Association between Cortical Volume and Working Memory

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July 10, 2019

Abstract

The neocortex was the latest step in the evolution of our brains, and is thought to be important for cognition. The aim of this study was to acquire more information regarding the relationship between cognition and anatomic brain structure. With linear regression between cortical volume and working memory from 551 children subjects (taken from IMAGEN dataset) at the age of circa 14 years, a larger cortical volume seems to correlate with higher working memory. The correlation between more cortical volume and higher working memory was expected, and since the results of study is in line with literature, one could therefore expect a positive correlation in the neocortex as well. Further studies could investigate a more local comparison between working memory and brain structure.

Acknowledgements

I would like to thank Saga Jonsson for helping me as an instructor during my four weeks at Rays – for Excellence. My gratitude goes to Prof. Torkel Klingberg for letting me do research at his laboratory, and Sebastian Ghomri for his unwavering pedagogic and systematic teaching during my time at the department. Finally, I would like to thank Rays – for Excellence for this opportunity, as well as Kungliga Patriotiska Sällskapet and Kjell och Märta Beijers Stiftelse for collaborating with Rays – for Excellence.

Contents

1 Introduction

What is consciousness? Are animals conscious? Could we in the future modify our cognitive capabilities for the better? These questions are all heavily discussed, however, they require tremendous amounts of advancements in cognitive neuroscience to be answered. Therefore this study will aim to bring us one step closer to those answers.

In this study, the terms cognition, higher cognitive function, cognitive functions, and cognitive skills will be used almost synonymous to describe the ability in humans where knowledge and thoughts can be gathered and processed.

1.1 Brain Structure

Apart from being divided into lobes, the brain is also divided into different "matter" depending on the composition of that part in the brain.

1.1.1 White and gray matter

White matter is the part of the brain mostly made of myelinated axons, see Figure 1. The axons fill almost half of the human brain, and they connect the parts of the brain containing gray matter [1]. Gray matter has relatively many cell bodies compared to white matter, which have fewer, longer axons. Gray matter is primarily located in a part of the brain called the neocortex, however, gray matter is also located in deeper parts of the brain [2, 3]. The striatum, Figure 1, marked in red, is an example of that.

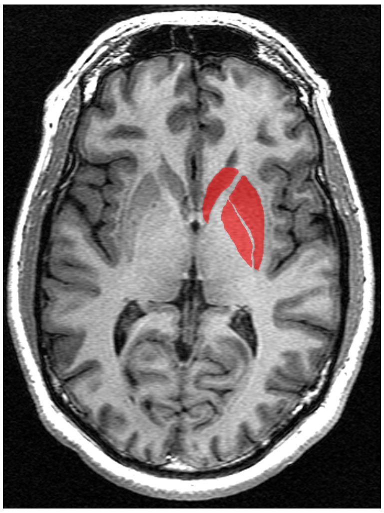

Figure 1: The striatum colored in red. Lighter parts are predominantly white matter, whereas dark gray parts are primarily gray matter. Figure taken from Lidsay Hanford et. al. [4].

1.1.2 The Neocortex

The neocortex is 2-4 mm thick, spread out as a thin layer on the outside of the large folded part of the brain, as seen as the darker areas in Figure 2, and has six horizontal cell-layers which are different in structure and have different purposes [5]. The neocortex was the latest step in evolution for our brains, and its evolution is arguably one of the key factors for higher cognitive function. The characteristics of the neocortex is separate from other mammals. For example, the human neocortex has many wrinkles called gyri, see Figure 2. These gyri increase the potential surface area of the neocortex tremendously, and their role in cognition need to be studied further. [2, 6]

1.2 Cognition

Cognitive function is often biologically described as cerebral activity (which often includes activity in the neocortex). Working memory is a cognitive function explained by Baddeley [8] as the ability to store and process information in connection with other cognitive tasks such as learning, problem-solving, and memorizing.

Cognitive neuroscience is the scientific field studying biological processes affecting

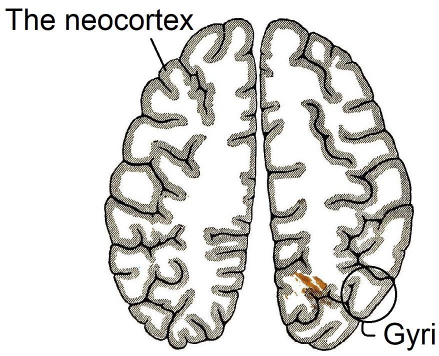

Figure 2: Cross-section of the brain with gyri and neocortex pointed out. Picture based from Emil Villiger et. al. [7].

cognition [2]. Methodological improvements in neuroimaging have enabled studies to investigate the relationship between cognitive functions, like working memory, and brain structure on a macroscopic level. Understanding the macroscopic changes would provide information regarding processes of the microscopic level that ultimately is what cognitive neuroscientists are in search of. Knowing those mechanisms would reveal much information about how the brain works and what causes higher cognitive function.

1.3 Background

To analyze the relationship between cortical volume and working memory, some foundational knowledge in common software and statistical analysis are needed. To understand how the correlation between working memory and cortical volume can be isolated, one must also understand the principle of confounders.

1.3.1 Software

Python is a programming language that enables statistical analysis, mathematical calculations, and processing of large data in this study. A package for python called statsmodel.api enables OLS regressions. OLS is a common linear least squares method for linear regression models. Statsmodel can also give p-value and β_i for a function. P-value (p), used in Table 1, is the probability that there is no relationship between two measured phenomena, and is rated between 0 and 1 [9]. β_i is just the slope value for function i.

Data can be saved in various forms, and one example is as a CVS-file. A CSV-file is a textfile where each data is separated with a comma, thereby its name CSV or “Comma-separated values”. It is mostly used to process raw data through programming scripts.

IMAGEN is a database and research project funded by the European Commission that investigated how different brain structures were affected by environmental and genetic differences [10]. 1963 subjects from northern Europe were scanned with MRI and information about them was cataloged.

Freesurfer is a commonly used software package for processing and visualizing neuroimaging studies. It can analyze both structural and functional magnetic resonance.

1.3.2 Statistics

In studies investigating a correlation between two phenomena, subjects are divided in groups based on age and sex to combat interference in the results. Such differences that affect the independent variable or have their own effect on the dependent variable (like sex and age), whilst being variable in value for every test-group (in this case every subject) are called confounding variables [11]. See Figure 3.

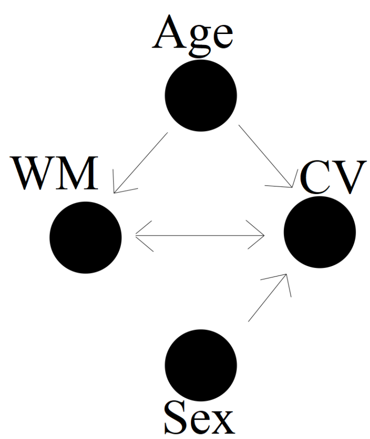

Figure 3: Confounding variables age and sex are changing the values for working memory (WM) and cortical volume (CV).

Confounding variables, or confounders, can affect the analysis in a way so as to suggest a causal effect where there is none, and also hide potential correlations that would not be seen otherwise. Knowing the difference in age and sex for the subjects of the study gives the opportunity to produce what is called “adjusted” estimates of the correlation. With that, one can extract the coefficient between cortical volume and all the covariates. Covariates are different independent variables that correlate with the dependent variable. If the covariates interact, then they can become confounding. One could also use the coefficients of the confounders and compare them to literature as assurance to see if the results are plausible.

1.4 Previous Research

Earlier studies have examined the surface area as well as the thickness of the neocortex in children and adults. They found positive correlations between both cortical thickness and surface area compared with intelligence[3, 12]. Though, there was a wide variety of ages in those studies. The relationship between frontal gray matter volume and cognition in adults has also been investigated, however, the relationship varied over time [13]. Cortical volume has been analyzed in children and adults before, though correlating only with cognitive-motor abilities, and not with higher cognitive functions such as working memory[14].

1.5 Aim of the Study

The aim of this study is to compare working memory score to cortical volume to see if there is a linear correlation between the two. If there is one, then future studies could do local analysis of the neocortex. Thereafter local biological mechanisms could be studied for correlation with cognition.

2 Method

Images have been gathered from IMAGEN and surface-based pre-processed to extract information about the morphology of the brain using Freesurfer. The number of subjects was reduced to 551 after manual quality control. Each subject had 163 842 data points (N) measured for cortical thickness and surface area in cortical measure maps. When having different scan-sites, local scanner effects might affect results. Therefore imaging results were harmonized. Meaning, calibrating so sex and age does not differ per unit between scan-sites [15].

The volume (V) of the neocortex from each participant was then calculated, and saved as an array, with equation below where a and h are matrices for respective surface area and cortical thickness:

$$V = ah^T$$

Working memory was tested using three sub-tests. One where subjects needed to remember where objects were placed after disappearing from an image, one where subjects had to remember which card was which after shuffling, and lastly, one where subjects had to predict patterns on spinning objects. Using the results of these tasks, a compounded working memory score was calculated using confirmatory factor analysis. The working memory scores were collected from IMAGEN and processed with a CSV-file text converting script. The working memory scores were then saved as an array. Using both arrays, a linear regression through OLS was made, and a graph was plotted. Analysis of p-value was used to to determine the significance of the results.

3 Results

Correlations between cortical volume and co-variables are shown in Figure 4, 5 and 6. Looking at Figure 4 and Table 1, one can see a positive slope value on $7743\,\mathrm{mm}^3$. Figure 5 shows the $5.763 \cdot 10^4$ mm^3 difference in average volume comparing the sex of the subjects. Cortical volume and age, Figure 6, displays a negative slope value of -22.53 mm^3/working memory unit with high certainty, see Table 1.

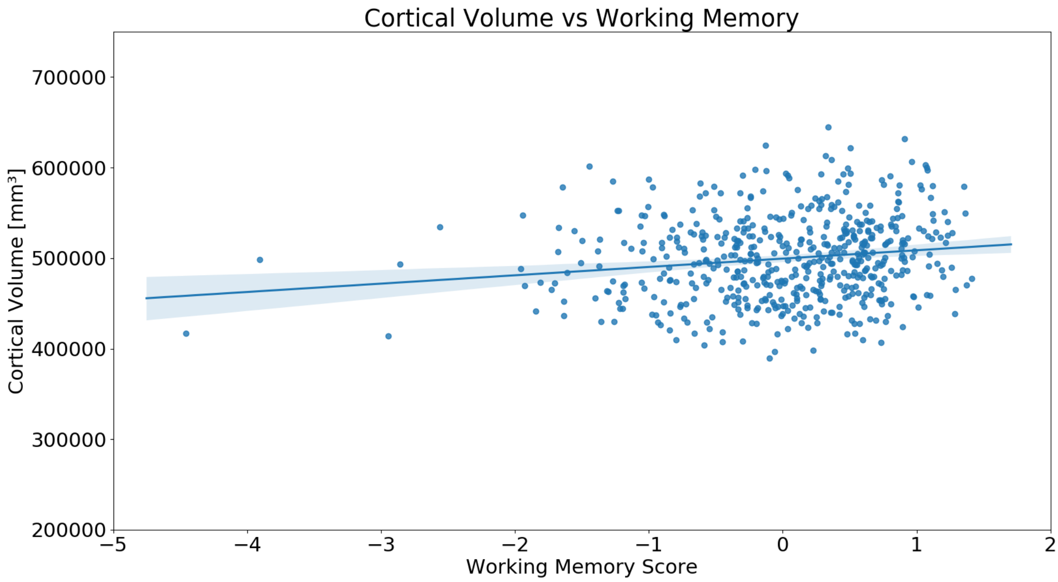

Figure 4: Cortical volume against working memory, note the positive correlation.

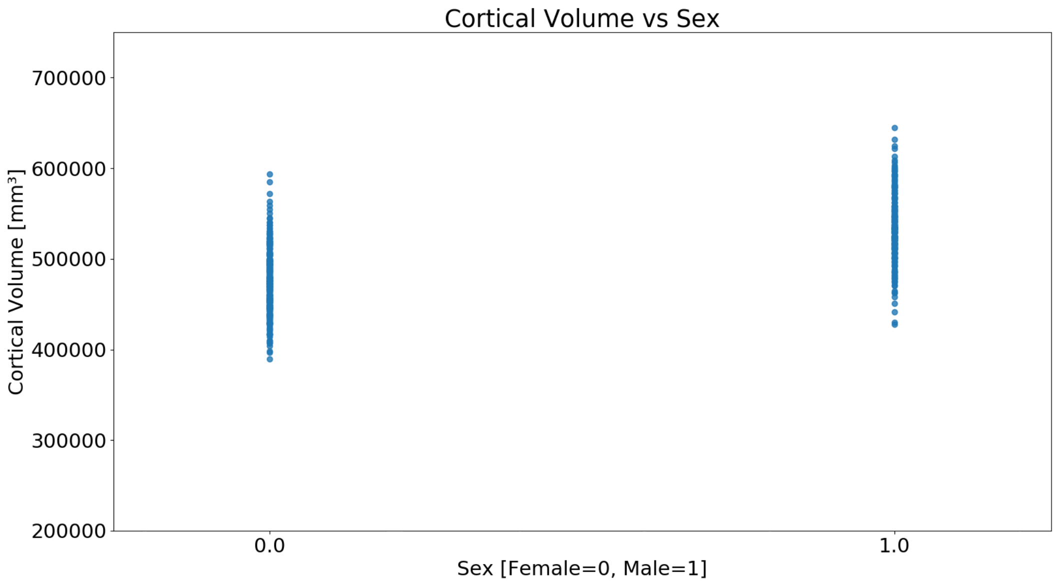

Figure 5: Cortical volume against sex, note the difference in average volume.

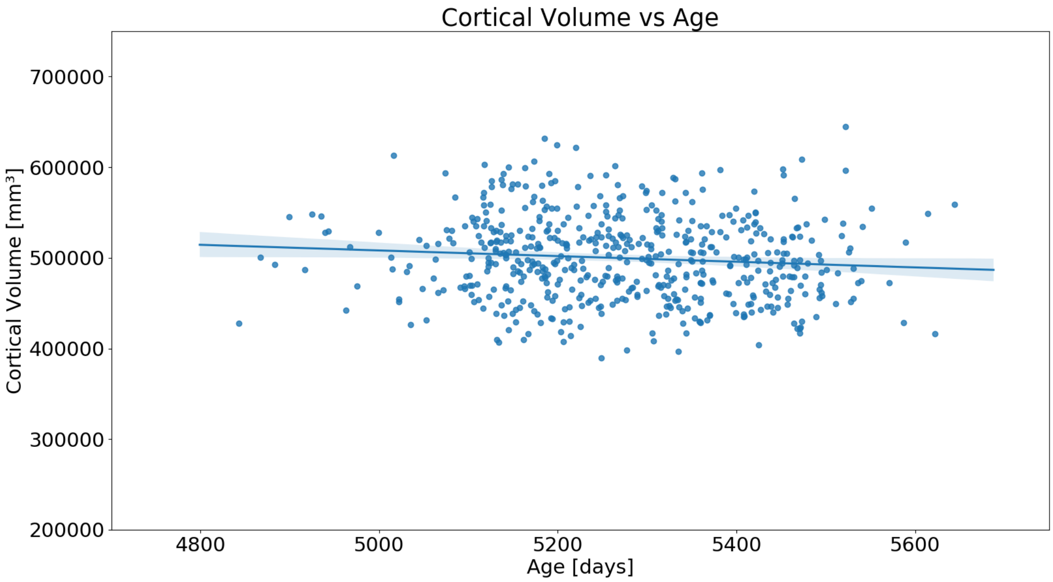

Figure 6: Cortical volume against age, note the negative correlation.

Following table shows p-value and slope value for each graph:

Table 1: OLS Regression Results with slope value (β) for function (i) and p-value (p).

Indep. Variable	β_i	p
WM	$7.774 \cdot 10^3$	0.000
Age	$-2.253 \cdot 10^1$	0.038

4 Discussion

The potential correlation between cortical volume and working memory was investigated. In comparable groups, more cortical volume seem to correlate with higher working memory. This means that future studies could investigate more local associations with working memory.

4.1 Explanation of results

The correlation between cortical volume and working memory was expected. When studies have investigated the association between total brain volume and cognitive function, total cortical volume has indirectly been investigated compared to cognitive function as well. Since there have been many studies where a positive association between total brain volume and other cognitive functions have been found, one would expect a positive correlation in the neocortex as well. In this study the area of interest was more local, and the cognitive function measured was different, but there should not have been any practical difference.

Looking at cortical volume and working memory in Figure 4, we can see that people with the same sex and age will have a higher probability to have larger cortical volume (dependent variable) if they have a higher score in working memory (independent variable). Though, the two variables affect each other, see Figure 3, and it is difficult to determine which variable precedes the other.

We can observe from Figure 5 that people with the same working memory and age on average differ in cortical volume depending on sex. This is probably due to men generally having bigger skulls, and therefore often larger brains. If they have larger brains, it is likely that they have more cortical volume. This does not mean that men generally have better working memory, nor could one conclude anything similar. Though, since the difference in cortical volume is a rational result, it does give a higher probability that the rest of the results are reasonable.

Looking at cortical volume and age in Figure 6 one can see that the slope value is negative. This might seem illogical at first, since the subjects are in their adolescence and their brains are not fully developed yet. Though, cortical thinning is a well known process in neuroscience called neuromaturation, and is thought to be where the cells specialize and cortical volume (cortical thickness more specifically) decreases. A study looking at cortical thinning in subjects of similar age showed a negative correlation between age and cortical thickness which also supports the results of this study [16]. Nevertheless, further studies in the field are required.

Looking at the significance of the graphs, see Table 1, and comparing results to literature, one can see a strong statistical significance in the results.

4.2 Applications

Does this mean that companies should have MRI scans as a requirement for job applications? Probably not. There are many factors that one misses when looking at just working memory and cortical volume. Some argue that there are many psychological differences that influences cognition which cannot be measured with neuroscience. In fact, an employer would be better off making the job applicant take a working memory test instead. The results of this study are therefore purely usable for future research.

4.3 Implications for further research

This study was not longitudinal. Meaning, the subjects were not investigated over time to see if different ranges of age affected the correlation between working memory and cortical volume differently. Future studies could take measurements from time point 2 from IMAGEN, and perform this longitudinal study.

This study further points to the correlation between the neocortex and working memory. Future studies aiming to find a more specific correlation need to test local associations with working memory in the structure of the neocortex. If positive correlations can be found, then one could look at cellular interactions in those areas to further understand the biological mechanisms governing cognition.

5 Conclusion

The study showed a positive association between cortical volume and working memory. We can therefore conclude, with earlier research [3, 6, 12, 13], that the neocortex has a major role in cognition. The results imply that the next step in cognitive neuroscience could be to search for more local correlations to cognitive functions in the neocortex.

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