Intelligence 63 (2017) 78–88

Contents lists available at ScienceDirect

Intelligence

journal homepage: www.elsevier.com/locate/intell

Sex differences in brain size and general intelligence (*g*)

Dimitri van der Linden[a,*], Curtis S. Dunkel[b], Guy Madison[c]

[a] Institute of Psychology, Erasmus University Rotterdam, The Netherlands
[b] Department of Psychology, Western Illinois University, USA
[c] Department of Psychology, Umeå University, Sweden

ARTICLE INFO

Keywords:
Sex differences
General intelligence
g
Brain volume
Gray and white matter
Cognitive abilities
Method of correlated vectors

ABSTRACT

Utilizing MRI and cognitive tests data from the Human Connectome project ($N = 900$), sex differences in general intelligence (*g*) and molar brain characteristics were examined. Total brain volume, cortical surface area, and white and gray matter correlated 0.1–0.3 with *g* for both sexes, whereas cortical thickness and gray/white matter ratio showed less consistent associations with *g*. Males displayed higher scores on most of the brain characteristics, even after correcting for body size, and also scored approximately one fourth of a standard deviation higher on *g*. Mediation analyses and the Method of Correlated Vectors both indicated that the sex difference in *g* is mediated by general brain characteristics. Selecting a subsample of males and females who were matched on *g* further suggest that larger brains, on average, lead to higher *g*, whereas similar levels of *g* do not necessarily imply equal brain sizes.

1. Introduction

Characteristics of the brain, such as its size, the density of neurons, and the proportion of gray and white matter have been shown to relate to various cognitive abilities (Colom et al., 2009; Wickett, Vernon, & Lee, 1994). General intelligence is the measure of cognitive ability that has received the most attention in this context, in accordance with its status as representing the overall efficiency to process information and solve novel problems (Duncan, Seitz, Kolodny, et al., 2000; Jensen, 1998). A widely used operationalization of general intelligence is *g*; a latent factor representing the proportion of common variance across a wide range of cognitive tasks (Jensen, 1998). The *g* factor is an important predictor of many of real-life outcomes such as educational attainment, job performance and health (e.g., Gottfredson, 1997).

Several meta-analyses have provided reliable estimates of the associations between *g* and brain characteristics. For example, McDaniel (2005) reported a population meta-analytic correlation between *g* and brain size of 0.33. Recently, Pietschnig, Penke, Wicherts, Zeiler, and Voracek (2015) expanded the number of studies, and arrived at a revised meta-analytic correlation of 0.24. Positive associations between *g* and the amount of gray and white matter have also been reported, although the associations regarding the latter seem to be slightly lower and less consistent (Narr et al., 2007; Posthuma et al., 2002). Finally, studies have also reported positive associations between general intelligence and the cortical thickness of specific brain areas (Narr et al., 2007; Shaw et al., 2006).

However, the association between *g* and brain characteristics is complicated by the fact that brain size is correlated with body mass. In the context of sex differences, males and females differ in average body length and mass, which transcends to sex differences in brain morphology (Ankney, 1992; Gur et al., 1999). Specifically, males have larger brains than females ($d \approx 0.7$), even after controlling for body size (Allen, Damasio, Grawboski, Buss, & Zhang, 2003; Ankney, 1992; Burgaleta et al., 2012; Rushton & Ankney, 1996). Combining this fact with the empirically determined correlation between brain size and *g* would predict that males also have higher *g*, but the literature has been inconsistent on this topic (e.g., see Colom, Juan-Espinosa, Abad, & García, L. F., 2000; Halpern, 2013; Halpern & LaMay, 2000). Inasmuch as this inconsistency has been addressed, it has been argued that differences in brain size across the sexes do not translate to *g* because of other anatomical sex differences, such as the density of neurons (Witelson, Glezer, & Kigar, 1995), cortical thickness (Sowell et al., 2007), the ratio of gray to white matter (Gur et al., 1999), or the functional organization of the brain (Sanders, Sjodin, & De Chastelaine, 2002). All these factors may lead to equal levels of *g* despite differences in brain volume (for a discussion see, Halpern et al., 2007).

Lynn (1994) noted that many studies showing null results were based on children and early adolescents, and pointed out that males and females differ in their growth curves and other aspects of maturation. If some aspect of brain development hinges on the level of hormones, and, in particular, sex differences in androgens, sex differences in intelli-

* Corresponding author at: Institute of Psychology, Erasmus University Rotterdam, P.O. Box 9104, 3000 DR Rotterdam, The Netherlands.
E-mail address: vanderlinden@fsw.eur.nl (D. van der Linden).

http://dx.doi.org/10.1016/j.intell.2017.04.007
Received 7 October 2016; Received in revised form 19 April 2017; Accepted 19 April 2017
Available online 02 May 2017
0160-2896/

gence should be absent or otherwise slight until the age of around 15. From that age on, however, differences will start to emerge and eventually lead to a sex difference in *g* estimated to abound one third of a standard deviation, which translates to 3 to 5 IQ points (Lynn & Irwing, 2002, 2004). Consistent with this idea, several studies indicate that sex differences in *g* are related to sex differences in brain size in adults (Ankney, 1992; Lynn, 1994).

Sex differences in brain morphology are well established (Allen et al., 2003; Ruigrok et al., 2014) and neurological sex differences are receiving increased attention (Cahill, 2016). Whether those differences are also accompanied with differences in *g* remains unclear. First, as noted above, there seems to be no consensus yet regarding the basic question whether there are sex differences in *g* in the first place. Colom et al. (2000) reported only negligible sex differences in general intelligence in two samples totaling 10,474 adult applicants to a private university. Iliescu, Ilie, Ispas, Dobrean, and Clinciu (2016) tested several large representative samples in Romania and categorized the sample into various age groups. They reported that significant sex differences in general intelligence only occurred in a few of those age groups, whereas in the majority of the groups no significant differences were found. Halpern and LaMay (2000) reviewed the literature and concluded that even though there are sex differences in specific cognitive abilities, there are no differences in general intelligence.

Second, even when assuming that there may be sex differences in *g*, it remains a debate whether those are directly related to sex differences in brain characteristics. For example, Escorial et al. (2015) matched males and females on intelligence scores and found that despite equal levels of intelligence in those groups, males still had significantly larger brains than females, which led them to conclude that sex differences in brain size do not translate into average intelligence differences. Using the same line of reasoning, one of the more recent studies on brain morphology and *g* is of particular interest. Burgaleta et al. (2012) used structural MRI data of one hundred undergraduate students, and replicated the aforementioned sex difference in total brain volume, operationalized as the sum of the gray and white matter volume. After correcting for body size, the brain volume of males was approximately 0.75 of a standard deviation larger than that of females, consistent with differences in general brain size and gray and white matter. Burgaleta et al. (2012) also found that the differences in brain size were accompanied by sex differences in a limited set of specific cognitive abilities, mainly spatial ones. The sex difference in *g* was 0.12 in favor of males, which is small but not trivial, but it was not statistically significant. Altogether, Burgaleta et al. (2012) concluded that sex differences in brain morphology (i.e., size, proportion of gray and white matter) are not related to differences in *g*, but are instead associated with sex differences in specific cognitive abilities such as spatial ability, which, they argued, is facilitated by total brain volume in particular. Yet, Burgaleta et al. (2012) acknowledged several limitations that deserve attention. First, they used a sample of undergraduate psychology students only, which is not representative for the general population and which is likely to suffer from range restriction in *g*. Second, although their sample size ($N = 100$) was relatively large for a typical MRI study, it is quite small in absolute sense and may not have enough power to detect differences of the relevant size.

Thus, (1) Burgaleta et al. (2012) reported a small but non-significant sex difference in *g*, as well as a sex difference in brain size, and (2) Escorial et al. (2015) found that even in subsamples in which males and females have equal average intelligence scores, differences in brain size remain. Given these indeterminate results and conclusions, the question whether sex differences in *g* relate to sex differences in brain size remains open and motivates further evaluation with larger and more representative samples.

To this end, we analyzed the brain imaging findings and cognitive ability tests of the Human Connectome Project (HCP; Marcus et al., 2013; Van Essen, et al., 2013). The HCP is a large collaborative study designed to understand the neurobiology associated with an array of psychological variables, including cognitive ability. One of the advantages is that the most recent release of the HCP data comprises approximately 900 participants, which is a very large sample in comparison to other MRI studies. Although the HCP data still have a somewhat restricted age-range (22 to 37 years), the sample is demographically diverse and can be considered a more population-representative sample compared to that of Burgaleta et al. (2012). The HCP data set includes measures of intracranial volume and gray and white matter volume, which can be used to calculate total brain volume. Moreover, it provides measures of cortical thickness as well as cortical surface area. The HCP data also contains an array of ten cognitive tests, suitable for computing a *g* factor.

Beyond the relevance of testing brain and *g* sex differences in one of the largest MRI-datasets available, the present study contributes to the existing literature in the following ways. First, the detailed morphological data allow us to not only test for sex differences in brain characteristics and *g*, but also directly test whether brain characteristics statistically mediate any relation between sex and *g*. Second, we apply the Method of Correlated Vectors (MCV; Jensen, 1998). The MCV can be used to test to which extent the '*g* dependence' of specific cognitive tasks relate to other variables. As such it allows to examine the extent to which any sex differences in the specific cognitive tasks occur as a function of *g* and brain size. Third, we apply a similar method as Escorial et al. (2015) in which a subsample of males and females who are matched on intelligence is tested on sex differences in brain size.

2. Method

2.1. Sample

The most recent release of the HCP contains 970 participants (HCP; 900 subject + MSM-All Reference Manual and Appendices, 2015) of which MRI and behavioral data is present from 896 participants, 393 males and 503 females. While the final sample is scheduled to include 1200 participants, data collection is ongoing and data are released in batches. Stringent selection procedures were followed to ensure that the participants were both physically and mentally healthy (Marcus et al., 2013; Van Essen, et al., 2013). The age of the participants ranged from 22 to 37 with a mean age of 28.82 years ($SD = 3.66$).

2.2. Brain imagine acquisition and processing and brain measures included

At Washington University, the brain magnetic resonance images (MRI) of the participants were obtained with a 3.0 Tesla (Siemens Skyra) scanner using a 32-channel head coil. The present study utilized the MRI imaging data that had been processed by the HCP team, using the following procedure. T1-Images were obtained with the T1-weighted 3D MPRAGE sequence using the following parameters: repetition time = 2400 ms; echo time = 2.14 ms; inversion time = 1000 ms; flip angle = 8°; field of view = 224 mm; matrix = 320 × 320; voxel size = 0.7 mm^3 (Marcus et al., 2013; Van Essen et al., 2013). For the T2-weighted images, the 3D T2-Space sequence used the following parameters: repetition time = 3200 ms; echo time = 565 ms; the flip angle, field of view, matrix, and voxel size setting were identical to the ones used for the T1-weighted images.

For image processing, the HCP FreeSurfer processing pipeline was used (Glasser et al., 2013). Image processing was conducted using Talairach transformation, pial surface creation, skull registration, extraction of subcortical region volume, subcortical region segmentation, down sampling of T1-weighted images from 0.7 to 1 mm, and