being assessed, both independently and as a general measure of cognition.

McGivern and colleagues (1997) investigated whether sex differences seen in younger participants are attributed to differences in information processing. According to the Meyers-Levy (1989) Selectivity Hypothesis, cognitive sex differences arise due to differences in information processing between males and females. Specifically, it suggests that males tend to organize information in a personal or self-related fashion while females tend to focus on information in a more comprehensive manner. The authors hypothesised that males would outperform females only when a stimulus was relevant to capturing the male's attention. To investigate this hypothesis, the authors tested a total of 422 male and female children aged 10 to 15 and an additional 62 adults. Child participants completed a set of four visual-recognition memory tasks, one with male-oriented objects, one with female-oriented objects, one with objects of random nature, and one with patterned stimuli. Adult participants only completed three of the four tests, as they did not complete the patterned stimuli test since it initially revealed significant ceiling effects. These effects occur when a test is relatively easy for the sample of participants being studied, therefore they either score or score close to the maximum score. This does not allow their true abilities to be accurately assessed (Uttl, 2005), so it was omitted from the study. The author's results further revealed a significant effect of sex on visual-recognition memory in both children and adults.

McGivern and colleagues (1997) found that females significantly outperformed males in recognizing random and female-oriented objects. Their results revealed that males performed slightly better in recognition of male-oriented objects, but this finding was non-significant. Despite the non-significant results, the authors interpreted these findings to conclude that males tend to implement self-reliant strategies in completing cognitive tasks and thus focus on information that is particularly relevant to themselves while females tend to utilize more comprehensive or inclusive strategies for information processing. These findings are relevant since they suggest that sex-based differences in information processing can lead to differences in cognitive performance. However, a shortcoming of this study is that the authors tested the selectivity hypothesis on basic memory tasks exclusively rather than using a wide range of higher-order cognitive functions. As a consequence, it is unknown whether the selectivity hypothesis would hold true for other cognitive tasks.

Cognition Across Development

While the research on the sex differences in cognition of younger individuals is quite limited, the emergence of these sex differences that appear in the cognitive development of both children and adults has been well studied. Despite ample amounts of evidence, there are mixed findings within the literature with respect to when certain cognitive differences emerge in development. For example, one study demonstrated that the male advantage in mental rotation can be seen as early as 3 months old (Quinn & Liben, 2013), while contradictory findings suggest that this advantage can only be seen once individuals reach 10 months old (Fricke & Möhring, 2013).

Barel (2018) conducted two studies investigating cognitive performance changes as a function of age as well as the emergence of cognitive sex differences. In the first study, Barel (2018) identified the influential role that sex hormones have during critical development periods in the embryo and how they are linked to pubertal changes later in life. Barel's (2018) first study investigated patterns of cognitive abilities prior to puberty using data gathered from 250 participants ranging in age from 9 to 12 years. Each participant was given six measures of cognitive abilities: three verbal tests and three visuospatial tests. Barel (2018) found evidence of sex differences in verbal abilities, favouring females, between the ages of 9 and 12. Contrary to previous findings, sex differences were not observed in visuospatial tasks, such as mental rotation. Nonetheless, Barel's study demonstrates that sex differences can be identified prior to puberty and his findings were contradictory to prior studies that did find visuospatial sex differences.

Barel and Tzischinsky (2018) conducted a follow-up study using the same tasks, but instead of using child and adolescent participants exclusively, they included adult participants as well. The results of this study confirmed Barel's (2018) initial findings that sex differences are not found in adolescents completing visuospatial tasks but are indeed seen in adults, with males outperforming females. Furthermore, there were contradictory findings between the initial and subsequent study regarding verbal abilities. In fact, the authors identified a reversal in sex differences during the course of development as females were found to perform better prior to puberty, while males performed better only after puberty. As noted by Barel and Tzischinsky (2018), the absence of sex differences in visuospatial abilities may be explained by the differences in the nature of the tasks used to measure mental rotation. While adults were given tasks including 3D rotation, children were given tasks involving 2D objects. Furthermore, a crucial limitation of this study is the gap in the age of adolescent and adult participants. The adolescent participants included in the study were between the ages of 5 to 12 years old, with the oldest participant being 12 years old. The adult participants were 21 years of age and older, and thus, an important age range (12 to 21 years) critical to cognitive development was excluded from these studies. In order to fully grasp the emergence of cognitive sex differences, an inclusive yet wide age range should be used.

Finally, Voyer and colleagues' (1995) large, but dated, meta-analysis on the spatial abilities of participants aged 4 to 60 years is worth considering. Their meta-analysis analyzed the effect sizes of 286 studies on spatial abilities and revealed that sex differences in spatial abilities were present. However, the authors emphasized that the small effect sizes found are in part due to the measures used and further noted how these different measures focus on different processes within a cognitive domain. For example, the authors recommend that future analyses use tests such as the Mental Rotations test to assess spatial abilities since it produces the most robust sex differences in comparison to other tests. In terms of the emergence and magnitude of sex differences, the authors found a positive correlation between age and sex differences, thereby demonstrating that sex differences do increase with age. Furthermore, performance on various spatial measures demonstrated sex differences at ages 7 and 14, contradicting Barel's (2018) findings. Voyer and colleagues (1995) noted that spatial abilities are not unitary and rely on skills developed at various points in development. Thus, the emergence of sex differences is heavily influenced by the tests used. Measures of cognitive abilities should be both reliable and valid in measuring a cognitive skill.

The Present Study

The existence of sex-based differences in the cognitive abilities of males and females is evident from past research. There is also data supporting the fact that these differences may emerge during childhood and adolescence. However, past studies that have found sex-based differences suffered from significant limitations like the exclusive use of adult participants and the use of simple and conceptually narrow tasks. Furthermore, previous studies relied mainly on in-person testing using the traditional paper-pencil format, thereby limiting their sample sizes. Using an online platform for cognitive tests will provide an important advantage to this study by increasing the sample size. Thus, the present study will make use of an exceedingly large and diverse sample size as well as comprehensive tasks to answer two central questions: a) do sex-based differences in cognition exist in children and young adults, and b) when do these differences emerge during the course of cognitive development?

The current study will make use of pre-existing data to explore the presence and emergence of cognitive sex differences in children and young adults. A powerful tool that is commonly used to measure cognitive abilities are computerized neurocognitive batteries, a collection of online tests evaluating one's ability or skill in a particular cognitive domain. These tests have clear advantages compared to the traditional paper-pencil format, including better standardization of administration and scoring, tracking of subjects' responses, cost efficiency, and the ability to generate large and more accurate databases (Gualtieri, 2004).

The data used was obtained from over 8,000 participants who completed the Cambridge Brain Science (CBS) test battery, an online-testing platform consisting of 12 tasks measuring performance in cognitive domains such as: visuospatial working memory, episodic memory, spatial planning, mental rotation, attention inhibition, deductive reasoning, short-term memory, and grammatical reasoning. Compared to previous studies that assessed a limited number of cognitive abilities, this battery offers a more comprehensive and complex series of tests that provide a more reliable and valid measure of cognitive performance. These CBS tasks have been used by researchers who study intelligence (Hampshire et al., 2012), concussion (Stafford et al., 2020), sleep (Wild et al., 2018), and acute intensive care or hospitalization (Honarmand et al., 2019) in relation to cognitive functioning.

The study has two main hypotheses. The first hypothesis is that sex-based differences exist in children and young adults. Based on the existing literature, particularly the findings of Gur et al. (2012) and Barel (2018), it is predicted that females will outperform males on tasks of verbal and memory abilities, specifically verbal short-term and episodic memory, while males will outperform females on visuospatial tasks, such as visuospatial working memory and mental rotation. Furthermore, following Barel's (2018) findings on the variability of cognitive development based on sex, it is hypothesized that the sex differences in cognition outlined in the first hypothesis will emerge in the elementary school group (i.e., 4 to 10 years of age), remain relatively stable in the middle school group (i.e., 11 to 12 years of age), and begin to disappear in the high school group.

Method

The data for the present study was previously collected by researchers at Brain Balance Achievement Centers, in conjunction with Cambridge Brain Sciences (CBS). Data was collected between March 2019 and October 2020. The data were originally collected to test the efficacy of an integrative and multimodal training program on improving cognitive functioning.

Participants

Participants were referred to the program after demonstrating cognitive or developmental difficulties in everyday functioning. Data were collected for individuals between 4 and 18 years of age. Participants were included in the study if they did not have any known genetic conditions and demonstrated a developmental readiness for the program. The researchers defined this readiness as the ability to cooperate with instructors, follow one-step directions, attempt at tasks, and complete tasks through the duration of the program. Further, participants were included in the study if they tested below the age-appropriate levels across a variety of basic motor assessments. Data was collected for 12,317 participants and stored in the CBS database. Participants were removed from the study if they had any incomplete or missing test scores, as well as if they were below the age of 4 or above the age of 18. After missing test scores were removed, a sample size of 8,184 remained. Remaining participants were divided into three age categories: an elementary school group consisting of individuals 4 to 9 years old (M = 8.50, SD = 0.90), a middle school group of those 10 to 13 years old (*M* = 11.76, *SD* = 1.13), and lastly, a high school group consisting of those 14 to 18 years old (*M* = 15.82, *SD* = 1.31). The individuals were divided in this fashion to ensure that similar age grades and learning content remained together throughout the study. A summary of participants' age, sex, mean, and standard deviation can be found in Table 1. The present study was approved by the Western University Non-Medical Research Ethics Board (NMREB; see Appendix B).

Table 1

Age and Sex Breakdown with Mean and Standard Deviation of Each Age Group

		Age (years)				Sex	
Group	N	Mean	SD	Min	Max	Male (N)	Female (N)
Elementary School	3345	8.50	0.90	4.03	9.99	2292	1053
Middle School	3201	11.76	1.13	10.00	13.99	2187	1014
High School	1638	15.82	1.31	14.00	18.99	1056	582

Materials

Cognitive Test Batteries

Participants were tested using the CBS Cognitive Test Battery, an online platform consisting of 12 neurocognitive tests measuring various components of cognition. This collection of cognitive tasks has been previously used and validated in a wide range of large-scale studies assessing cognition (Hampshire et al., 2012; Honarmand et al., 2019; Wild et al., 2018). The tests provide a superior measure of cognitive abilities since the areas of cognitive performance measures overlap with one another but can also be used as independent constructs using composite scores. From the 12 CBS tasks used, specific cognitive abilities were measured while the general measure of cognition as a whole was equally captured. The tests were administered at the Brain Balance Achievement Centers, under the supervision of trained staff members. However, due to the COVID-19 pandemic, several participants completed the CBS tasks from home, under the supervision of a parent or guardian. A description of each CBS task is outlined below.

Double Trouble (DT) Task. This task is a modified version of the classic Stroop task (Stroop, 1935). A target word appears on the top of the screen in either red or blue. Participants must identify the ink colour of the target word by choosing one of the two probe words written below. Participants must solve as many problems as possible in 90 seconds.

Odd One Out (OOO) Task. This task is a sub-set of problems from the Cattell Culture Fair Intelligence Test (Cattell, 1949). Several groups of objects appear on the screen. Participants are required to identify the feature that relates the groups together and then identify the group that does not correspond to that rule. Each trial increases or decreases in difficulty, depending on whether the participant completed the previous trial correctly. Scores are based on how many problems can be solved within 3 minutes. This task is used to measure an individual's deductive reasoning abilities.

Digit Span (DS) Task. This task consists of a series of problems similar to the verbal working memory component of the Weschler-Adult Intelligence-Revised Test (WAIS-R; Weschler, 1981). A sequence of digits appears on the screen, one at a time, and participants are required to repeat the sequence of digits by clicking on the keyboard of numbers, displayed on the screen. Each trial increases or decreases in difficulty, depending on whether the participant completed the previous trial correctly. The objective is to reach the level with the highest number of digit strings.

Feature Match (FM) Task. This task is derived from a classic search task used to measure attentional processing

(Tresiman & Gelade, 1980). Two grids of various objects appear, side-by-side. The groups can be identical or differ by one item and the participant is required to indicate if the groups match. Each trial increases or decreases in difficulty, depending on whether the participant completed the previous trial correctly. Participants' scores are based on how many problems they solve within 90 seconds.

Polygons (PO) Task. This is a task based on the Interlocking Pentagons Task, a test routinely used in the assessment of age-related disorders and in visuospatial processing (Folstein et al., 1975). In this specific task, two overlapping figures appear on the left-hand side of the screen, while a single figure appears on the right-hand side. Participants are required to indicate if the figure on the right-hand side matches any one of the figures on the left-hand side. Each trial increases or decreases in difficulty (i.e., figures become more or less similar), depending on whether the participant completed the previous trial correctly. Participants' scores are based on how many problems they solve within 90 seconds.

Paired Associates (PA) Task. This is a test of memory functioning where numerous boxes appear on the screen and reveal an icon that is placed in the box. The icon then appears in the middle of the screen and the participant is required to click on the box that the icon first appeared in. Each trial increases or decreases in difficulty, depending on whether the participant completed the previous trial correctly. Participants' scores are based on the highest number of boxes that were correctly identified in which the icon first appeared.

Monkey Ladder (ML) Task. A modified version of a task from non-human primate literature (Inoue & Matsuzawa, 2007), this task is used to assess visuospatial working memory. Participants are required to click randomly spaced boxes on the screen in the correct ascending numerical sequence. Each trial increases or decreases in difficulty, depending on whether the participant completed the previous trial correctly. The objective is for the participant to reach the level with the highest number of boxes.

Grammatical Reasoning (GR) Task. Derived from Alan Baddeley's three-minute grammatical reasoning test (Baddeley, 1967), this task is used to assess verbal memory abilities. A written statement appears at the top of the screen and the participant is required to indicate if the statement correctly describes the shapes that appear below the written statement. Participants must solve as many problems as possible in 90 seconds.

Rotations (RT) Task. A task adapted from the Spatial Rotation Task, this task is used to measure mental rotation abilities (Silverman et al., 2000). Two grids appear on the screen containing coloured squares (each with a certain number of squares). One of the grid's squares may be rotated by a multiple of 90 degrees. The grids may be identical or differ by one item position and participants would have to indicate if the groups match. The objective is to solve as many problems as possible within 90 seconds.

Spatial Span (SS) Task. Adapted from the Corsi Block Tapping Task, this task is used to measure short-term memory capacity (Corsi, 1972). Sixteen purple squares first appear on the screen and are followed by a randomly ordered sequence of green squares. Participants are required to repeat the sequence of green squares by clicking on the purple squares in the same order. Each trial increases or decreases in difficulty, depending on whether the participant completed the previous trial correctly.

Token Search (TS) Task. A task used to assess working memory and strategic abilities during search behaviors (Collins et al., 1998). A green token is hidden inside multiple boxes. Once a token is found, it moves to another box and participants must work through the boxes to find the missing token, without clicking on the same box twice or clicking on a box that has already had the token. Each trial increases or decreases in difficulty, depending on whether the participant completed the previous trial correctly. The objective is for the participant to get to the level with the highest number of tokens.

Spatial Planning (SP) Task. Based on the 'Tower of London' task (Shallice, 1982), Spatial Planning is a neuropsychological test that measures executive functioning. Participants are instructed to arrange numbered beads that are positioned on a tree in the correct ascending numerical order. Each trial becomes increasingly harder and participants must try to solve as many as possible within 3 minutes.

Participants between the ages of 4 to 6 were instructed to complete a battery consisting of three tasks: Paired Associates, Spatial Span, and Feature Match, as these tasks do not require advanced reading comprehension skills, while participants aged 7 and above were tasked with all 12 CBS tests.

Demographic Questionnaire

A 29-item demographic questionnaire was used to control for covariates (i.e., characteristics of the participants that may impact results). The questionnaire was completed by a parent or guardian of each participant, following the completion of the first set of CBS tasks. The questionnaire was provided on Qualtrics, an online survey software. The questionnaire collected information such as participants' biological sex, age, birthdate, ethnicity, medical diagnoses or medications, social, sleep, and physical activity patterns, and concentration and motivation tendencies. In addition, the questionnaire included items pertaining to participants' family life: family income, primary languages spoken at home, and parents' level of education. Questionnaire instructions asked parents and guardians to answer as accurately as possible and allowed respondents to skip any questions they did not wish to answer (see Appendix C).

Procedure

Upon signing up for the program, participants' parents and guardians were given a document containing the Brain Balance Privacy Policy to review, ensuring that they agreed to the terms of the program before the program began. A copy of this policy can be found on the Brain Balance website (https://www.brainbalancecenters.com). Once admitted to the program, participants were assessed at various Brain Balance Achievement Centers by trained staff members to ensure that they met the inclusionary criteria of the study. If participants met the criteria, they were instructed to return back to the Brain Balance Achievement Centers at a later date to proceed with the first set of CBS tasks. The CBS tasks were completed on a standard computer under the supervision of a trained Brain Balance staff member, and in the presence of a parent or guardian. Before completing the tasks, both the participants and their guardians were asked to read over the Cambridge Brain Sciences' Terms of Use and Privacy Policy, located on the CBS website (https://www.cambridgebrainsciences.com). Once participants and guardians agreed to the terms, the participants proceeded with the CBS tasks.

Participants were instructed to complete either a 3-task battery or a 12-task battery depending on their age group. The cognitive battery consisting of all 12 tasks and took approximately 30 minutes to complete, while the 3-task battery took anywhere from 5 to 15 minutes to complete. Once the CBS tasks were completed, the participants' parents and guardians completed the demographic questionnaire through Qualtrics. A subset of the original participants then completed the 3-month learning program, which consisted of three 1-hour sessions focusing on sensory stimulation and academic activities. Participants either completed a second set of CBS tasks during the 3-month period or once the 3-month program was completed. The current study will only make use of the data collected from all participants at the initial CBS testing stage, prior to the 3-month program.

Results

The present study implemented a cross-sectional research design to test the relationship between age and sex and participants' performance on a set of cognitive tasks.

To determine whether sex differences in cognition exist in children and young adults, 3 (Age: elementary, middle, high school) x 2 (Sex: female, male) factorial analyses of variance (ANOVA) were conducted, assessing performance on each of the 12 tasks. P-values were adjusted using a Bonferroni correction for multiple comparisons. Females scored significantly higher on the tasks Odd One Out, $F(1,8178) = 44.26$, $p_{adj} < .001$, $\eta^2 = .005$, and Feature Match, $F(1, 8178) = 10.76$, $p_{adj} = .017$, $\eta^2 = .001$, while males scored significantly higher on the task Spatial Span, $F(1, 8178) = 13.95$, $p_{adj} = .003$, $\eta^2 = .001$. Age had a significant effect across all 12 tasks (see Table A2).

Since the CBS tasks themselves are not entirely independent constructs, four composite scores were also created: domain scores for reasoning, short-term memory (STM), and verbal abilities, as well as an overall score. These scores were created using factor loadings derived from previous factor analyses using the CBS tasks (Hampshire et al., 2012). The loadings were extracted using a Principal Component Analysis (PCA), with a Varimax Rotation (see Table A3). An additional four 3 (Age: elementary, middle, high school) x 2 (Sex: female, male) factorial ANOVAs were completed to assess the effects of age and sex on these four composite scores. Females scored significantly higher on the verbal composite score, $F(1, 8178) = 479.24$, $p_{adj} < .001$, $\eta^2 = .105$, as well as on the reasoning composite score, $F(1, 8178) = 18.15$, $p_{adj} < .001$, $\eta^2 = .002$, whereas male scored significantly higher on the STM composite score, $F(1, 8178) = 15.45$, $p_{adj} = .001$, $\eta^2 = .002$. However, the effect of sex on the overall score was non-significant, $F(1, 8178) = 1.69$, $p_{adj} = 1.000$, $\eta^2 < .001$. In addition, a significant effect of age was also found for all four composite scores (see Table A2).

Sixteen 3 (Age: elementary, middle, high school) x 2 (Sex: female, male) factorial analyses of covariance (ANCOVA) were conducted to control for the following covariates: participants' medical diagnoses, socioeconomic status, mother's educational level, and father's educational level. The covariate of medical diagnosis had three levels: presence of an attention deficit disorder (i.e., attention hyper deficit disorder or attention deficit disorder), presence of another diagnosis, and no diagnosis. Socioeconomic status had two levels: income in poverty level ($0 – $35000) and above poverty level ($35 001+). Both mother's and father's educational status had two levels: no post-secondary education and record of post-secondary education. Sex had no effect for the 16 scores compiled (i.e., CBS tasks and composite scores), while age had a significant effect for all 16 scores (see Table A4).

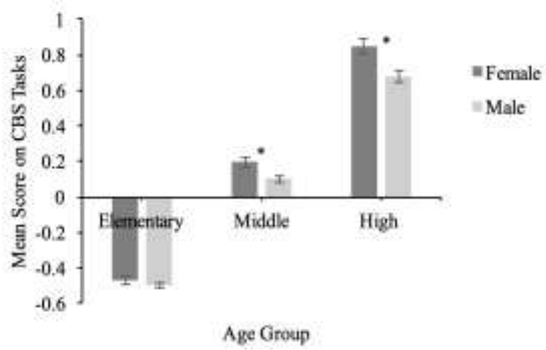
The present study further conducted a series of Šidák post-hoc analyses to determine when the few sex differences in cognition that were observed, emerged across development. The estimated marginal means were analyzed using a pairwise comparison for the scores demonstrating a significant effect of sex. A significant difference in the performance of males and females in the elementary school group was observed on the

Spatial Span (p = .011) and Odd One Out (p =.038) tasks. Furthermore, a significant difference was identified in middle school-aged males' and females' performance on the Spatial Span Task (p = .011), the Odd One Out Task (p < .001), the short-term memory domain score (p = .030; see Figure 1B), and on the reasoning domain score (p = .007; see Figure 1A). Lastly, a significant difference in the performance between males and females in the high school group was observed in the Odd One Out (p < .001) and Feature Match (p = .009) tasks, and in the short-term memory (p = .003; see Figure 1B), verbal (p = .028; see Figure 1C) and reasoning (p < .001; see Figure 1A) domain scores (see Table A5).

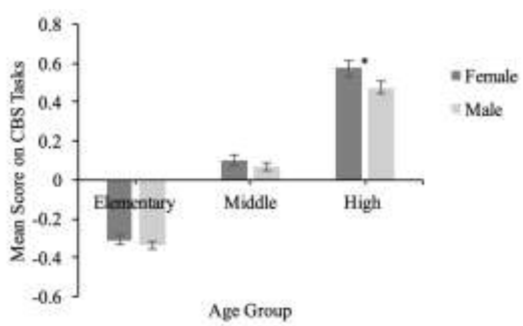
Figure 1

Difference in Performance on CBS Tasks Between Males and Females in Each Age Category

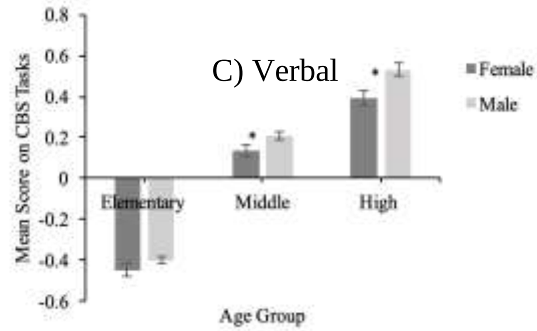
A) Reasoning



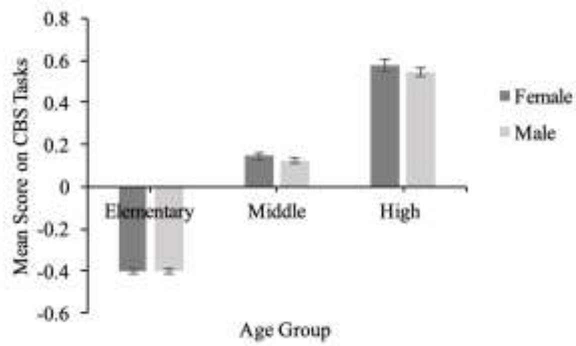
B) STM



C) Verbal



D) Overall domain scores



Note. Mean scores on the CBS Tasks as a function of sex and age on A) Reasoning, B) Short-term Memory (STM), C) Verbal, and D) Overall domain scores. *Significant effect corrected for multiple comparisons using Bonferroni correction (N = 16).

Discussion

The purpose of the present study was to investigate whether sex differences exist in the cognitive performance of children and young adults and, more specifically, to determine when these differences emerge across cognitive development. It was first hypothesized that sex differences exist in the cognitive performance of school-aged children, specifically where females outperform males on verbal and memory abilities, while males outperform females on visuospatial tasks. Secondly, this study hypothesized that sex differences in cognitive performance would first emerge during childhood, and then remain stable throughout adolescence, before disappearing as an individual completes puberty and enters adulthood.

The results of the present study only somewhat support the initial hypothesis positing sex-based differences in the cognition of children and young adults. Prior to controlling for covariates, the present study observed sex differences between child and young adult females and males, but the areas in which these differences were observed in were not consistent with the initial hypotheses. Females were found to outperform males on a deductive reasoning task, whereas males outperformed females on a spatial short-term memory task. However, consistent with the hypothesis, females outperformed males on the verbal composite score. Nonetheless, males outperforming females on the short-term memory composite score is inconsistent with this study's initial hypothesis. When controlling for covariates, sex ultimately had no significant effect on any of the cognitive task scores nor on the study's overall score, all inconsistent with the initial hypothesis.

The results of the present study were inconsistent with this study's second hypothesis positing the emergence of sex differences in cognition during the stages of childhood and adolescence before incrementally disappearing as the individual approaches adulthood. Consistent with this hypothesis, significant differences were found between elementary school-aged males and females in cognitive tasks measuring spatial short-term memory and deductive reasoning. However, significant sex differences were also found in the middle and high school-aged groups, a finding that is inconsistent with the initial hypothesis positing the incremental disappearance of these differences as the individual approaches adulthood.

Significant parallels can be drawn between this study's findings and those of previous research. For instance, Gur and colleagues (2012) found significant effects of age and sex in the cognitive performance of individuals aged 8 to 21. Similar to the present study, the authors found that performance significantly improves with age. In addition, they also found that males outperformed females on spatial working memory tests and sex differences in cognition occurring after mid-adolescence. However, Gur and colleagues (2012) also found that females performed worse than males on tasks of attention, a finding that is contradictory to this study's finding that females performed better than males on attentional tasks.

The findings of the present study are consistent with those of Ardila and colleagues' 2011 study assessing the cognitive performance of individuals aged 5 to 16. Ardila and colleagues (2011) ultimately demonstrated that sex differences in cognitive development are minimal and only appear in a small number of tests. Initially, the present study found that sex had a significant effect on a small number of the scores analyzed. However, after controlling for covariates, this significance disappeared. Thus, the results of present study support those of Ardila and colleagues (2011), asserting the minimal sex differences that exist in the cognitive development of younger participants.

McGivern and colleagues (1997) concluded that sex differences in cognition ultimately arise from sex differences in information processing, in accordance with the selectivity hypothesis. Specifically, the authors found significant sex differences in visual-recognition memory tasks. According to the selectivity hypothesis, this sex difference arises due to the different ways in which males and females organize the information they receive, thereby influencing their performance on cognitive tasks measuring short-term memory and visual recognition. The findings of the present study lend some support to the results found by McGivern and colleagues (1997) since males outperformed females in a spatial short-term memory task.

In terms of identifying when sex differences emerge across development, the findings of the present study are somewhat supportive of previous research. Barel's 2018 study found sex differences in verbal abilities, specifically where females outperform males, in childhood (defined in this study as individuals aged 9 through 12). The results of the present study are inconsistent with this finding since only high school-aged females outperformed males in the verbal composite scores while no sex differences were found in this task in the elementary and middle school aged groups.

Lastly, the findings of the present study somewhat support those of Voyer and colleagues' 1995 meta-analysis. The meta-analysis demonstrated significant sex differences in participants aged 7 and 14 on spatial ability tasks. The results of the present study also found significant sex differences in elementary and middle school-aged participants' performance on a spatial short-term memory task. Thus, both studies found significant sex differences in participants of the same age groups.

Implications

The findings of the present study demonstrate that child and young adult females and males are more similar than they are different from a cognitive perspective. This reduction in cognitive sex differences could be in part due to the progressive changes to social norms and gender expectations that we see more and more of today. As Halpern and Miller (2014) note, biology and environment are "two sets of intertwined factors that influence each other in a continuous causal loop" (p.5). This relationship could explain how changes to gender norms and expectations are impacting sex differences (or similarities) in cognition. This study's findings thus support previous research suggesting that the increasing overlap between the interests and behaviours of child and young adult males and females is influencing their cognitive performance so they are more similar than different, particularly when compared to past sex differences found. This result suggests that the strict sex binary that once existed, separating males and females, is beginning to diminish (Miller & Halpern, 2014).

Despite the fact that, overall, sex was not associated with cognitive differences in this study, evidence of sex differences in cognition were nevertheless identified in the middle and high school age groups. Following Halpern and Miller's (2014) and Barel's (2018) arguments on the inextricable relationship between biology and society, this finding demonstrates how the complex interplay between biology and environment impacts the cognitive development of individuals in different ways (Barel, 2018). This finding supports previous research asserting the emergence of sex differences in cognition as males and females develop based on the complex interplay of their biological sex and gender identity in society.

Limitations and Future Directions

A limitation of the present study is the unequal sample size of each age category. Elementary and middle school-aged participant groups were similar in size, with a sample size of 3345 and 3201, respectively. However, the high school-aged participants had a significantly smaller sample size of 1638 participants. The decreased sample size of this group of participants could have resulted in a loss of statistical power, thereby impacting this study's findings since a loss of statistical power reduces the likelihood that a statistically significant effect will be detected (Dumas-Mallet et al., 2017). Thus, it is likely that the significantly smaller sample size of this high school age group is what hindered this study in finding statistically significant sex differences in the cognition of school-aged children.

To prevent significant decreases in statistical power, future studies are encouraged to ensure that a relatively equal distribution of participants is present in each age category. In addition, it would be beneficial for subsequent analyses to assess participants' cognitive performance at each specific age, rather than dividing participants into larger groups consisting of many ages. Perhaps then, a significant sex difference could be observed when analyzing cognitive performances at a specific age rather than age group. In assessing each age independently, researchers could determine whether the non-significant effects of sex are a result of the way participants were grouped, and provide greater insight into whether specific ages of males and females differ cognitively.

Another limitation of the present study is that brain maturation rates and sex hormone levels were not controlled for. Past research has demonstrated a link between cognitive sex differences and brain maturation rates in males and females (Waber, 1977). Furthermore, studies have found a link between the production of sex hormones such as androgens and the development of areas in the cerebral cortex, the area of the brain responsible for a vast majority of cognitive processes (Barel, 2018; Raznahan, 2010). It would have been beneficial to control for these factors, ensuring the results reflected cognitive performance and not differences in brain maturity or hormonal levels. Future studies are therefore encouraged to implement brain-imaging techniques and other physical measurements, in addition to cognitive tests, to determine what role these physical changes have in cognition and whether the lack of sex differences seen in younger participants are a result of these structural and chemical processes.

A final shortcoming of the present study is that it did not control for selection bias. The data analyzed in the present study was collected from participants that were self-selected for the extra learning program since they were experiencing learning, cognitive, or attentional deficits. Thus, these deficits that many participants were experiencing may have impacted scores on the CBS tasks as well as the non-significant effects found throughout this study pertaining to sex differences in cognition. It would have been advantageous for the study to have implemented a control group with participants who were not experiencing any deficits and to compare this group's cognitive performance with that of the experimental group. By including a control group, subsequent studies can determine whether the lack of statistically significant sex differences is a result of the cognitive difficulties being experienced or truly reflective of children and young adults as a population.

Conclusion

In conclusion, the present study demonstrates that sex differences in the cognitive performance of children and young adults do exist, however, when controlling for other demographic information, they are limited. Furthermore, this study found that most sex differences appear later in childhood and adolescence, and likely extend into adulthood. These findings provide valuable direction and encouragement for future research and indicate that males and females today are ultimately more alike in cognitive performance, than they are different.

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Appendix A

Table A2

Results of Factorial ANOVA on Each of the CBS Tasks and Composite Scores

Task	Factor	df		F	p	p_{adj}	η^2
SS	Sex	1	8178	13.95	<.001	.003	.001
	Age	2	8178	739.19	<.001	<.001	.153
	Sex*Age	2	8178	0.19	.827	1.000	< .001
GR	Sex	1	8178	1.78	.182	1.000	< .001
	Age	2	8178	841.23	< .001	< .001	.170
	Sex*Age	2	8178	4.27	.014	.224	.001
DT	Sex	1	8178	3.36	.067	1.000	< .001
	Age	2	8178	471.29	< .001	< .001	.103
	Sex*Age	2	8178	1.70	.183	1.000	< .001
OOO	Sex	1	8178	44.26	< .001	< .001	.005
	Age	2	8178	609.14	< .001	< .001	.129
	Sex*Age	2	8178	3.54	.029	.465	.001
ML	Sex	1	8178	8.39	.004	.061	.001
	Age	2	8178	835.01	< .001	< .001	.169
	Sex*Age	2	8178	1.38	.253	1.000	< .001
RT	Sex	1	8178	6.95	.008	.135	.001
	Age	2	8178	707.60	< .001	< .001	.147
	Sex*Age	2	8178	0.09	.915	1.000	< .001
FM	Sex	1	8178	10.76	.001	.017	.001
	Age	2	8178	1118.28	< .001	< .001	.214
	Sex*Age	2	8178	1.07	.345	1.000	< .001
DS	Sex	1	8178	7.72	.005	.088	.001
	Age	2	8178	614.86	< .001	< .001	.131
	Sex*Age	2	8178	0.10	.905	1.000	< .001
SP	Sex	1	8178	0.02	.879	1.000	< .001
	Age	2	8178	333.37	< .001	< .001	.075
	Sex*Age	2	8178	0.32	.730	1.000	< .001
PA	Sex	1	8178	3.57	.059	.942	< .001
	Age	2	8178	217.41	< .001	< .001	.050
	Sex*Age	2	8178	1.29	.275	1.000	< .001
PO	Sex	1	8178	6.36	.012	.187	.001
	Age	2	8178	425.19	< .001	< .001	.094
	Sex*Age	2	8178	0.57	.567	1.000	< .001
TS	Sex	1	8178	1.79	.181	1.000	< .001

Task	Factor	df		F	p	p_{adj}	η^2
	Age	2	8178	476.60	< .001	< .001	.104
	Sex*Age	2	8178	0.54	.582	1.000	< .001
STM	Sex	1	8178	15.45	< .001	.001	.002
	Age	2	8178	567.72	< .001	< .001	.122
	Sex*Age	2	8178	1.28	.279	1.000	< .001
VERB	Sex	1	8178	479.24	< .001	< .001	.105
	Age	2	8178	6.11	.002	.036	.001
	Sex*Age	2	8178	0.92	.398	1.000	< .001
RSN	Sex	1	8178	18.15	< .001	< .001	.002
	Age	2	8178	1030.82	< .001	< .001	.201
	Sex*Age	2	8178	3.41	.033	.531	.001
OVER	Sex	1	8178	1.69	.194	1.000	< .001
	Age	2	8178	1716.99	< .001	< .001	.296
	Sex*Age	2	8178	0.56	.573	1.000	< .001

Note. p_{adj} = p-value with Bonferroni correction. Significant effects corrected for multiple comparisons (*N* = 16).

Table A3

Factor loadings of CBS Test Scores

	Domain Score		
	STM	Reasoning	Verbal
SS	0.72	-	-
GR	-	0.49	0.56
DT	0.27	0.35	0.47
OOO	-	0.59	-
ML	0.72	-	-
RT	-	0.63	-
FM	0.29	0.60	0.15
DS	-	-	0.81
SP	0.48	0.43	-
PA	0.55	-	0.38
PO	-	0.60	0.25
TA	0.58	-	-

Note. Values were obtained using a Principal Component Analysis (PCA) with Varimax rotation. Coefficients with values greater than 0.2 are included.

Table A4

Results of the Factorial ANCOVA on Each of the CBS Tasks and Composite Scores

Task	Factor	df		F	p	p_{adj}	η^2
SS	Gender	1	699	0.08	.779	1.000	< .001
	Age	2	699	41.52	< .001	< .001	.104
	Gender*Age	2	699	3.83	.022	0.355	.010
	Family Income	1	699	3.73	.054	0.860	.005
	Medical Diagnosis	1	699	1.00	.318	1.000	.001
	Mother's Education	1	699	0.15	.696	1.000	< .001
	Father's Education	1	699	4.57	.033	0.528	.006
GR	Gender	1	699	1.18	.279	1.000	.001
	Age	2	699	65.57	< .001	< .001	.156
	Gender*Age	2	699	1.34	.262	1.000	.003
	Family Income	1	699	4.25	.040	0.635	.005
	Medical Diagnosis	1	699	1.32	.251	1.000	.002
	Mother's Education	1	699	1.37	.243	1.000	.002
	Father's Education	1	699	2.97	.085	1.000	.003
DT	Gender	1	699	0.74	.391	1.000	.001
	Age	2	699	35.56	< .001	< .001	.092
	Gender*Age	2	699	1.09	.338	1.000	.003
	Family Income	1	699	0.00	.956	1.000	< .001
	Medical Diagnosis	1	699	1.29	.257	1.000	.002
	Mother's Education	1	699	1.61	.205	1.000	.002
	Father's Education	1	699	0.01	.944	1.000	< .001
OOO	Gender	1	699	4.10	.043	0.691	.005
	Age	2	699	25.77	< .001	< .001	.068
	Gender*Age	2	699	0.05	.952	1.000	< .001
	Family Income	1	699	0.45	.503	1.000	.001
	Medical Diagnosis	1	699	2.16	.142	1.000	.003
	Mother's Education	1	699	3.05	.081	1.000	.004
	Father's Education	1	699	5.72	.017	0.273	.008
ML	Gender	1	699	1.35	.245	1.000	.002
	Age	2	699	54.93	< .001	< .001	.135
	Gender*Age	2	699	0.90	.406	1.000	.002
	Family Income	1	699	3.87	.049	0.791	.005
	Medical Diagnosis	1	699	0.97	.325	1.000	.001
	Mother's Education	1	699	0.28	.596	1.000	< .001

Task	Factor	df		F	p	p_{adj}	η^2
	Father's Education	1	699	2.72	.100	1.596	.003
RT	Gender	1	699	0.00	.956	1.000	< .001
	Age	2	699	47.78	< .001	< .001	.120
	Gender*Age	2	699	0.49	.616	1.000	.001
	Family Income	1	699	1.43	.233	1.000	.002
	Medical Diagnosis	1	699	0.66	.417	1.000	.001
	Mother's Education	1	699	0.17	.684	1.000	< .001
	Father's Education	1	699	1.17	.280	1.000	.001
FM	Gender	1	699	4.00	.046	0.736	.005
	Age	2	699	83.10	< .001	< .001	.188
	Gender*Age	2	699	1.77	.171	1.000	.004
	Family Income	1	699	0.83	.363	1.000	.001
	Medical Diagnosis	1	699	2.21	.137	1.000	.003
	Mother's Education	1	699	0.55	.459	1.000	.001
	Father's Education	1	699	10.69	.001	0.018	.012
DS	Gender	1	699	0.00	.990	1.000	< .001
	Age	2	699	45.10	< .001	< .001	.112
	Gender*Age	2	699	1.94	.144	1.000	.005
	Family Income	1	699	9.00	.003	0.045	.011
	Medical Diagnosis	1	699	3.01	.083	1.000	.004
	Mother's Education	1	699	0.07	.797	1.000	< .001
	Father's Education	1	699	3.27	.071	1.000	.004
SP	Gender	1	699	0.00	.956	1.000	< .001
	Age	2	699	20.79	< .001	< .001	.056
	Gender*Age	2	699	0.07	.936	1.000	< .001
	Family Income	1	699	0.24	.624	1.000	< .001
	Medical Diagnosis	1	699	0.74	.390	1.000	.001
	Mother's Education	1	699	0.18	.670	1.000	< .001
	Father's Education	1	699	0.28	.600	1.000	< .001
PA	Gender	1	699	0.32	.575	1.000	< .001
	Age	2	699	20.11	< .001	< .001	.054
	Gender*Age	2	699	0.85	.428	1.000	.002
	Family Income	1	699	0.20	.654	1.000	< .001
	Medical Diagnosis	1	699	2.60	.107	1.000	.004
	Mother's Education	1	699	1.86	.173	1.000	.003
	Father's Education	1	699	0.17	.684	1.000	< .001
PO	Gender	1	699	0.09	.771	1.000	< .001
	Age	2	699	35.76	< .001	< .001	.093

Task	Factor	df		F	p	p_{adj}	η^2
	Gender*Age	2	699	0.03	.970	1.000	< .001
	Family Income	1	699	1.47	.225	1.000	.002
	Medical Diagnosis	1	699	0.34	.558	1.000	< .001
	Mother's Education	1	699	2.38	.124	1.000	.003
	Father's Education	1	699	1.91	.168	1.000	.002
TS	Gender	1	699	0.53	.466	1.000	.001
	Age	2	699	26.90	< .001	< .001	.071
	Gender*Age	2	699	0.06	.945	1.000	< .001
	Family Income	1	699	0.20	.659	1.000	< .001
	Medical Diagnosis	1	699	2.18	.140	1.000	.003
	Mother's Education	1	699	2.21	.137	1.000	.003
	Father's Education	1	699	5.24	.022	0.359	.007
	Age	2	699	33.92	< .001	< .001	.088
	Gender*Age	2	699	1.67	.189	1.000	.004
	Family Income	1	699	1.23	.267	1.000	.002
	Medical Diagnosis	1	699	2.23	.136	1.000	.003
	Mother's Education	1	699	0.09	.760	1.000	< .001
	Father's Education	1	699	2.77	.097	1.000	.004
VERB	Gender	1	699	0.04	.844	1.000	< .001
	Age	2	699	43.32	< .001	< .001	.109
	Gender*Age	2	699	2.44	.088	1.000	.006
	Family Income	1	699	6.78	.009	0.151	.008
	Medical Diagnosis	1	699	3.19	.074	1.000	.004
	Mother's Education	1	699	0.95	.331	1.000	.001
	Father's Education	1	699	0.70	.403	1.000	.001
RSN	Gender	1	699	3.52	.061	0.977	.004
	Age	2	699	76.65	< .001	< .001	.178
	Gender*Age	2	699	0.20	.817	1.000	< .001
	Family Income	1	699	0.06	.803	1.000	< .001
	Medical Diagnosis	1	699	0.11	.738	1.000	< .001
	Mother's Education	1	699	2.78	.096	1.000	.003
	Father's Education	1	699	5.46	.020	0.316	.006
OVER	Gender	1	699	0.39	.531	1.000	< .001
	Age	2	699	118.58	< .001	< .001	.249
	Gender*Age	2	699	1.31	.270	1.000	.003
	Family Income	1	699	3.53	.061	0.970	.004
	Medical Diagnosis	1	699	3.42	.065	1.000	.004
	Mother's Education	1	699	2.38	.123	1.000	.003

Task	Factor	df		F	p	p_{adj}	η^2
	Father's Education	1	699	7.27	.007	0.115	.008

Note. df = Degrees of Freedom, F = F-statistic, p = P-value, p_{adj} = Adjusted P-value, η^2 = Effect Size. *Significant effects corrected for multiple comparisons (*N* = 16).

Table A5

Pairwise Comparison of Estimated Marginal Meals Demonstrating When Sex Differences Emerge Across Age Groups

CBS Task	Age Group	Gender	Gender	MD	SE	*p*
SS	1	Male	Female	0.114*	0.05	.011
	2	Male	Female	0.117*	0.05	.011
	3	Male	Female	0.07	0.06	.245
FM	1	Male	Female	-1.97	1.13	.082
	2	Male	Female	-1.30	1.15	.259
	3	Male	Female	-4.11*	1.57	.009
OOO	1	Male	Female	-2.02*	0.10	.038
	2	Male	Female	-0.50*	0.10	< .001
	3	Male	Female	-0.59*	0.14	< .001
STM	1	Male	Female	0.05	0.03	.148
	2	Male	Female	0.07*	0.03	.030
	3	Male	Female	0.14*	0.05	.003
VERB	1	Male	Female	-0.03	0.03	.410
	2	Male	Female	-0.34	0.03	.300
	3	Male	Female	-0.99*	0.05	.028
RSN	1	Male	Female	-0.02	0.03	.507
	2	Male	Female	-0.09*	0.03	.007
	3	Male	Female	-0.17*	0.05	< .001

Note. p_{adi} = p-value with Bonferroni correction.

*Significant difference between males and females at that age, at $p < .05$)

Appendix B

Ethics Approval Letter

Western Research

Date: 17 November 2020

To: Dr. Adrian Owen

Project ID: 117890

Study Title: A retrospective investigation of higher-order cognitive functioning in school-aged children.

Short Title: Brain Balance

Application Type: NMREB Initial Application

Review Type: Delegated

Full Board Reporting Date: 04/Dec/2020

Date Approval Issued: 17/Nov/2020 22:31

REB Approval Expiry Date: 17/Nov/2021

Dear Dr. Adrian Owen

The Western University Non-Medical Research Ethics Board (NMREB) has reviewed and approved the WREM application form for the above mentioned study, as of the date noted above. NMREB approval for this study remains valid until the expiry date noted above, conditional to timely submission and acceptance of NMREB Continuing Ethics Review.

This research study is to be conducted by the investigator noted above. All other required institutional approvals must also be obtained prior to the conduct of the study.

Documents Approved:

Document Name	Document Type	Document Date	Document Version
BB_questionnaire	Online Survey	23/Oct/2020	1
CBS_task_descriptions	Other Data Collection Instruments	23/Oct/2020	1

No deviations from, or changes to the protocol should be initiated without prior written approval from the NMREB, except when necessary to eliminate immediate hazard(s) to study participants or when the change(s) involves only administrative or logistical aspects of the trial.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario. Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB. The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Please do not hesitate to contact us if you have any questions.

Sincerely,

Ms. Katelyn Harris , Research Ethics Officer on behalf of Dr. Randal Graham, NMREB Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Appendix C

Demographic Questionnaire

(available upon request)