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The Relationship Between Brain Size and Intelligence in Human

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Abstract: A fundamental neurobiology question is whether brain size correlates with intelligence. Numerous studies have been performed to answer this question in the last 150 years. Most early studies are case reports. Many well-performed and methodology-sound studies have been published in the last few decades. The majority of these studies showed that brain size indeed correlates with intelligence. However, various coefficients ranging mostly from 0 to 0.6 for this correlation have been reported. In this study, we will briefly review the evidence for the correlation between brain size and intelligence by discussing the results of meta-analyses. We will focus our study on discussing factors complicating the analysis of the relationship between brain size and intelligence. These factors may explain why different degrees of the correlation were observed in the previous studies. Finally, we will briefly discuss the direction of future studies to understand why people with bigger brain are smarter.

Key words: Age, brain size, human, intelligence, lateralization, sex

INTRODUCTION

The neurobiological basis for the variation in human intelligence is not known. One question regarding this issue is whether brain size correlates with intelligence. German anatomist Frederick Tiedmann believed in as early as 1836 that there was “an indisputable connection between the size of the brain and the mental energy displayed by the individual man”. Since then, scientists have been searched for evidence to support this claim. Early studies were mainly case reports. Studies in the last few decades used better scientific approaches. Data from most of these studies support the notion that people with bigger brain are more intelligent. However, the coefficients for the positive correlation between brain size and intelligence varies from as low as 0.071 (Akgun, 2003) to higher numbers such as 0.62 (Tan *et al*., 1999). We will focus our study on the evidence supporting the positive correlation between brain size and intelligence and some of the factors complicating the analysis of this correlation, which may explain why different degrees of the correlation were observed in the previous studies.

METHODS TO MEASURE BRAIN SIZES

Four methods have been used to measure brain size in the literature: External head size measurement, brain size measured by Magnetic Resonance Imaging (MRI) endocranial volume measured from empty skulls and measurement of brain weight and volume at autopsy. These methods are listed in the order of accuracy to measure brain size. The first three methods indirectly measure brain size and the last one is a method to directly measure brain size. Although it is practical to weigh the wet weight of brain, the measurement of brain volume by water displacement method often requires brain fixation. It has been shown that formalin fixation does not cause significant changes of brain weight and volume (Quester and Schroder, 1997; Witelson *et al*., 2006) However, fixation can introduce errors into the measurements. Obviously, the estimation of brain size by head size and MRI can be performed in living people and are frequently used in the studies on the relationship between brain size and intelligence.

Head size can be estimated by following method. A spreading micrometric caliper is used to measure head length that is from the glabellas between the brow ridges to the posterior head, head breath that is the maximal distance between the left side and right side of the head at a location above the attachment of ears and cranial height that is vertically from the cartilaginous trigone in front of the ear canal to the top of the head. These measurements will be applied to a formula developed by Lee and Pearson (1901) to calculate the head size.

The estimation of brain size by MRI is to make a series of horizontal MRI slices from the lowest margin of the cerebellum in the midsagittal view to the top of the brain. The area of each slice is calculated and the sum of the slices is used to estimate the brain size.

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INTELLIGENCE TESTS

There are many tests designed to measure intelligence. Most modern Intelligence Quotient (IQ) tests are derived from Alfred Binet's proposal that IQ tests should measure skills such as judgment, comprehension, problem-solving and reasoning. The Wechsler Adult Intelligence Scale and the Wechsler Intelligence Scale for Children are popular IQ tests, which give not only an overall IQ, but also separate IQs for verbal and performance subtests (Wechsler, 1981). The verbal tests include information, comprehension, arithmetic, similarities and vocabulary. The performance tests have digit symbol, picture completion, spatial, picture arrangement and object assembly. The IQ scores are assigned based on the IQ distribution of general population with the mean value 100.

EVIDENCE TO SUPPORT THE NOTION THAT PEOPLE WITH BIGGER BRAIN ARE SMARTER

Numerous studies have been performed to study the relationship between brain size and intelligence. The correlation coefficient from most studies range from 0 to 0.6, (McDaniel, 2005; Vernon *et al*., 2000; Nguyen and McDaniel, 2000; Gignac *et al*., 2003) although negative coefficient has been occasionally reported (Aylward *et al*., 2002). The earlier studies often used head size to approximate brain size and had a smaller coefficient. Rushton and Ankney (1996) reviewed 32 such studies and found a mean coefficient 0.2 ($p<10^{-10}$) with the pooled data. When the brain size is estimated by MRI, a bigger coefficient for the correlation between brain size and intelligence is often revealed (McDaniel, 2005). Early reviews of these studies showed a coefficient in the range of 0.33 to 0.37 (Vernon *et al*., 2000; Nguyen and McDaniel, 2000; Gignac *et al*., 2003). The most recent review on this topic was conducted by McDaniel (2005). In the meta-analysis, 37 studies including 1530 subjects were identified and analyzed. The mean coefficient of the correlation between brain volume and intelligence for the pooled data was 0.33. These results strongly suggest that people with bigger brain are more intelligent.

Interestingly, the positive correlation between brain size and intelligence is not only supported by the studies using subjects from general population but also by two studies using subjects within families (Jensen, 1994; Jensen and Johnsen, 1994) In these 2 studies, head sizes were used to reflect brain size. However, another study that investigated 36 adult sisters and measured brain size by MRI did not show a consistent relationship between brain size and intelligence among sib pairs, although a positive correlation of brain size with intelligence was shown when the inter family data was analyzed (Schoenemann *et al*., 2000). These results suggest that nongenetic influences play a role in the relationship between brain size and intelligence.

Factors that complicate the analysis of the relationship between brain size and intelligence: As discussed above, measuring brain size by MRI usually leads to a larger coefficient for the correlation between brain size and intelligence than that if the brain size is estimated from head size. This phenomenon may be caused by less accurate measurement of brain size by head size because the variation in skull thickness among individuals renders external attempts at measuring cranial capacity and brain size inaccurate. In addition to the choice of the methods to measure brain size, many other factors including age, sex, lateralization, racial and ethic background can affect the relationship between brain size and intelligence and contribute to the variation in the coefficient for this relationship in the previous studies.

Ahmet Akgun *et al*. (2003) studied 89 men and 56 women. They measured the head size to estimate the brain size. Hand preference was determined by using the Edinburgh Handedness Inventory. The authors found that among right-handed males and females, the correlations were low (r = 0.23 and 0.071, respectively) while in left-handed males and females, the correlations were higher (r = 0.90 and 0.78, respectively). The mean correlation for both males and females was 0.30. Although left-handed males and females were under represented in this study (8 left-handed males to 74 right-handed males and 8 left-handed females to 48 right-handed females), it is still important to note the strong influence of lateralization on the correlation between brain size and intelligence.

Age and sex can also affect the relationship between brain size and intelligence. The meta-analysis by McDaniel (2005) showed that adults for either sex had a higher correlation than children. Females also correlated better then males. A study related to this issue was published recently (Arden and Plomin, 2006). The authors studied a large population of British children from 2 to 10 years old. They found that girls performed better than boys on IQ tests at younger age but this phenomenon reversed by age 10. Although the brain size was not measured and the correlation between brain size and intelligence was not determined in the study, different patterns of brain development of boys and girls suggest that sex and age can complicate the analysis of the relationship between brain size and intelligence.

A very elegant study on the influence of lateralization, age and sex on the relationship between brain size and intelligence was performed by Witelson *et al.* (2006). In the study, the authors analyzed data from 100 adult subjects. The subjects were screened for neurological problems before death and their IQs were scored according to the Wechsler Adult Intelligence Scale. Handedness was determined by performing hand use for a series of 12 unimanual and bimanual tasks. After death, brains were removed. After removing the blood vessels and the meninges, brains were weighed and the volumes of hemispheres were determined by water displacement. Thus, this study directly measured the brain size and is the only study so far that used directly measured brain size to correlate with intelligence. The study found that the cerebral volume and weight decreased with increased age in men but did not change significantly with aging in women, although all female subjects in the study are post-menopausal and were not on estrogen replacement therapy. Whereas both men and women did not have aging-related changes of Verbal Scaled Score (VSS), aging decreased the Performance Scaled Score (PSS) in both men and women. The study showed a positive correlation between age-adjusted cerebral volume and age-adjusted VSS ($r = 0.51$) among the consistent right-handed women. The correlation coefficient was 0.28 (non-statistical significant trend) for the relationship between cerebral volume and the PSS. For non consistent right-handed women, the correlation coefficients were 0.46 and 0.20, respectively for the relationship between cerebral volume and VSS or cerebral volume and PSS. Both coefficients did not reach statistical significance. A positive correlation between age-adjusted VSS and age-adjusted cerebral volume ($r = 0.62$) was found in the consistent right-handed men. However, this correlation did not exist in the non consistent right-handed men. Although a positive relationship between PSS and cerebral volume ($r = 0.63$) was found in consistent right-handed men, this correlation may be caused by aging because age-adjustment abolished this relationship in those men. There was no relationship between cerebral volume and PSS in non consistent right-handed men. Thus, this study found a strong relationship between brain size and VSS in the consistent right-handed men and women. In addition, the study also showed that men needed larger brains to score the same VSS as women. In an example given by the authors, to obtain a score of 80, men generally had a cerebral volume of 1300 mL, while women had around 1100 mL. This study convincingly showed the complex effects of handedness, age and sex on the relationship between brain size and intelligence. This study also provides strong evidence to support the notion that people with bigger brain are smarter. However, further research is needed to confirm the findings and investigate why the positive relationship between brain size and intelligence can be shown only in certain groups of people.

Racial and ethical background can also complicate the analysis of the relationship between brain size and intelligence. It has been shown that the average IQ is different among racial and ethical groups of people. Asians and their descendants have the highest average IQ (Rushton, 2000). Studies also show that Asians and their descendants have the largest head size (Rushton and Rushton, 2003). Although these results apparently support the positive relationship between brain size and intelligence across races, the correlation coefficient for this relationship may be different among people with different racial and ethical backgrounds, which may contribute to the variation of the coefficients obtained in the previous studies.

Future studies: Most previous studies have determined the relationship between intelligence and gross brain size. However, human brain has a well-established cortical localization of function. The size of a particular brain region may have a better correlation with its corresponding functions. In addition, brain tissues are complex and have numerous components. The correlation of these components with the function/intelligence may be even stronger if certain components, such as gray matter or white matter, or certain histological features, such as ratio of neurons to glia, of brain are quantified and used in the analysis. Up till now, only a few of such studies have published (Schoenemann *et al.*, 2000; Machullich *et al.*, 2002; Keenan *et al.*, 2001; Andreason *et al.*, 1993; Gur *et al.*, 1999). This line of research will ultimately reveal the anatomic basis and the neural substrates of intelligence, a fundamental question of neurobiology. Although direct quantification of brain regions and components in vitro at autopsy is accurate, this approach requires administration of a reliable IQ test within a short period of time before death because human brain, especially the brain of man, is decreasing in size with aging (Witelson *et al.*, 2006). Thus, using modern imaging techniques, such as MRI, to quantify these structures in vivo will be the main approach for the studies. Thus, advance of technology to accurately perform the in vivo measurements will greatly facilitate these studies.

Another direction of research related to the topic is to investigate the genetic contribution to the relationship between brain size and intelligence. Although the results from Schoenemann *et al.* (2000) suggest minimal genetic influences on this relationship, studies of twins have suggested that genetic factors very strongly contribute to the size of brain structures and intelligence and the relationship between brain structure size and intelligence (Posthuma *et al.*, 2002; Thompson *et al.*, 2001) Further studies are needed to clarify this issue and to investigate the genetic basis of intelligence.

Finally, the electrophysiological and molecular basis for the notion that people with bigger brain are smarter is a very interesting area. These studies may provide us the ultimate keys to improve human intelligence.

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