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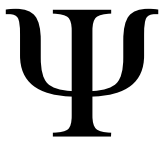

Fluid Intelligence in a Norwegian Sample of Middle-Aged and Older Adults

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RUNNING HEAD: FLUID INTELLIGENCE IN MIDDLE-AGED AND OLDER ADULTS

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Preface

Writing this thesis has been a great learning experience for me. I have learned a lot about human intelligence and the changes in cognitive abilities that are associated with increasing age. I have learned a lot about statistics. Although with vigorous guidance, I have been able to do all the statistical analyses myself, which I hope will be evident by the syntax I have attached at the end of this document.

This thesis is written as my contribution to a large, ongoing study of cognitive aging. I want to thank Dr. Eike Wehling for the work she has done in recruiting the participants and gathering the first Wave of data, which I have benefited from in this current study. I would also like to thank the participants. I would like to thank Judit Haász for the MRI analyses, and for providing the figures of the brain I have used. I would like to thank Rune Eikeland for guidance and support. He gave me the input for the methods part of the MRI analysis, and has read several drafts of this thesis. I would like to thank my friends and family for their ongoing support.

Most of all, without whom writing this thesis would have been impossible; I would like to express my greatest appreciation to Professor Astri J. Lundervold. She has always kept an open-door policy, giving me more time than I could possibly ask for, allowing me to ask all sorts of questions and giving me plenty of support throughout the process. She has with her warmth and enthusiasm inspired me and kept me going, enabling me to reach ever further. Thank you!

You are all social multipliers in my life.

Abstract

Introduction: Based on results from earlier studies, fluid intelligence (Gf) is expected to decline with age and symptoms of depression, while crystallized intelligence (Gc) is expected to remain stable. Gf is expected to show a relation to cortical thickness in parieto-frontal areas. *Method: N* = 125 (83 females) healthy middle-aged and older adults completed WASI Matrix Reasoning, Cued Discrimination Task, California Verbal Learning Test-II and Color Word Interference Test, giving the means to derive Gf. WASI Vocabulary was used to derive Gc. Beck's Depression Inventory provided self-reported symptoms of depression. MRI measures of cortical thickness of $n = 91$ were attained. *Results:* Aging was associated with a decline on Gf ($r = -.436$, $p < .001$), but not Gc. Symptoms of depression were significantly correlated with Gf ($r = -.514$, $p < .001$) and Gc ($r = -.365$, $p = .017$) in males, but not in females. There were correlations between cortical thickness and Gf, but these disappeared when correcting for age. *Discussion:* The Gf factor relies heavily on measures of cognitive speed, known to decline with age. The effect of symptoms of depression might challenge the current theoretical approach to intelligence, and give implications for clinical practice. Methodological factors may explain the non-significant correlations between cortical thickness and Gf when age was accounted for.

Keywords: aging, fluid intelligence, crystallized intelligence, psychometric, minimal depression, cognitive decline, P-FIT, neuro-g, neuropsychology, neuropsychological assessment

Sammendrag

Introduksjon: Basert på funn fra tidligere studier forventes flytende intelligens (Gf) å svekkes med alderen og med symptomer på depresjon. Krystallisert intelligens (Gc) forventes å være stabil. Gf forventes å være korrelert til kortikal tykkelse. *Metode: N* = 125 (83 kvinner) friske middelaldrende og eldre fullførte WASI Matriser, Cued Discrimination Task, California Verbal Learning Test-II og Color Word Interference Test, som ble brukt til å utlede Gf. WASI Ordforståelse ble brukt til å utlede Gc. Beck's Depression Inventory ble brukt som et selvrapporteringsmål på depressive symptomer. MRI mål på kortikal tykkelse var tilgjengelig for 91 deltakere. *Resultater:* Alder var korrelert med nedgang på Gf (r = -.436, p < .001), men ikke på Gc. Depressive symptomer var negativt korrelert med Gf (r = -.514, p < .001) og Gc (r = -.365, p = .017) hos menn, men ikke hos kvinner. Det var en korrelasjon mellom kortikal tykkelse og Gf, men denne forsvant da vi kontrollerte for alder. *Diskusjon:* Gf påvirkes sterkt av mål på kognitiv hurtighet, som er vist at svekkes ved aldring. Depressive symptomers påvirkning kan utfordre den rådende teoretiske tilnærmingen til intelligens. Mangelen på signifikante korrelasjoner mellom kortikal tykkelse og Gf når man kontrollerer for alder kan ha sammenheng med metodologiske forhold.

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Aging is associated with cognitive decline (Salthouse, 2004, 2009). In your early twenties most of your cognitive abilities will be at their peak, although some of them might not to be fully matured yet (e.g., semantic understanding and world knowledge; Park & Reuter-Lorenz, 2009). As one reaches old age, one's cognitive abilities are expected to decline. However, all cognitive abilities will not necessarily decline at the same pace for every individual (Stern, 2002, 2009). The distinction between cognitive abilities that remain stable with age and those that decline is an important one, with considerable clinical implications (Richards & Deary, 2005). To promote factors associated with preservation of cognitive abilities will be of great importance for everyday functioning of older individuals.

This study is part of the Norwegian Cognitive NeuroGenetics study (Espeseth, et al., 2012), which gathers information about brain structure and cognitive function. The present study focuses on measures of two general cognitive abilities, referred to as fluid and crystallized intelligence (Davies, et al., 2011), and how these measures are related to individual differences within a sample of middle-aged and older adults. The importance of age will be investigated, as increased age is one important factor that may explain these differences in cognitive functioning (Salthouse, 2012). Depression has also been shown to be an important factor in relation to cognitive function (Alexopoulos, 2005; Herrmann, Goodwin, & Ebmeier, 2007; Santos et al., 2012). Although consisting of healthy participants, screened for psychiatric illnesses, all participants in this study have completed a self-report questionnaire of depressive symptoms (Beck, Brown, & Steer, 1996). This enables us to study the impact of depressive symptoms on cognitive function. As intelligence is related to measures of the brain, this study will also investigate whether individual differences in fluid intelligence are associated with cortical thickness measures (Jung & Haier, 2007). Sex

is known to be a factor influencing both brain-size and cognitive abilities (Burgaleta et al., 2012; Haier, Jung, Yeo, Head, & Alkire, 2005; Steinmayr, Beauducel, & Spinath, 2010), as well as self-reporting of psychiatric complaints (Tousignant, Brosseau, & Tremblay, 1987). Thus, the importance of sex will be considered. Before the results are presented, I will give a short historical introduction to the current approach of studying differences in human intellectual function. I start by giving the definition of general intelligence David Wechsler, a pioneer in the history of measuring cognitive abilities, introduced in 1939: "Intelligence is the aggregate or global capacity of the individual to act purposefully, to think rationally and to deal effectively with his environment" (Wechsler & Edwards, 1974).

1.1 Historical Glimpses From the Psychometric Search for Intelligence

The endeavor of trying to identify and measure valid constructs related to the concept of intelligence has a long and controversial history. Galton (1869/1978) had a quest of identifying what could be a common factor for explaining the success of men of science in 19th century England. Often criticized for ignoring that social class surely must have had beneficial effects on the people he studied, Galton emphasized reaction time measures as an objective indicator of intelligence. As it were, Galton was ahead of his time; reaction time measures proved to be unreliable measures of intelligence for more than a century, and have only recently been empirically validated as such (Deary, Der, & Ford, 2001). In an effort to further develop the notion of being able to test cognitive abilities, J. M. K. Cattell (1890) is accredited as being the first to mention the importance of constructing a mental test. Binet and Simon (1905/1916) established the modern, pragmatic approach to testing intelligence with items thought to be indicative of mental age. In the preparation of introducing mandatory public schooling for all children, the French government hired Binet and

Simon to develop tests that would enable the schools to decide which students needed extra support. Binet and Simon based their approach on interviews with teachers who informed them as to what tasks children of specific ages could be expected to solve. Spearman (1904) is generally credited as being the first to state that all tests of mental ability tend to correlate. He subsequently identified this uniting tendency as stemming from an underlying general factor of intelligence, which he named the g-factor (Spearman, 1927/1970).

Thurstone (1938), a contemporary of Spearman, notoriously disagreed with there being only one general factor of intelligence, insisting instead that there are several different factors of intelligences, which Thurstone dubbed primary mental abilities. Thurstone and Thurstone (1941) later had to admit that it was possible to extract a g-factor in their own data using the same factor-analytic approach as Spearman did. However, they still retained the notion of separable mental abilities as the only meaningful interpretation of their results, with a factor of reasoning ability being the one with most significant correlations in their data. R. B. Cattell (1963), and subsequently also his student, Horn (Horn & Cattell, 1966), argued that the g-factor was too general to be meaningful. They developed an investment theory of intelligence, dividing the general factor of intelligence into a fluid (Gf) and a crystallized (Gc) part. Their theory is commonly referred to as the Gf-Gc theory of intelligence. This made a huge impact on further studies of the structure of human intelligence. The legacy of Cattell and Horn still has a strong presence in studies of today (Carroll, 1993; Davies et al., 2011; Johnson & Bouchard Jr, 2005; McGrew, 2009), providing the theoretical basis for this current study.

There has been much dispute about the concept of human intelligence, both in the public and the scientific domain (and there still is), which Herrnstein and Murray

(1994) illuminate in their book "The Bell Curve". The book itself sparked a lot of public controversy, but its contents were not controversial within the field itself (Gottfredson, 1997). John B. Carroll (1993), in publishing his seminal book titled "Human Cognitive Abilities", putting together his life work of reviewing factor analytic studies of intelligence, is accredited of bringing "Consensus where there previously had been none" in the psychometric approach to intelligence (Deary, 2012). Carroll argued that there are three layers or "strata" of intelligence emerging from factor analytic studies, a g-factor at the top, a limited amount of broad cognitive factors at the second stratum, including fluid and crystallized intelligence, and several narrow, specific factors at the bottom of the hierarchy. This is commonly referred to as the Cattell-Horn-Carroll (CHC) theory of intelligence (McGrew, 2009).

1.2 Fluid and Crystallized Intelligence

Fluid and crystallized intelligence are terms coined by Raymond Cattell (1943, 1963; Horn & Cattell, 1966); fluid intelligence describes the capacity to think logically and solve novel problems, independent of previously acquired knowledge; crystallized intelligence describes accumulated learning experiences and world knowledge.

1.2.1 Fluid intelligence. Fluid intelligence and its relationship with normal aging is of great interest and concern for professionals in various health-disciplines, for scientists in the vast field of neuroscience, as well as for the general public (Deary, 2012). Fluid intelligence is important in its own right, as it is an indicator of general intelligence, and as such predicts socioeconomic status, health and longevity (Deary, 2012). In terms of aging, fluid intelligence can serve as an indicator of cognitive decline, giving valuable information to the clinician and patient in terms of condition and prospects (Salthouse, 2012). General intelligence is found to be relatively

consistent after "settling" in the pre/early teenage years (Gow et al., 2011), with the exception of the increase of crystallized intelligence and the decline of fluid intelligence with age. With the World's aging population, and the fact that aging is probably one of the major health challenges we are facing today (Fugelsnes, 2011; World Health Organization, 2011), it is of great interest to characterize "normal" changes in fluid intelligence, identify factors contributing to preserving cognitive function in older age, and to be aware of pathological changes. Fluid intelligence is commonly measured with matrix reasoning tasks and cognitive speed measures (Lezak, Howieson, & Loring, 2004), which also provides the basis for deriving Gf in this study.

1.2.2 Crystallized intelligence. Crystallized intelligence is both theoretically thought, and empirically found, to increase with age (Cattell, 1971; Park & Reuter-Lorenz, 2009). Crystallized abilities are found to be relatively intact even in the presence of brain pathologies, and can thus serve both as an indicator of previous functioning, and give a mean of assessing the relative age-dependent decline on fluid intelligence (Lezak, et al., 2004). Crystallized intelligence is commonly assessed with lexical knowledge, such as a vocabulary task or tasks probing the semantic understanding of different words. Solving crossword puzzles can be indicative of crystallized intelligence (Salthouse, 2012). In this study a vocabulary task from the Wechsler Adult Intelligence Scale is used to derive Gc (Wechsler, 1999).

1.3 Age-Related Changes in Fluid and Crystallized Intelligence

In the investment theory of intelligence postulated by Cattell (1963, 1971), fluid forms of intelligence would be the most dominant and important forms of intelligence in young age, enabling learning from experience, acquiring new understandings and providing the means to resolve novel challenges. As one grows

older, crystallized forms of intelligence would take form with verbal ability, semantic comprehension and accumulated world knowledge reaching their peak. Crystallized intelligence would then eventually taking a greater claim of the cognitive machinery that is at core of intelligence. The theory predicts different paths for fluid and crystallized intelligence, with fluid intelligence being at its peak early in life, and then declining with increasing age; and with crystallized intelligence being at its infancy at early ages, only to emerge as fully developed later in life, and not necessarily declining. In fact, Horn and Cattell (1966) viewed fluid intelligence as the capacity to learn, and crystallized intelligence as a mere static storage for lessons learned. Horn and Cattell (1967) further investigated the theory of fluid and crystallized intelligence, concerning the age-related changes in these respective cognitive abilities. They came to the conclusion that there was an age-related decline on measures of fluid intelligence, as well as an age-related increase on measures of crystallized intelligence when comparing older adults with younger adults. This observation has later been supported by Deary, Penke, and Johnson (2010), who describe fluid intelligence as "intelligence-as-process" and crystallized intelligence as "intelligence-as-product" (p. 204), providing a further framework for understanding the different age-related changes that face these different measures of intelligence.

1.4 Depression and Intelligence

Severe symptoms of depression have long been known to have an impact on mood, movement and cognition. However, depression's relations to cognitive abilities pertinent to the concept of intelligence, such as fluency, cognitive speed and memory, have long been neglected as a potential functional neuropathology of this condition, having tended to being ruled out as mere epiphenomena (Austin, Mitchell, & Goodwin, 2001). Recent studies have shown that increased reaction times and

increased distractibility are symptomatic for severely depressed patients, with symptoms of depression having an impact above and beyond that of age (Hammar, Lund, & Hugdahl, 2003b). This lowered cognitive performance for the depressed patients did not improve over a 6-month period, even though their symptoms of depression significantly improved (Hammar, Lund, & Hugdahl, 2003a). The same has been found regarding effortful attention and executive functions (Hammar et al., 2010).

Depression and cognitive decline can be confounded with one another (Alexopoulos, 2005). Both are clinically important in middle-aged and older adults. Especially as older adults constitute the fastest growing demographic group in the industrialized world (Wetherell, 2010). If it turns out that there is a causal link between symptoms of depression and reduced cognitive abilities in older adults, treating the symptoms of depression might alleviate cognitive problems, and as such possibly having a delaying effect on full-blown clinical presentation of dementia, by increasing older adults functional level on daily activities (Alexopoulos, 2005; Areán et al., 2010; Wetherell, 2010). In fact, Hammar and Årdal (2012) have found in a ten-year follow-up study of majorly depressed patients that those who recovered from their psychiatric symptoms also regained their cognitive function, at a level comparable to healthy controls. In this current study we ask if symptoms of depression are related to cognitive abilities even at subclinical levels of depression.

1.5 Biological Correlates of Intelligence

There are not only cognitive but also biological aspects to aging, such as cortical thinning, reduced plasticity and reduced white-matter integrity. This may very well account for the relationship between normal, healthy aging and cognitive decline

(Anderton, 2002; Garlick, 2002; Haász, et al., 2012; Haier, Jung, Yeo, Head, & Alkire, 2005).

1.5.1 Historic approach. The search for the biological underpinnings of human intelligence has a long (and controversial) history, going back, at least in recorded history, to the ancient Greek philosopher Plato, who spoke of the inheritance of traits suited for higher and lower ranks in society (Plato, trans. 2012). In more modern times, the British scientist Charles Darwin in his seminal book, "On the Origin of Species", published in 1859 (Darwin & Endersby, 1859/2009), has epitomized the notion of heritability by means of natural selection of favorable traits, such as intelligence. Taking this even further, and at the same time igniting the psychometric search for the heritability of human intelligence differences, Darwin's cousin, sir Francis Galton (1869/1978), published the book "Hereditary Genius" ten years later in 1869. In this book he associated the notion of greater cognitive ability with outcomes related to scientific accomplishments.

1.5.2 Modern approach. The neuroscientific understanding that the heritability of intelligence is mediated by the brain has from its humble beginnings, exemplified by Halstead (1947) seeking to understand this connection in his book "Brain and Intelligence", exploded in the past two decades with the invention and availability of brain imaging techniques, particularly fMRI, and increasingly more sophisticated methods for analyzing the data from these measures (Jung & Haier, 2007). It has been shown that a lot of regions involved in processing of language, perception, attention and memory, as well as the networks binding these regions together, comprise an important biological substrate to the concept of general intelligence. This has lead to the formulation of a parieto-frontal integration theory (P-FIT) of intelligence. P-FIT is based on studies identifying regions and networks of the brain associated with

measures of general intelligence by structural and functional brain imaging techniques (Jung & Haier, 2007). Jung and Haier (2007) argue that the parietal lobe plays an important part in the perceptual processes underlying intelligent behavior, whereas the frontal lobe integrates and shifts between attending to competing stimuli, thus exhibiting an executive function. Deary, et al. (2010) enquire into the different neurological underpinnings related to measures of fluid and crystallized intelligence, as they show markedly different trajectories with aging. Davies, et al. (2011) have found a genetic basis for fluid and crystallized intelligence, indicating that the field of research has come full circle back to the propositions of inheritance of human intelligence differences, raised in the middle of the 19th century.

However, the brain being a biological entity should not imply that its structural and functional connectivity remains unchanged with environmental influences (Garlick, 2002). Although our biological fundament has not undergone great changes in the last generations, Flynn (2007) illuminates that the increase in IQ on so-called "culture free" tests (Cattell, 1943), such as matrix reasoning tasks, has been enormous. IQ on these tests has risen with as much as a standard deviation in a single generation (Flynn, 1987). Our environments influence us, but we also choose and influence our environments, amplifying this effect on intelligence that seems to have a genetic origin. Thus, what Flynn (2007) calls "social multipliers" implies that the people we surround ourselves with, and the stimuli we engage ourselves with, will have an influence on our cognitive abilities and on how these age. Although while not finding solid empirical evidence to back the claim that cognitive training improves cognitive function, Salthouse (2006) nevertheless encourages us to keep training, as the potential benefits of engaging with cognitive stimulation is to great to dismiss while empirical evidence backing this is pending.

1.6 Research Hypotheses of the Present Study

In spite all of the disconcerting readings above, denoting how all "fluid" cognitive abilities inevitably decline with increasing age, this decline is seldom met with apparent functional nor emotional detriment in everyday life (Mather, 2012; Salthouse, 2004). This may have to do with the fact that cognitive ability is but one of several variables that promote a successful, healthy and happy existence. Other important factors, such as motivation, persistence, emotional stability, conscientiousness and agreeableness are all important on the individual level, and might not show the same age-related trajectories as cognitive abilities do (Mather, 2012; Salthouse, 2004). Friendships, family and societal factors are also important in everyday life and functioning (Bronfenbrenner, 1986). However, keeping the focus on individual cognitive abilities, we rarely have to perform at peak levels at all times, especially when performing familiar activities, which may ameliorate the effects of cognitive decline with age (Salthouse, 2004). With increasing age often comes increased experience, and potentially also wisdom (although this might be hard to measure), allowing for less dependence on the ability to solve novel problems at great speed (Salthouse, 2004). This might create a link from Gf back to the construct of Gc, a measure of world knowledge, which does not tend to show significant decline with age. In fact, studies have found that Gc shows a curve-linear relationship with age, increasing well into the 50's and 60's, only to declining at the oldest end of the age-spectrum (Park & Reuter-Lorenz, 2009). This brings us to the current study of cognitive aging in healthy middle-aged and older adults, with the research hypotheses stated below.

1.6.1 First hypothesis. Age is expected to be negatively correlated with fluid intelligence. Age is not expected to be negatively correlated with crystallized intelligence.

1.6.2 Second hypothesis. Depressive symptoms are expected to correlate negatively with fluid intelligence. Depressive symptoms are not expected to correlate with crystallized intelligence.

1.6.3 Third hypothesis. Depressive symptoms will add to the predictive value of age and sex in explaining fluid intelligence.

1.6.4 Fourth hypothesis. Fluid intelligence will be correlated with gray matter thickness of parieto-frontal areas.

2 Method

2.1 Participants

Healthy individuals were invited through advertisements in local newspapers to take part in the first wave of a longitudinal study of cognitive aging. Participants in wave one were assessed in 2005, and followed up two more times; wave two in 2008 and wave three in 2011. All participants were interviewed before inclusion, and participants with present or previous neurological or psychiatric disorders, a history of substance abuse, or other significant medical conditions were excluded. Participants were examined according to an extensive neuropsychological test protocol which included tests used to extract measures of crystallized and fluid intelligence. Although scores on the much used MMSE (Folstein, Folstein, & McHugh, 1975) were not gathered in the first wave, the neuropsychological test-results were reviewed by experienced neuropsychologists, ensuring that the participants were not demented or suffered from mild cognitive impairment (MCI) (Petersen et al., 2001). Of the initial participants in the dataset $n = 163$, $n = 11$ were excluded because of missing data on

the measure of full-scale IQ, or because of too low raw-score on this measurement (IQ < 80, which was 3 *SD*s below the sample mean of 116.2 (*SD* = 11.1)). Another 27 participants were excluded because they lacked a full test-protocol, to ensure the same number of participants on all measures. Of the remaining 125 participants, 83 were females. The age of the participants ranged from 46 to 79. All participants had completed obligatory schooling of at least 7 years (Wehling, Nordin, Espeseth, Reinvang, & Lundervold, 2011) and were in general well educated (see Table 1 for a summary of the sample demographics). All participants provided informed consent according to the Declaration of Helsinki (World Medical Association, 1997). The Regional Committee for Medical and Health Research Ethics of Southern Norway approved the first wave of the project.

2.2 Neuropsychological Assessment

All participants in this dataset have completed a neuropsychological test battery. The Matrix Reasoning (MR) subtest of the Wechsler Abbreviated Scale of Intelligence (WASI) (Wechsler, 1999) provided a measure of reasoning ability. The experimental Cued letter Discrimination Task (CDT) (see Espeseth et al., 2006, for a more detailed description; based on Parasuraman, Greenwood, Haxby, and Grady, 1992, and Posner, 1980) provided a measure of processing speed and spatial orienting. The official Norwegian translation of the California Verbal Learning Test (CVLT), Second Version (Delis, Kramer, Kaplan, & Ober, 2000), measured episodic memory function. The Color-Word Interference Test (CWIT) (Delis, Kaplan, & Kramer, 2001), developed from the more well-known Stroop test (Stroop, 1935), provided a measure of cognitive speed and executive functioning. The Vocabulary subtest from WASI was used to measure semantic knowledge. Performance on the first four of these cognitive tests was used to calculate Gf in the present study, and the

Vocabulary subtest was used to calculate Gc. The selection of these tests to compose the scores of Gf and Gc was inspired by the genome-wide association study by Davies and colleagues (2011), and the method of deriving the Gf is described in more detail in a previous publication from the project (Haász, Westlye, Espeseth, Lundervold, & Lundervold, 2012). All participants in the current study have also completed Beck's Depression inventory (BDI) (Beck, et al., 1996), providing a measure of symptoms of depression. More detailed descriptions of the tests are provided below.

2.2.1 Reasoning ability. Reasoning ability was assessed by the MR test from WASI (Wechsler, 1999). MR is a nonverbal abstract problem-solving test. In this test the participants were presented with incomplete patterns. The task was to complete those patterns by selecting one of five alternative response options. The outcome measure was the number of correctly completed patterns.

2.2.2 Processing speed and spatial orienting. Processing speed and spatial orienting was assessed by the reaction time (RT) of the CDT (Parasuraman, et al. (1992); see Espeseth, et al. (2006) for the current version used in this study). In the adaptation of the CDT for wave 1, the participants were instructed to fixate on a centrally located cross on the computer screen which was present for 500 ms, until a centered location cue (being an arrow pointing to the right, left or both directions) appeared. This cue was valid in predicting the subsequent target location on 50% of the trials, invalid on 16.7%, neutral on 16.7% and missing on the last 16.7%. The centered location cue appeared for a variable cue-target stimulus onset asynchrony (500 or 2000 ms) after which a letter target appeared 6.7 degrees to the left or right of the fixation cross. The participants were told to make rapid categorizations of the target stimulus, either a vowel or consonant, by pressing one of two response buttons.

The inter-trial interval was varied between 2200, 2500 or 2800 ms. The overall mean RT across all CDT conditions was then used as a measure of processing speed.

2.2.3 Processing speed and inhibition. Processing speed and inhibition as indicators of executive functioning in this study was measured by the four conditions of the CWIT from the Delis-Kaplan Executive Function System (D-KEFS) (Delis, et al., 2001). In the first condition, the participants were shown color patches in three different colors (red, blue and green) on a white surface, and the task was to name the colors as rapid and correctly as possible. In the second condition they were shown three words (red, blue and green) written in black ink on a white surface, and the task was to read the words as fast and accurately as possible. In the third and more cognitively demanding condition, the participants were shown the same three words, but now the words were written in incongruent ink color. The task was to name the ink color and thus inhibit the more automatic response of reading the word. The fourth condition measured both inhibition and switching. The same three words were written in incongruent colors, but some of the words were written inside a rectangular box. The task was to switch between naming the ink color, thus inhibiting reading of the word, and reading the word when the word was inside the box. The outcome measure used in this present study is the time it took the participants to finish each of these four conditions.

2.2.4 Episodic memory function. Episodic memory function was measured using the official Norwegian translation of CVLT, second version (Delis, et al., 2000). A list of 16 words was read out loud to the participants five times (List A). The task was to recall as many words as possible after each presentation. Immediately after the fifth trial, the participants were read a new list (List B) and asked to recall it. Then, the participants were asked to recall the words from List A, immediately after recalling

the words from List B, indicating their short-delayed free recall skills, and then according to given categories (cues). After 30 minutes, the participants were asked to repeat List A words, indicating their long-delayed free recall skills. Finally, they were asked to repeat the measures according to given cues and in a recognition trial. The present study included three CVLT measures: the number of hits across the five list A learning trials (1-5), and the short- and long-delayed free recall conditions.

2.2.5 Semantic knowledge. Semantic knowledge was assessed by the score on the Vocabulary subtest from WASI (Wechsler, 1999). This test indicates the degree to which one has learned factual knowledge, and is able to comprehend and verbally express one's understanding. Giving the participants a target word and asking them to define it provides the measure for this construct. Complete definitions are given an item score of 2, while incomplete definitions are given a partial credit item score of 1. The total score is then the sum of the item scores.

2.2.6 Self-reports of depressive symptoms. Signs of subclinical depression were in this study measured by the scores on Beck's Depression Inventory-II (BDI) (Beck, et al., 1996). The BDI score ranges from 0 to 63 points, with higher scores indicating severity of depression. A score of BDI $\leq$ 13 is labeled in the manual as indicative of minimal depression, scores ranging from 14 to 19 is labeled mild depression, from 20 to 28 is labeled moderate depression, $\geq$ 29 is labeled severe depression.

2.3 Magnetic Resonance Imaging (MRI)

MRI data were gathered for 91 of the 125 participants in this study. Separate Gf and Gc scores were calculated for this subsample, using the same procedure as described for the main sample in the statistics section, to make sure that the analysis of the relationship between cortical thickness and the cognitive measures were as accurate as possible.

2.3.1 MRI acquisition. Imaging data were acquired on a 1.5 T GE Sigma Echospeed scanner with a standard 8-channel head coil, using 256 × 256 × 124 dual-volume sagittal T1-weighted 3D FSPGR IR prepared acquisitions (TR/TE/TI/FA = 9.5 ms/2.2 ms/450 ms/7^{o}) at voxel-size 0.94 × 0.94 × 1.4 mm^3 with FoV= 256 × 256 mm^2. Total scan duration was approximately 15 min.

2.3.2 MRI morphometric analysis. Segmentation of brain structures was performed using FreeSurfer 4.3.1 (2012). Computational resources were provided by the Nordic Data Grid Facility (2012). The two sets of T1-weighted images were averaged during FreeSurfer analysis to increase signal-to-noise ratio. Topologically accurate surface models were constructed during the segmentation and deformation procedure (Dale, Fischl, & Sereno, 1999; Fischl et al., 2002; Fischl, Sereno, & Dale, 1999). The cortical thickness measure at each vertex of the cortical mesh was mapped on the inflated surface of each participant's reconstructed brain. For group surface analysis, the individual maps were smoothed using a circularly symmetric Gaussian kernel across the surface with a full width a half maximum (FWMH) of 10 mm and were averaged across participants using a high-dimensional averaging method and mapped on the inflated surface of the FreeSurfer`s average brain. Individual segmentations were controlled and manually corrected where necessary. The cortex was then parcellated into standard, anatomically valid and reliable gyral-based neuroanatomical regions using an automated labeling system (Desikan et al., 2006). This process resulted in 34 cortical regions, and the mean cortical thickness was calculated in each. Each labeled region was manually inspected for accuracy.

2.4 Statistics

2.4.1 Factor analysis. Raw scores from the MR, CDT, CVLT, CWIT and Vocabulary test were z-standardized to obtain the same unit of measurement across

all variables. The standardized scores of CDT and CWIT were inverted to obtain the same ordinal order as the other three test scores (higher scores indicate better cognitive functioning).

A hierarchical principal component analysis (PCA) was performed to obtain the Gf factor score. There was a strong correlation between the four components of Gf; MR, CDT, CVLT and CWIT. First two separate first-order PCAs were run on the three CVLT scores and the four inverted CWIT scores, and the first, unrotated scores of these two factors were obtained. Then a second-order PCA was run on the z-standardized MR score, z-standardized and inverted CDT RT score, and the first, unrotated factors of the CVLT and CWIT. Bartlett's test of sphericity was highly significant (on both the 1st and 2nd order PCAs) (Bartlett, 1954), indicating that the data were suitable for hierarchical principal component analysis (Pallant, 2010). Finally a single PCA component was extracted based on the two first order PCA analyses, MR and CDT, and the component scores of the first unrotated principal component were used to represent the Gf. The z-standardized raw score from the WASI Vocabulary test was used to represent Gc.

2.4.2 Correlations and analysis of variance. Pearson's correlation analysis was used to investigate relations between age, depression and the neuropsychological measures. To compare the sexes, an independent samples t-test for the equity of means was run, assuming equal variance. Analysis of variance (ANOVA) was used to control for main and interaction effects. All test were two-tailed.

2.4.3 Linear regression. The predictive value of age, sex and depressive symptoms in explaining Gf was investigated by running a linear regression analysis using the General Linear Model (GLM) package in SPSS, including age and sex as independent variables in the first model, and then adding BDI scores as an independent variable in

the second model. Gf and its four components were used as dependent variables in separate analyses.

2.4.4 Qdec analysis. The MRI data were analyzed using Qdec (2012). Qdec is an acronym for Query, Design, Estimate and Contrast. It is intended to aid researchers in performing inter-subject / group averaging and the inference on the morphometry data (cortical surface and volume) produced by the FreeSurfer processing stream.

All statistical analyses were performed using the SPSS statistics package version 19 for Mac, except to assess the relationship between cortical thickness and Gf, where we used a GLM as implemented in Qdec.

3 Results

3.1 Sample Characteristics and Results From the Cognitive Ability Tasks

The females in the sample were somewhat younger (M = 59.4, SD = 7.7) and more educated (M = 14.2, SD = 3.2) than the males (M_{age} = 61.1, SD = 8.4; $M_{education}$ = 13.9, SD = 3.4), but the differences were non-significant. Symptoms of depression as assessed by BDI ranged in scores from 0 to 21, with a non-significant difference between males (M = 6.5, SD = 4.5) and females (M = 5.7 SD = 4.5). The mean IQ was in the higher range of the normal distribution, both in males (M = 116.9, SD = 11.4) and females (M = 115.8, SD = 11.0).

Table 1 about here

Performance on the neuropsychological tests used to derive Gf and Gc is reported in Table 2, with mean scores on each of the tests, their relations to sex, age and depression, and factor loadings from the PCA. In deriving the 1st order factors in constructing the Gf factor, the Kaiser-Meyer-Olkin (KMO) measure of sampling

adequacy was .768 for the CVLT-factor and .681 for the CWIT-factor (Kaiser, 1974). The KMO on the second-order PCA leading to the Gf factor was .592, indicating that the data were suitable for PCA (Kaiser, 1974; Pallant, 2010). Correlations with age ranged from $p < .05$ to $p < .01$ on all test scores, except for the Vocabulary raw score, used to derive Gc, where age was non-significant. The females significantly outperformed the males in the sample on all subcomponents of the CVLT, as well as the first two conditions of the CWIT.

Tables 2 and 3 about here

3.2 Age, Sex and the G-factors

A univariate ANOVA including Gf as the dependent variable and age and sex as fixed factors showed significant main effects, $F(30, 72) = 1.891$, $p = .015$ for age, and $F(1, 72) = 11.326$, $p = .001$ for sex, but no sex-age interaction, $F(21, 72) = .758$, $p = .758$. A correlation analysis showed that age was significantly correlated with a decline on Gf in both males ($p = .003$) and females ($p < .001$) (Table 3, Figure 1a). In females, the age-related decline was evident in CDT ($p = .020$) and the CWIT factor ($p < .001$), in males in the CVLT factor ($p < .001$). The correlations with age were non-significant for both sexes regarding Gc (Table 3, Figure 1b). Independent t-tests between females and males showed statistically significant lower results in males than females on the Gf, $t(123) = -3.0$, $p = .003$, $d = -0.54$, the CVLT factor, $t(123) = -5.1$, $p < .001$, $d = -0.92$, and the CWIT factor, $t(123) = -2.2$, $p = .027$, $d = -0.40$.

Figure 1 about here

3.3 Depression and the G-factors

A bivariate correlation analysis showed that the BDI score was negatively correlated with Gf ($p < .001$) and three of its components; MR ($p = .039$), CDT ($p = .003$), and the CWIT factor ($p < .001$), but not Gc ($p = .258$) (Table 3).

Separate analyses of the sexes indicated an interaction with age on BDI score (Figure 2a, 2b). However, running a univariate ANOVA with BDI score as the dependent variable showed that the age-sex interaction was statistically non-significant, $F(21, 72) = 1.494$, $p = .107$. The BDI score was negatively correlated with Gf ($p < .001$) and Gc ($p = .017$) in males (Table 3), but not in females ($p = .088$ and $p = .829$, respectively). The BDI score was significantly correlated with age in females ($p < .001$), but not in males ($p = .225$). The CWIT factor score correlated significantly with the BDI score in both females ($p = 0.019$) and males ($p = 0.009$). Males also showed significant BDI correlations for MR ($p = 0.040$) and the CDT ($p < .001$).

Figure 2 about here

3.4 Predictive Value of Depression on Gf

As age was shown to influence Gf, and sex has been shown to have a substantial effect as well, these two variables were entered in the first model of a hierarchical regression analysis, with symptoms of depression (i.e., BDI score) added as a variable in the second model. From the correlation analysis we found that depression explained 9.8% of the variance of Gf when looked at separately. When age and sex were accounted for, the addition of symptoms of depression explained 5.4% unique variance of the scores on Gf (Table 4). Separate analyses for the

subcomponents of Gf showed that the unique variance explained by depression, after accounting for age and sex, was significant in two of the components, 5.2% for the CDT, $R^2 = .101$, $\Delta R^2 = .052$, $F(1,121) = 4.527$, $p = .009$, and 6.0% for the CWIT factor, $R^2 = .242$, $\Delta R^2 = .060$, $F(1,121) = 10.020$, $p = .002$.

Table 4 about here

3.5 Cortical Thickness and Gf

A significant positive linear relationship between cortical thickness and Gf was found in 21 cortical areas in the left hemisphere (LH), and 20 cortical areas in the right hemisphere (RH). Table 5 shows significant correlations between Gf and vertexes in LH. Table 6 shows the correlations in RH. Figures 3 and 4 visualize the statistically significant effects of Gf on cortical thickness at the level of individual vertexes. The figures are shown on the inflated surface of a template brain. Left and right hemispheric superior, lateral and medial surface views are shown. The color-coding system shown at the bottom of each figure indicates the level of statistical significance: Areas of red color indicate regions of positive association between Gf and cortical thickness, while blue indicates a negative relationship. The relationship between Gf and cortical thickness showed an expected pattern of fronto-temporal activation. Most of the significant correlations remained when correcting for sex (16 in LH, 12 in RH), but disappeared when correcting for age and/or multiple comparisons (False Discovery Rate = 0.05).

Tables 5 and 6 about here

Figures 3 and 4 about here

4 Discussion

The present study showed that increased age was correlated with lower scores on Gf but not Gc, in line with the first hypothesis. Secondly, Gf was expected to be associated with symptoms of depression. Although higher scores on symptoms of depression were correlated with lower Gf scores, the results revealed some interesting sex-differences. The association was primarily true for males, with the same scores on BDI having little influence on cognitive abilities among the female participants. In line with the third hypothesis, depression did add significant explanatory variance to the predictive model of decline on fluid intelligence, even when age and sex were accounted for. However, further analyses revealed that depression only added explanatory variance in predicting the scores of Gf in males. Finally, we investigated associations between cortical thickness measures and the Gf scores. Gf was significantly correlated with MRI measures of cortical thickness, but these correlations disappeared when controlling for age and/or multiple comparisons.

4.1 Possible Mediators of the Age-Related Cognitive Decline

As noted above, there was no significant age-related decline on the measure of Gc, which is to be expected based on previous studies (Salthouse, 2004). Further, we found that Gf and all its components significantly declined with age. With correlations ranging from $r = -.2$ to $r = -.4$, they were not as large as what have been found in some other studies of cognitive abilities across the lifespan (Salthouse, 2004). This may be due to the restricted age-range of the current sample. With the

youngest participants already in their mid-forties one can expect that a certain amount of cognitive decline has already taken place (Salthouse, 2009). In fact, Salthouse contends that in contrast to popular belief, cognitive decline doesn't tend to make people's performances on these kinds of measures more dissimilar. This is in contrast to arguments from Ghisletta, Rabbitt, Lunn and Lindenberger (2012), who have found heterogeneity in between-person cognitive decline. Ghisletta et al. (2012) did however observe a quite general within-person cognitive decline with age. In this study we have observed a cognitive decline that seems to influence everyone in generally the same fashion, in line with Tucker-Drob and Salthouse (2008). What underlies what seemingly common cognitive decline with age? Different possible mediators are explored in the literature, and here we will discuss cognitive components such as cognitive speed, executive function and memory. Biological substrates such as cortical thinning, reduced white-matter integrity and plasticity; as well as symptoms of depression as possible mediators, will be discussed in separate sections.

4.1.1 Cognitive speed. The cognitive speed measures show significant age-related declines in the current study. Previous studies have reported similar findings of declining cognitive speed (Ghisletta, et al., 2012; Salthouse, 2004), which in our study could explain a big proportion of the cognitive decline observed on Gf. In fact, our definition of Gf rests heavily on cognitive speed measures, with two out of four components measuring cognitive speed (CDT and the CWIT factor). However, other studies, using definitions of fluid intelligence less reliant on cognitive speed (per se, such as matrix reasoning), also report consistent declines with increasing age (Park & Reuter-Lorenz, 2009).

4.1.2 Executive function. The largest age-related decline in this study was found on CWIT, a test not only being a measure of cognitive speed but also of executive function (Delis, et al., 2001). Executive function, which includes inhibition, updating and focusing of attention, has been investigated to see whether this superordinate construct can explain some of the variance in cognitive aging (Colom, Rubio, Shih, & Santacreu, 2006; Salthouse, Atkinson, & Berish, 2003). However, these studies have found that executive function seems to have surprisingly insignificant explanatory impact on constructs of intelligence in aging compared to the effect of working memory, leading us to the next potential mediator of cognitive decline.

4.1.3 Memory. In our study, the CVLT gives an index of episodic memory function, relying on the participants' ability to retain verbal information over a short period of time, as well as after 30 minutes of performing other tasks (Delis, et al., 2000). Our finding of an age-related decline on CVLT is an indicator of the potential importance of this underlying construct in the decline on Gf. Working memory and general intelligence has been found to be highly correlated, yet it is still not quite settled why this is so (Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008; Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004). There are different possible models that can explain this link, some indicating a capacity of short-term storage as a potential mediator, others pointing to the role of executive functions in mediating the relationship between intelligence and working memory. However, when testing different models explaining the relationship between memory and intelligence, Colom, et al. (2008) have found that the links with speed-measures and executive functions disappear when a short-storage component is accounted for, indicating that memory function is an important mediator in age-related declines in Gf. Further

research with more comprehensive designs, testing for different components simultaneously, might help solve this riddle.

4.2 Depression, Cognitive Decline, and the Effect of Sex

4.2.1 The emotional brain. Depression might in some cases debut in older age, but research show that older adults tend to be better at regulating their emotional states than younger adults (Mather, 2012). This is however the case in normal, healthy aging. One explanation for depression in older age is that lower cognitive abilities make individuals more susceptible to experiencing depressive symptoms (Gottfredson, 2004). As the current sample was highly intelligent on average, another explanation to the association between symptoms of depression and a decline on Gf is the possibility of brain atrophy being an underlying factor, causing both cognitive decline and an increase in depressive symptoms (Anderton, 2002; Jung & Haier, 2007; Mather, 2012). With deterioration of the prefrontal cortex (PFC), there is a strong association with depressive symptoms in older age. The PFC is shown to be very important in the cognitive ability tasks that comprise Gf in this study (Jung & Haier, 2007), which might provide a link between these two outcomes. Cognitive speed measures, which the Gf factor in this study relies heavily on, are shown to symptomatically decline in older adults with depression (Herrmann, et al., 2007). This hypothesis was not investigated in the present study, but will probably be followed up by further studies within the main cognitive aging project.

4.2.2 Sex differences. It has long been known that women have a tendency to report more symptoms on mental health surveys than men do (Tousignant, Brosseau, & Tremblay, 1987). One possible explanation of the discrepant finding of the effects of depressive symptoms, having a large impact on male cognitive ability but not on female cognitive ability, might be that women tend to “over-report” psychiatric

symptoms, whereas males tend to "under-report" psychiatric symptoms, indicating a possible greater influence of the subclinical scores of depression in the male sample compared with that of the female sample (Piccinelli & Wilkinson, 2000). This might help explain the comparatively big differences in this current study between the sexes in the effects of symptoms of depression, especially on Gf. The unexpected negative correlation of Gc with depression in males might perhaps have to do with a theoretical issue. Cattell (1963) hypothesized in his theory that fluid intelligence would be a form of processing capacity, whereas crystallized intelligence would simply be a passive storage house for knowledge gained. As will be explored further in a following paragraph, perhaps this conceptualization of intelligence needs to be reinvestigated. One approach views the Vocabulary test not so much as a test for "intelligence as product", as Deary, et al. (2010) stated it, but rather that this test reflects current verbal intelligence ability. Males are known to perform lower than females on verbal ability tests (Delis, et al., 2000; Lezak, et al., 2004). Depression is shown to have a negative impact on structural and functional measures related to verbal ability (Herrmann, et al., 2007). It is thus not surprising that symptoms of depression would have a negative impact on verbal ability, creating this at first seemingly discrepant finding of Gc being influenced by symptoms of depression in males.

4.3 The Relationship Between Cortical Thickness and Gf

Fluid intelligence was related to cortical thickness in frontal, parietal and temporal cortical areas, in line with the P-FIT hypothesis of Jung and Haier (2007). Men have larger brains than women on average, and larger brains have been found to correlate with general intelligence (Burgaleta, et al., 2012). The females in this sample performed significantly better than the males on Gf. This did not seem to influence the relationship between cortical thickness and Gf too much in the current

study, as most significant correlations remained after controlling for sex. This may be because sex differences in brain volume are related to specific skills, not to general intelligence (Burgaleta, et al., 2012). However, the association between Gf and cortical thickness disappeared after controlling for age and multiple comparisons. There are several possible reasons for the lack of significant findings after making these two corrections.

The sample size was relatively small. Having MRI measures for 91 subjects, there might not have been sufficient power to establish the link between cortical thickness and Gf after making these corrections and thus limiting the degrees of freedom in these analyses. There might however exist a publication bias, publishers favoring studies finding significant results, possibly leading to negative findings being underrepresented, as they may have been considered mere failed replications of already well-established findings (Salthouse, 2011).

Fluid intelligence might be reflected in other brain measures than the parieto-frontal cortical areas. One line of inquiry points to the underlying white matter structure of the brain. White matter has been found to be important in cognitive speed measures (Li et al., 2009; van den Heuvel, Stam, Kahn, & Hulshoff Pol, 2009), executive function (Salthouse, 2011) and memory (Tang et al., 2010), all components found to underlie the construct of fluid intelligence (Colom, Karama, Jung, & Haier, 2010).

The aging brain undergoes degeneration and reorganization that might make it more difficult to identify brain behavior relationships (Salthouse, 2011). There is the possibility of the brain architecture supporting intelligence being plastic, and that networks and functional regions change during normal aging (Haier, et al., 2005). However, it may be that finding a “neuro-g” in itself will prove to be a difficult task,

as this involves correlating brain measures with composite scores of vastly different cognitive tasks (Haier et al., 2009). A novel approach that might prove promising is the study of anatomical brain networks and the efficiency of functional brain networks in association with intelligence (Li et al., 2009; van den Heuvel, et al., 2009). As Gf and Gc most likely are widely distributed in the brain, network-model approaches might have more success in pinpointing the anatomical correlates of intelligence, and how this changes with age.

4.4 General, Fluid and Crystallized Intelligence: Controversy or Consensus

4.4.1 Statistical disputes. Gould (1981), an evolutionary biologist, proposed that the g-factor of intelligence is a statistical artifact, that it is the byproduct of the particular method used to approach the study of human intelligence differences by the means of correlating a variety of cognitive ability tests. Deary (2000) argues that the g-factor need not be an artifact of the psychometric/factor analytic approach to human intelligence differences, as a g-factor need not emerge from factor analysis. In fact, in the psychometric approach to the study of personality, there appears to be at least five distinct traits (McCrae & Costa, 1987), and not a single g-factor of personality emerging from factor analysis at all (Gottfredson, 1998). Deary (2000) argues that no matter what factor analytic approach you use, you will indeed be confronted with the fact that scores from different cognitive ability tests tend to correlate with each other. In fact, Deary (2000) argues that the first unrotated factor of the principal component analysis accounts for such a large proportion of the variance in cognitive ability tests given to samples of the population, that it lends itself easily to the interpretation of the existence of a g-factor of intelligence. Although voicing some concerns regarding the methods used to extract the general factor of intelligence (e.g. Principal Component Analysis may actually create a g simply as a mathematical artifact if the dataset is

suboptimal), Arthur Jensen, a strong advocate of the meaningfulness of the concept of g, argues that "Almost any g is a "good" g and is certainly better than no g" (Jensen & Weng, 1994).

4.4.2 Beyond psychometrics. Gardner (1983), however, dismissed the notion of measuring intelligence in the way described here. He posits a vastly different approach to the understanding of intelligence, claiming that we have multiple intelligences with no meaningful way of conceptualizing a general factor above these. Empirically testing of Gardner's theory has been somewhat difficult as his suggested competencies can be hard to operationally define, e.g. how does one measure kinesthetic intelligence? Even so, there have been empirical tests of his theory, finding that there is a substantial common g-factor shared between his concepts, even of what Gardner suggested to be quite separate domains of intelligence (Deary, 2012). Robert J. Sternberg, one of the really big names in intelligence research, seems not to be overly positive to the concepts of "IQ" and "g" at all (Sternberg, 1985). Sternberg offers a different approach to intelligence, with his own triarchic theory of intelligence that is a cognitive process theory of intelligence. This theory examines how different socio-cultural contexts, individual experiences and cognitive components add up to explain individual developmental differences in intelligence. Not too unlike Flynn (2007), Sternberg points to the importance of individual agency, and how this will have an impact on our cognitive functioning, and thus ultimately the brain. This complicates the concept of cognitive aging, lending some support to the explanation that cognitive abilities get more widely distributed in the brain with increasing age, and that interpersonal variability might increase.

4.4.3 Clinical neuropsychology. In the neuropsychological tradition of assessing abilities and deficits related to brain structure and (mal-) function, some authoritative

authors seem not to be overly impressed by the notion of general intelligence, as they argue it tends to be too general to have any clinical value (Lezak, et al., 2004). In this tradition, a preferred conceptualization would be that the brain consists of many discreet functional regions and cognitive abilities, which would normally operating so smoothly in the intact brain as to give the impression and experience of being a single, seamless attribute of the mind. Lezak (1988) even proclaimed that the concept of general intelligence (originally represented by an IQ-score in her paper, or g in this context), as it represents a derived score from several measures of different cognitive abilities, should be put to rest. The argument being that g represents too many different and confounded functions to be conceptually meaningful. Granted that there is much to be gained in a clinical setting, with individuals who have some potential neurological abnormalities, by a more thorough and detailed neuropsychological assessment than relying on composite scores such as the g-factor, dismissing the concept of general intelligence altogether would be a misnomer, as a long research tradition indicates that these kinds of measures do add meaningful information to an individual's cognitive profile, albeit when used with the appropriate care (Deary, 2012).

4.4.4 The structure of intelligence. This study is based on the definition of Gf and Gc by Davies, et al. (2011), historically stemming from the works of Cattell and Horn (Cattell, 1943; Horn & Cattell, 1966). This might be a problematic theoretical approach to the understanding of intelligence. Kan, Kievit, Dolan and van der Maas (2011) have found that the Gf-Gc theory leads to the empirical finding that fluid intelligence equals general intelligence; that the general factor is undistinguishable from a factor representing fluid intelligence when using factor analysis on large datasets of cognitive ability tests. Kan et al. (2011) found that crystallized intelligence

is in effect non-existent, and empirically represented by a factor of verbal comprehension. Instead of relying on the investment theory of Cattell and Horn, where fluid intelligence equals raw ability and crystallized intelligence a mere storage of knowledge gained, a recent theoretical development in the understanding of intelligence is the verbal, perceptual and image rotation (VPR) model (Johnson & Bouchard Jr, 2005). Johnson and Bouchard claim that a modern, revised edition of Vernon's V:ed (verbal-educational) and K:m (spatial-mechanical) theory (Vernon, 1961), might provide a better theoretical approach to the study of human intelligence. The VPR model is found to have a better fit with empirical data from multiple studies of cognitive abilities, when these are re-investigated using confirmatory factor analysis (Major, Johnson, & Deary, 2012). The VPR model does not distinguish between fluid and crystallized intelligence, allowing for a more flexible framework with multiple potential strata of intellectual abilities, the VPR model simply contends that verbal abilities belong together, as do spatial abilities in the image rotation component, and cognitive discrimination and speed tasks in the perceptual component (Johnson & Bouchard Jr, 2005; Johnson, te Nijenhuis, & Bouchard Jr, 2007; Major, et al., 2012).

4.5 Implications of the Findings From the Current Study

What is to be expected of age-related cognitive declines in a sample of healthy middle-aged and older adults? These findings can attest to the current understanding that normal aging is in fact associated with a decline on measures of fluid intelligence (Salthouse, 2004). A finding from the current study is that minimal symptoms of depression, as defined by the scores of the present sample on BDI-II (Beck, et al., 1996), has a huge negative correlation with fluid intelligence, and further that this holds true only for the males in the sample, not the females. This is worthy of further

investigation, as this might have the clinical implications of that taking even small signs of depressive symptoms seriously is important with male patients from these cohorts. Another finding that might have implications for further studies is that the current sample shows non-significant age-related declines on measures of cortical thickness in relation to Gf. This might as noted above indicate that a bigger sample, with a greater age-range; or employing a different method of analysis, might be needed to find the results one might expect from the literature (Jung & Haier, 2007; Haier, et al, 2005), when investigating the brains of middle-aged and older adults.

4.6 Limitations of the Current Study

The participants of this current study represent a highly intelligent and well-educated sample, and the sample is therefore not representative of the population as a whole. With a mean of 116 points on full-scale IQ, these participants are more than a standard deviation above the standardized mean of 100. Also having completed more education than average, this may have confounding, and for the participants beneficial effects on cognitive abilities in this sample, building up their "cognitive reserve" (Stern, 2009). In fact, the risk for developing dementia in older age has been found to show a twofold increase for those with less than 8 years of education (Stern, 2009). In this sample the mean years of education is 14. The restriction of age-range in this current sample may also mask some effects of cognitive decline, as one can expect individuals to decline on measures of fluid intelligence already from their late twenties onwards (Salthouse, 2009). Samples with a broader age-range and more diverse characteristics, more representative of the population as a whole, can provide the answers to the impact of these effects in this current sample. High IQ and high levels of education can potentially skew the results in this study to only apply for those with high initial cognitive function.

Only one cognitive ability test, the WASI Vocabulary test (Wechsler, 1999), is used to comprise the factor of Gc. This may be problematic as all stands and falls on this one test, limiting the possibility of variability over a range of different tests evening each other out. On the other hand, this approach with only one vocabulary test as a measure of crystallized ability is seemingly common in the literature, where it appears to be unproblematic and robust enough for current purposes (Davies, et al., 2011; Park & Reuter-Lorenz, 2009).

As mentioned in a previous section, the factor of Gf relies heavily on cognitive speed measures. This might be problematic, as these measures have been found both to decline steadily with age, and to give a female test benefit, possibly explaining some of the current findings (Ghisletta, et al., 2012; Salthouse, 2009). Again, this is however seemingly a common approach to studying fluid intelligence, and might thus not be problematic in this study after all (Davies, et al., 2011).

This current study looks only at data collected in the first wave of a three-wave, longitudinal study. Thus, this is a cross-sectional analysis of individuals of different ages assessed at the same time, limiting the results to potentially confounding cohort effects, such as the "Flynn-effect" (Flynn, 1987; Herrnstein & Murray, 1994). Flynn (1987) had shown that cohorts born in the later decades of the 20th century did progressively better on intelligence tests than previous cohorts. This was especially true for tests measuring fluid intelligence such as matrix reasoning tests, where the later generations potentially scored as much as a standard deviation higher than the previous generation. This sudden surge of abstract reasoning ability could not be due to genetics, but had to come from environmental changes, such as better educational opportunities, and serves to confound the differences in test scores between cohorts. This limitation can be remedied by analyzing the longitudinal data.

The benefit of longitudinal studies is that they can provide the means to assess intra-individual change, whereas cross-sectional studies can only give a rapport of inter-individual differences (Schaie, 2005).

However, there is the potential danger of having the gains by analyzing longitudinal data lost by the fact that people tend to show quite large and confounding practice effects when taking intelligence tests, thus in effect creating a possibility of showing a slower decline than what would otherwise be expected (Salthouse, 2010). To avoid this being a problem and take into account test-retest effects, one might add untested participants within the same cohorts in following waves. Thus one can have an indication of what would be expected from "naive" participants on the measures of interest.

Already having looked into the potential confounding moderator of sex in relation to cognitive ability tests, it is worth mentioning here the fact that the current sample is quite biased in gender, with there being a 2:1 female to male ratio. This difference in sample size could have potential effects on the concepts we attempt to measure. However, this is seemingly common in these kinds of studies (Espeseth, et al., 2012; Haász, et al., 2012).

4.7 Conclusion

In this study we found that increased age was associated with cognitive decline. Although many nuances have been discussed concerning this correlation, this is a finding well supported by the analysis of the current data. Different cognitive abilities age differently. Cognitive speed and memory function are likely to show large declines, whereas semantic knowledge is likely to be retained and well preserved. Relatively minor symptoms of depression had a surprisingly large effect, and interestingly this holds true only for the males who participated in the first Wave.

This would be interesting to follow up, to see how this develops further in the longitudinal data. Clinically, one might best be advised to take seemingly minor symptoms of depression seriously when assessing middle-aged and older men, as this might have a great impact on their cognitive functioning, depending of course on what causes this association.

Brain imaging is more complicated than meets the eye, and the same might be said about (cognitive) aging. Perhaps the methods chosen were insufficient, or the sample size or power of the study was too small, to uncover the relationship between cortical thickness, age and fluid intelligence. Aging might serve as a confounder, influencing both cortical thickness and fluid intelligence, possibly in the same direction, or possibly diffusing the relationships between the once more clear-cut, intelligible intelligence processing streams and modules of the brain. Further studies, employing different methods such as analyzing brain network models of intelligence, will hopefully provide a more satisfying answer to this question.

Finally, although much can be said about the theoretical underpinnings of this current study, and the possible cohort effects of increasing fluid intelligence, the fluid-crystallized dichotomy does seem like a valid distinction in the present analysis. Fluid intelligence declines with increasing age, crystallized intelligence remains. Cattell and Horn (1966) may have identified a conceptually meaningful distinction between two capacities of our brains and minds. Whether the VPR-model proves to be a better fitting model, only further studies will tell.

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Table 1

Sample Characteristics

Demographic variables	*Mean (SD)*
n	125
Age	60.0 (7.9)
Sex (F/M)	83/42
Education (years)	14.1 (3.2)
Depression (BDI)	6.0 (4.5)
IQ	116.2 (11.1)

Table 2

Cognitive Tasks Used to Derive Gc and Gf

					1st order PCA		*2nd order PCA*
Cognitive task	*Mean (SD)*	*Sex (t)*	*Age (r)*	*Depression (r)*	*A*	*B*	*C*
Vocabulary Raw Score	65.46 (7.26)	0.12	-0.10	-0.10	-	-	-
Matrix Reasoning Raw Score	24.80 (4.83)	-0.33	-0.18*	-0.19*	-	-	0.56
CDT Overall Reaction Time	679.84 (111.11)	0.73	-0.22*	-0.26**	-	-	0.63
CVLT-II Immediate recall (trail 1-5)	51.87 (10.27)	5.06**	-0.29**	0.04	0.94	-	0.65
CVLT-II short delay free recall	11.15 (3.03)	4.77**	-0.28**	0.06	0.94	-	-
CVLT-II long delay free recall	12.02 (3.03)	4.32**	-0.29**	0.01	0.94	-	-
CWIT condition 1-color	29.84 (5.47)	2.35*	-0.26**	-0.20*	-	0.84	0.73
CWIT condition 2-word	20.93 (3.16)	2.97**	-0.23*	-0.24**	-	0.73	-
CWIT condition 3-color/word inhibition	56.55 (13.77)	1.28	-0.42**	-0.26**	-	0.84	-
CWIT condition 4-word inhibition/ switching	63.13 (15.01)	0.23	-0.32**	-0.29**	-	0.67	-
% explained by 1st component					88.04	60.08	41.76

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

A = PCA factor loadings for CVLT. B = PCA factor loadings for CWIT. C = PCA factor loadings for Gf.

Table 3

Correlation table

	Depression	*MR*	*CDT*	*CVLT*[a]	*CWIT*[a]	*Gc*	*Gf*
Overall							
Age	.162	-.183*	-.218*	-.304**	-.397**	-.103	-.436**
Depression	-	-.185*	-.262**	-.036	-.315**	-.102	-.313**
Females							
Age	.289**	-.138	-.255*	-.141	-.459**	-.110	-.409**
Depression	-	-.121	-.115	.044	-.257*	.024	-.189
Males							
Age	-.089	-.276	-.126	-.519**	-.270	-.088	-.454**
Depression	-	-.318*	-.583**	-.090	-.397**	-.365*	-.514**

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

[a] 1st order factor scores.

Table 4

Predictive Value of Depression on Gf

Step	*Predictor variable*	ß	R^2	ΔR^2	ΔF	*p*
	Overall					
1	Age	-.413	.238	.238	19.065	.001
	Sex	.220	-	-	-	.007
2	Depression	-.236	.292	.054	9.249	.003
	Females					
1	Age	-.409	.167	.167	16.228	.001
2	Depression	-.077	.172	.005	.522	.472
	Males					
1	Age	-.454	.206	.206	10.376	.003
2	Depression	-.560	.517	.311	25.059	.001

Table 5

Significant Correlations in the Left Hemisphere with Gf

ClusterNo	*Max*	*VtxMax*	*Size(mm2)*	*TalX*	*TalY*	*TalZ*	*NVtxs*	*Annotation*
1	3.8225	65598	187.29	-20.4	60.3	10.9	247	rostralmiddlefrontal
2	3.0497	58139	58.19	-38.6	-29.5	63.5	167	postcentral
3	2.8428	42155	64.85	-63.0	-41.0	9.1	157	bankssts
4	2.7245	81956	69.69	-8.2	-26.0	51.6	166	paracentral
5	2.6308	30250	17.31	-11.0	-45.4	2.5	58	isthmuscingulate
6	2.6194	95411	153.24	-16.0	-95.2	-1.5	179	pericalcarine
7	2.5932	15885	73.54	-37.9	-12.7	51.2	161	precentral
8	2.5674	87481	92.76	-10.5	-85.9	10.1	147	pericalcarine
9	2.5513	106587	35.15	-57.6	-20.6	23.5	84	postcentral
10	2.5269	66655	33.08	-42.9	23.7	36.7	61	rostralmiddlefrontal
11	2.3486	144367	30.57	-52.4	-6.9	40.8	70	precentral
12	2.3226	23011	16.66	-21.0	-27.7	-18.4	52	parahippocampal
13	2.2825	121762	58.62	-42.1	34.2	20.6	106	rostralmiddlefrontal
14	-2.2764	23090	13.57	-48.0	-49.8	43.5	32	supramarginal
15	2.2160	120128	20.55	-44.3	-29.7	2.5	58	superiortemporal
16	-2.2021	120821	15.69	-51.5	-61.5	-7.2	27	inferiortemporal
17	2.1852	10130	28.64	-16.8	-67.5	-7.7	34	lingual
18	2.1728	19500	14.09	-31.0	-39.4	51.9	31	superiorparietal
19	2.0865	117106	8.38	-11.6	13.7	59.4	13	superiorfrontal
20	2.0706	144470	24.95	-46.9	-6.6	46.5	37	precentral
21	-2.0308	132030	2.19	-23.7	-71.5	27.1	4	superiorparietal

Table 6

Significant Correlations in the Right Hemisphere with Gf

ClusteNo	*Max*	*VtxMax*	*Size(mm2)*	*TalX*	*TalY*	*TalZ*	*NVtxs*	*Annotation*
1	3.0902	86480	198.74	15.6	-76.9	11.9	281	pericalcarine
2	-3.0238	71118	109.36	7.0	21.4	23.6	260	caudalanterior cingulate
3	2.9760	117110	64.33	46.5	-0.2	33.6	112	precentral
4	2.9419	117632	111.97	5.6	-78.0	19.8	148	cuneus
5	-2.6935	33485	41.08	7.0	26.6	-10.2	94	rostralanterior cingulate
6	2.3848	118798	36.08	33.0	46.3	17.1	50	rostralmiddle frontal
7	2.3636	70659	23.12	19.0	-15.6	63.7	44	precentral
8	2.3517	34952	29.77	37.0	51.6	-4.2	39	rostralmiddle frontal
9	-2.3385	117914	11.90	58.0	-29.2	43.5	37	supramarginal
10	2.2871	142183	16.57	23.0	-56.4	53.5	39	superiorparietal
11	2.2838	60624	39.68	46.4	31.3	-12.9	70	parsorbitalis
12	2.2494	25038	44.08	7.8	55.9	24.9	81	superiorfrontal
13	-2.2239	70507	31.92	58.3	-7.6	-26.7	45	middletemporal
14	-2.2085	40721	14.51	36.3	-16.4	-1.4	38	insula
15	2.1705	24263	16.31	60.5	-29.2	7.3	32	superiortemporal
16	2.1508	45739	22.39	12.5	43.5	-22.6	45	lateralorbito frontal
17	2.0676	78440	6.49	45.2	-62.3	36.9	14	inferiorparietal
18	2.0573	33028	8.21	34.5	-30.3	58.1	13	postcentral
19	-2.0298	1768	2.78	29.3	-58.3	-4.8	5	lingual
20	2.0296	148619	10.26	14.7	-61.1	1.9	13	lingual

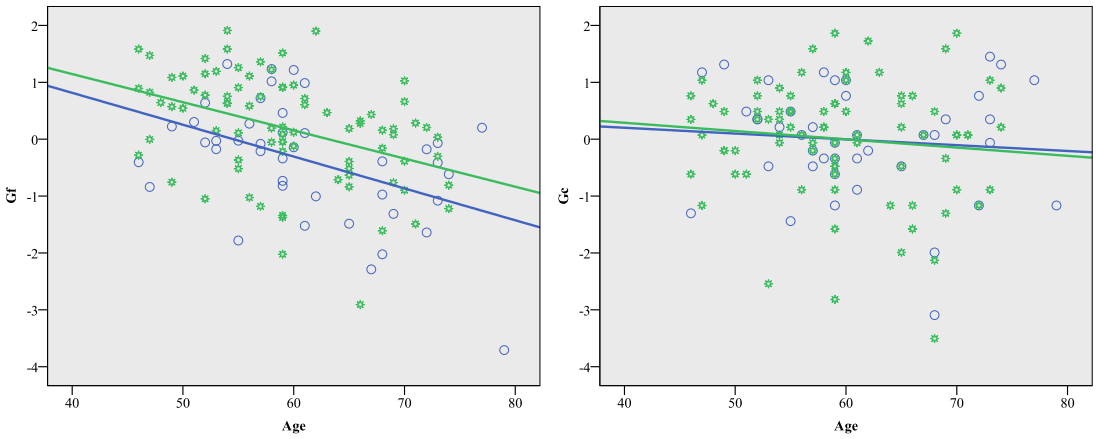

Figure 1. Scatterplots of age with Gf and Gc. Green is female, Blue is male.

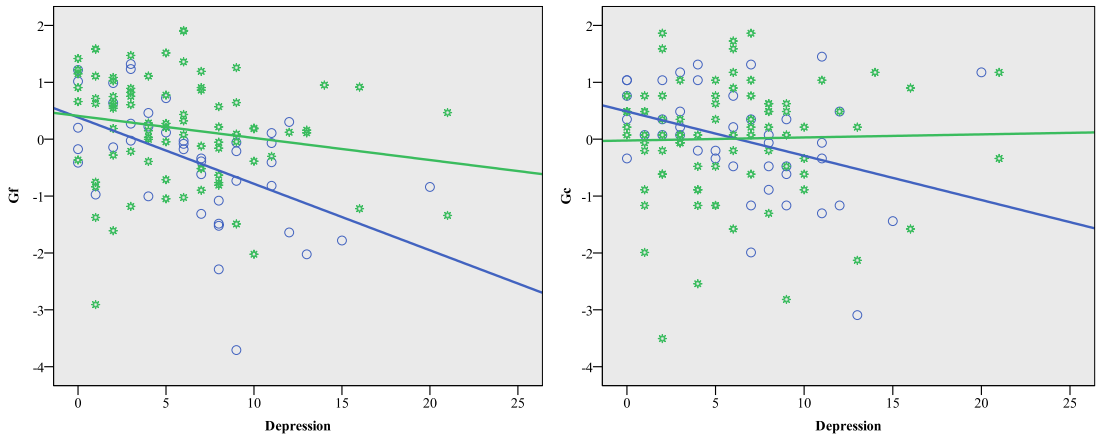

Figure 2. Scatterplots of depression with Gf and Gc. Green is female, Blue is male.

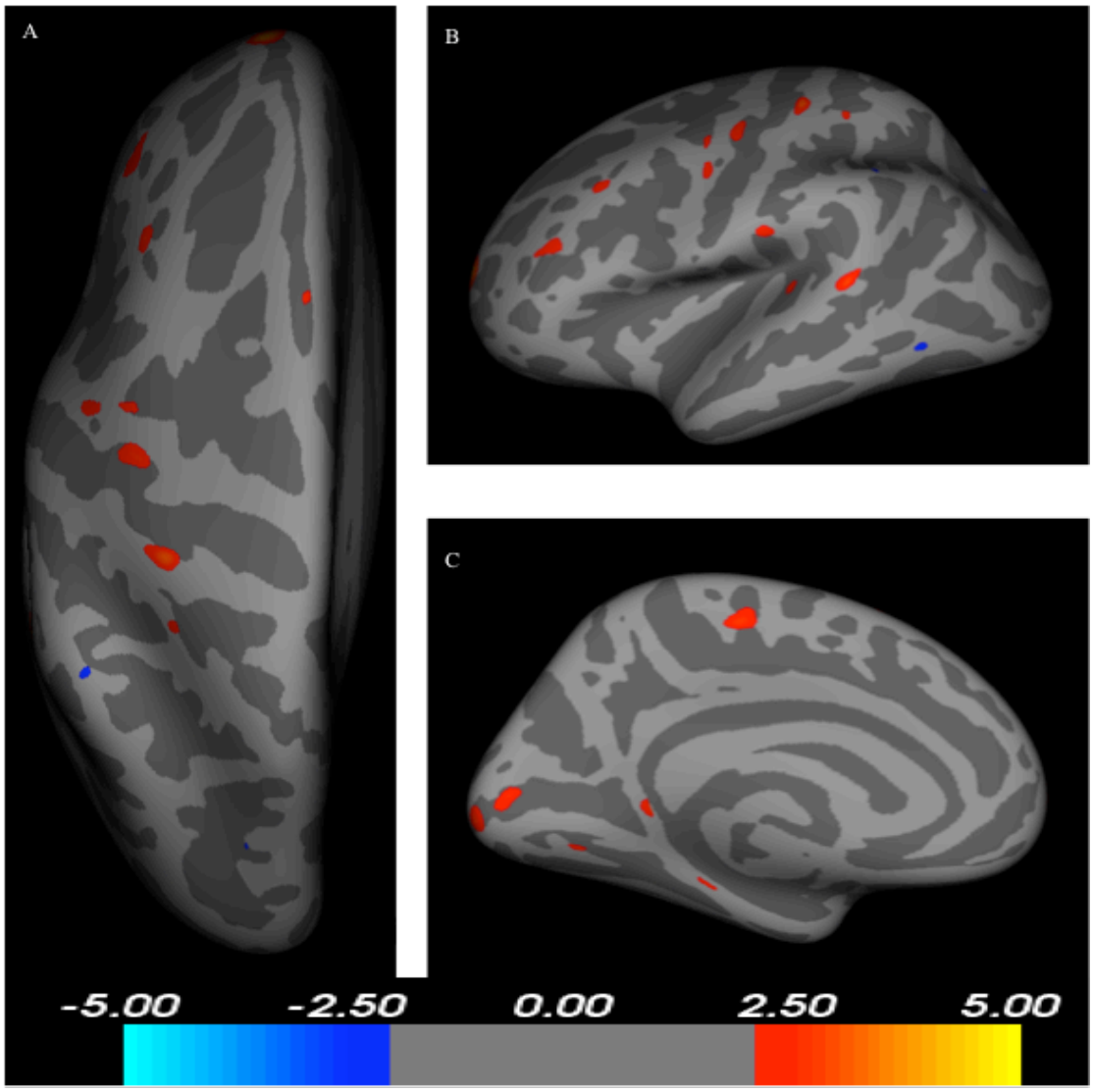

Figure 3. Significant correlations of vertexes in LH with Gf.

A. Superior View. B. Lateral View. C. Medial View. Color gradient indicates the strength of correlation between cortical thickness at each vertex and Gf.

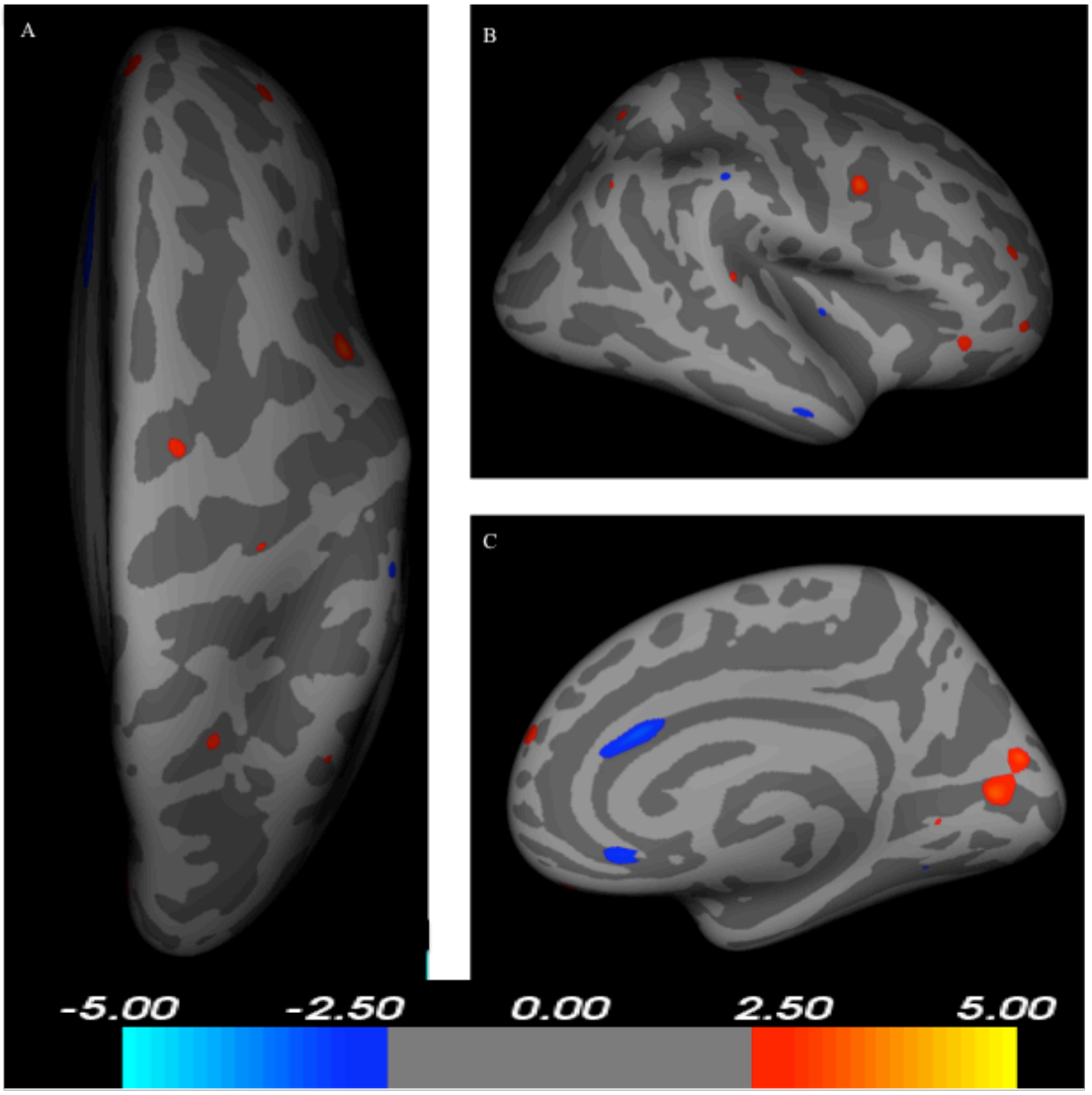

Figure 4. Significant correlations of vertexes in RH with Gf.

A. Superior View. B. Lateral View. C. Medial View. Color gradient indicates the strength of correlation between cortical thickness at each vertex and Gf.

Syntax of Calculations in SPSS

```
GET
  FILE='O:\Dropbox\Hovedoppgave\Datafiler\wave1_ERLEND_HOVEDOPPGAVE.sav'.
DATASET NAME DataSet1 WINDOW=FRONT.
* SAMPLE CHARACTERISTICS
FREQUENCIES VARIABLES=alder kjønn utdann bdi iq_total
  /STATISTICS=STDDEV MINIMUM MAXIMUM MEAN MEDIAN MODE
  /FORMAT=LIMIT(2)
  /ORDER=ANALYSIS.
* INVERTING CWIT (AND CDT FOR LATER)
COMPUTE CWIT_1_rev=cwi_1_color_r * (-1).
EXECUTE.
COMPUTE CWIT_2_rev=cwi_2_word_r * (-1).
EXECUTE.
COMPUTE CWIT_3_rev=cwi_3_inhib_r * (-1).
EXECUTE.
COMPUTE CWIT_4_rev=cwi_4_switch_r * (-1).
EXECUTE.
COMPUTE CDT_RT_rev=CDT_RT * (-1).
EXECUTE.
* DESCRIPTIVES
DESCRIPTIVES VARIABLES=wasi_ord wasi_m CDT_RT cwi_1_color_r cwi_2_word_r
    cwi_3_inhib_r cwi_4_switch_r cvlt_tri_tot_r cvlt_sd_fr_r cvlt_ld_fr_r
  /SAVE
  /STATISTICS=MEAN STDDEV MIN MAX.
* ZWASI_ORD IS GC
RENAME VARIABLES (Zwasi_ord = Gc).
* MATRIX REASONING IS FEATURE 1
RENAME VARIABLES (Zwasi_m = Matrices_feature1).
* INVERTED CDT IS FEATURE 2
COMPUTE CDT_RT_feature2=ZCDT_RT * (-1).
EXECUTE.
* FACTOR ANALYSIS CVLT AND CWIT (1ST ORDER PCA)
FACTOR
  /VARIABLES cvlt_tri_tot_r cvlt_sd_fr_r cvlt_ld_fr_r
  /MISSING LISTWISE
  /ANALYSIS cvlt_tri_tot_r cvlt_sd_fr_r cvlt_ld_fr_r
  /PRINT INITIAL KMO EXTRACTION
  /CRITERIA MINEIGEN(1) ITERATE(25)
  /EXTRACTION PC
  /ROTATION NOROTATE
  /SAVE BART(ALL)
  /METHOD=CORRELATION.
FACTOR
  /VARIABLES CWIT_1_rev CWIT_2_rev CWIT_3_rev CWIT_4_rev
  /MISSING LISTWISE
  /ANALYSIS CWIT_1_rev CWIT_2_rev CWIT_3_rev CWIT_4_rev
  /PRINT INITIAL KMO EXTRACTION
  /CRITERIA MINEIGEN(1) ITERATE(25)
  /EXTRACTION PC
  /ROTATION NOROTATE
  /SAVE BART(ALL)
  /METHOD=CORRELATION.
* CVLT AND CWIT ARE FEATURES 3 AND 4
RENAME VARIABLES (FAC1_1 = CVLT_feature3).
RENAME VARIABLES (FAC1_2 = CWIT_feature4).
* FACTOR ANALYSIS Gf (2ND ORDER PCA)
FACTOR
  /VARIABLES Matrices_feature1 CDT_RT_feature2 CVLT_feature3 CWIT_feature4
  /MISSING LISTWISE
  /ANALYSIS Matrices_feature1 CDT_RT_feature2 CVLT_feature3 CWIT_feature4
  /PRINT INITIAL KMO EXTRACTION
  /CRITERIA MINEIGEN(1) ITERATE(25)
  /EXTRACTION PC
  /ROTATION NOROTATE
  /SAVE BART(ALL)
  /METHOD=CORRELATION.
RENAME VARIABLES (FAC1_1 = Gf).
* CORRELATION TABLE OVERALL
CORRELATIONS
  /VARIABLES=alder kjønn bdi Matrices_feature1 CDT_RT_feature2 CVLT_feature3 CWIT_feature4 Gc Gf CDT_RT_rev
    cvlt_tri_tot_r cvlt_sd_fr_r cvlt_ld_fr_r CWIT_1_rev CWIT_2_rev CWIT_3_rev CWIT_4_rev
  /PRINT=TWOTAIL NOSIG
  /MISSING=PAIRWISE.
```

```
* CORRELATION TABLE FOR THE SEXES SEPARATELY
SORT CASES  BY kjønn.
SPLIT FILE SEPARATE BY kjønn.
CORRELATIONS
  /VARIABLES=alder bdi Matrices_feature1 CDT_RT_feature2 CVLT_feature3 CWIT_feature4 Gc Gf
  /PRINT=TWOTAIL NOSIG
  /MISSING=PAIRWISE.
SPLIT FILE OFF.
* T-TEST
T-TEST GROUPS=kjønn(2 1)
  /MISSING=ANALYSIS
  /VARIABLES=alder utdann bdi iq_total Matrices_feature1 CDT_RT_feature2 CVLT_feature3 CWIT_feature4 Gc Gf
    cvlt_tri_tot_r cvlt_sd_fr_r cvlt_ld_fr_r CWIT_1_rev CWIT_2_rev CWIT_3_rev CWIT_4_rev CDT_RT_rev
  /CRITERIA=CI(.95).
* ANOVA
UNIANOVA Gf BY alder kjønn
  /METHOD=SSTYPE(3)
  /INTERCEPT=INCLUDE
  /PRINT=OPOWER ETASQ HOMOGENEITY DESCRIPTIVE
  /CRITERIA=ALPHA(.05)
  /DESIGN=alder kjønn alder*kjønn.
UNIANOVA bdi BY alder kjønn
  /METHOD=SSTYPE(3)
  /INTERCEPT=INCLUDE
  /PRINT=OPOWER ETASQ HOMOGENEITY DESCRIPTIVE
  /CRITERIA=ALPHA(.05)
  /DESIGN=alder kjønn alder*kjønn.
* HIERARCHICAL REGRESSION ANALYSIS
REGRESSION
  /MISSING LISTWISE
  /STATISTICS COEFF OUTS R ANOVA CHANGE
  /CRITERIA=PIN(.05) POUT(.10)
  /NOORIGIN
  /DEPENDENT Gf
  /METHOD=ENTER alder kjønn
  /METHOD=ENTER bdi.
SPLIT FILE LAYERED BY kjønn.
REGRESSION
  /MISSING LISTWISE
  /STATISTICS COEFF OUTS R ANOVA CHANGE
  /CRITERIA=PIN(.05) POUT(.10)
  /NOORIGIN
  /DEPENDENT Gf
  /METHOD=ENTER alder
  /METHOD=ENTER bdi.
SPLIT FILE OFF.
* FURTHER ANALYSES
REGRESSION
  /MISSING LISTWISE
  /STATISTICS COEFF OUTS R ANOVA CHANGE
  /CRITERIA=PIN(.05) POUT(.10)
  /NOORIGIN
  /DEPENDENT Matrices_feature1
  /METHOD=ENTER alder kjønn
  /METHOD=ENTER bdi.
REGRESSION
  /MISSING LISTWISE
  /STATISTICS COEFF OUTS R ANOVA CHANGE
  /CRITERIA=PIN(.05) POUT(.10)
  /NOORIGIN
  /DEPENDENT CDT_RT_feature2
  /METHOD=ENTER alder kjønn
  /METHOD=ENTER bdi.
REGRESSION
  /MISSING LISTWISE
  /STATISTICS COEFF OUTS R ANOVA CHANGE
  /CRITERIA=PIN(.05) POUT(.10)
  /NOORIGIN
  /DEPENDENT CVLT_feature3
  /METHOD=ENTER alder kjønn
  /METHOD=ENTER bdi.
REGRESSION
  /MISSING LISTWISE
  /STATISTICS COEFF OUTS R ANOVA CHANGE
  /CRITERIA=PIN(.05) POUT(.10)
```

```
  /NOORIGIN
  /DEPENDENT CWIT_feature4
  /METHOD=ENTER alder kjønn
  /METHOD=ENTER bdi.
* SCATTERPLOTS
GRAPH
  /SCATTERPLOT(BIVAR)=alder WITH Gf BY kjønn
  /MISSING=LISTWISE.
GRAPH
  /SCATTERPLOT(BIVAR)=alder WITH Gc BY kjønn
  /MISSING=LISTWISE.
GRAPH
  /SCATTERPLOT(BIVAR)=bdi WITH Gf BY kjønn
  /MISSING=LISTWISE.
GRAPH
  /SCATTERPLOT(BIVAR)=bdi WITH Gc BY kjønn
  /MISSING=LISTWISE.
* FIN.
```