Neuropsychological and Morphometric Correlates of Decision Making with the Coin Flip Task

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NEUROPSYCHOLOGICAL AND MORPHOMETRIC CORRELATES OF DECISION MAKING WITH THE COIN FLIP TASK

by

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A thesis submitted in partial fulfillment of the requirements for graduation with Honors in the Biomedical Engineering

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Thesis Mentor

Spring 2018

All requirements for graduation with Honors in the Biomedical Engineering have been completed.

David Wilder
Biomedical Engineering Honors Advisor

This honors thesis is available at Iowa Research Online: https://ir.uiowa.edu/honors_theses/
Neuropsychological and Morphometric Correlates of Decision Making with the Coin Flip Task

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A thesis submitted in the fulfillment of the requirements for the distinction of honors in the major in the
Denburg Lab
Department of Neurology

May 7, 2018
Abstract

The purpose of this study was to determine how older adults perform on a decision-making task (referred to as the Coin Flip Task), and how this performance correlates with demographic, neuropsychological, and brain morphometry variables. The study of decision making ability among older adults is important for several reasons. First, older adults frequently make “weighty” decisions as they age, such as important financial and medical decisions. When less than optimal decisions are made, it is difficult for the older adult to recover from or fix that decision given their relatively limited longevity. Second, decision making ability emanates from a brain area (the prefrontal cortex) that is known to undergo the greatest age-related decline in normal aging, making sound decision making that much more crucial. From a biomedical perspective, understanding the mechanisms of how people age can help medical personnel to better tailor medicine and engineer devices that can assist the elderly in their lives and assure that they are well cared for. In the current study, 55 community dwelling, healthy older adult participants visited our laboratory for a series of visits that assessed their cognitive health, measured their decision-making abilities, and measured their brain’s structure and functioning. First, participants’ Coin Flip performance was analyzed. We did this a number of ways. One approach was to subdivide our sample into three clusters that varied based on their Coin Flip behavior (i.e., H-T-NG = poor decision makers; H-T= mildly advantageous decision makers; H/T= advantageous decision-makers). Next, we looked at associations between participants’ coin flip performance and their demographic and neuropsychological data. Several relationships between Coin Flip performance and the neuropsychological variables were identified, including findings involving both cognition
and psychological/personality variables. On the cognitive side, more advantageous Coin Flip performances was positively associated with psychomotor speed, executive functioning, and interoceptive sensitivity, to name just a few. On the psychological/personality side, more advantageous Coin Flip performances was negatively associated with self-reported anxiety. Finally, we correlated Coin Flip performance with cortical thickness. That analysis revealed several significant findings. One particularly robust finding indicated that older adults with more advantageous Coin Flip Task performance displayed greater cortical thickness an area of the prefrontal cortex, called the superior frontal region. The results are discussed in the context of the literature on the cognitive neuroscience of aging. Study limitations and future directions are also addressed.
Correlates of Decision Making with the Coin Flip Task

Studying decision-making in today’s world serves many advantages. Understanding the affects ageing has on decision-making can help family and medical professionals better treat and care for the again population. In this study, we utilized a decision-making task called Coin Flip in older adults to measure their ability to make good or poor decisions. These same older adults also completed a neuropsychological examination as well as an sMRI scan to measure the thickness of the grey matter surrounding their pre-frontal cortex. The purpose behind this was to understand how age-related defects in the pre-frontal cortex affect decision making in the older adult population. This study also observes how different emotional and behavioral variables in this population affected their performance on the decision-making task.

**Studying Decision Making (DM) in the Laboratory**

When one makes decisions, there are two types of conditions that their decisions may fall under: risk or ambiguity. The difference in the two lies in a person’s ability to know the probability of their choice, as well as the reward value associated with one’s decision. In decisions involving risk, a person is aware of their probability of choosing the correct answer, whereas in decisions involving ambiguity, a person does not know the probability or believes that the probability is close to chance. Also, in decisions involving risk there is a known value associated with each decision, whereas in decisions involving ambiguity there is no difference in the reward value of each decision (Krain et al, 2006). This study focused on the use of the Coin Flip task, a measure that asks participants to make decisions under risk. There is a known probability for each decision made, and there is an assigned reward value for each decision made. Decisions made under risk
utilize an area of the brain called the prefrontal cortex, and more specifically, the orbitofrontal and medial frontal cortices (Krain et al, 2006).

**How the Brain Changes with Age**

As people age, there are distinct changes that occur in the anatomy (both gross and microscopically) of the brain that researchers can observe in order to understand its effect on human behavior and cognition. The Frontal Lobe Hypothesis of Aging suggests that the prefrontal cortex (PFC) is at a higher risk of deterioration, than other brain areas, in regard to normal aging and can lead to impaired functioning in older adults (West, 1999). Let it be noted that the PFC (located in the frontal lobe posterior to the motor strip) is where a large portion of a human’s decision-making, planning, and personality lie. The hypothesis supports that a decline in cognition associated with the PFC can be observed earlier and in greater magnitude than cognition associated with non-frontal regions (West, 1999). A concept that has been argued in opposition to the the Frontal Lobe Hypothesis of Aging is that when an area within the frontal region decreases its function, another area in the frontal region increases its function (Cabeza et al. 1997, Grady 1998). Therefore, we can assume that age related declines and changes in the human brain are not universal, nor uniform across regions. It is for this reason that when we observe the PFC in regard to this study, it will be within specific regions of interest.

**How Emotion Impacts Decision Making**

The Somatic Marker Hypothesis states that decision making is a complex process that is assisted by emotional processes and somatic markers, which can occur through both the body, peripheral nervous system, and brain regions such as the VMPC and amygdala to name a few (Denburg et al., 2007). This hypothesis is supported through
Correlates of Decision Making with the Coin Flip Task

studies such as Bechara’s use of the Iowa Gambling Task (IGT). The Iowa Gambling Task is a measure that utilizes four decks of cards and gives the participant rewards and punishments based on decisions they make throughout the task. The goal of the Iowa Gambling Task is for the user to win as much money as they can. The participant must go through a series of 100 selections from one of the four decks labeled A, B, C, and D and is not notified on how many selections they must make before the task is over. Each deck is stacked with cards that either wins the user money or takes the user’s money away. Stacks A and B are stacked with cards that win the user a high amount of money quickly, but also take away a great deal of money quickly. Stacks C and D contain cards that steadily win the user money, even as it takes small gains away. Historically, normal users follow a trend in which they begin the task picking from the A and B decks, but as the task progresses users begin to pick primarily from the C and D decks (Bechara et al., 2000). In one of his studies, Bechara wanted to see the effects that patients with a ventromedial prefrontal cortex lesion had on. The VMPC patients, when given the chance to perform the IGT, performed in a manner that suggested they were not learning appropriately as they selected cards; in other words, their decisions were not becoming more advantageous as the task progressed. The VMPC patients rather than selecting from the advantageous decks (C and D) towards the end of the task, continued to select from the disadvantageous decks (A and B). This showed that patients impaired in an emotional region within the PFC, were making poorer decisions as compared to their healthy counterparts (Bechara et al., 2000).

Ways to Determine Neurological Health
In order to determine the neurological health of a person, a series of tests can be administered, and the resulting scores can be compared to normative data for a given age group. For this experiment, the following neuropsychological battery was administered: MMSE (Minnie-Mental State Examination), a general Health Interview, Rey Auditory-Verbal Learning Test, Rey Complex Figure Test, Wechsler Adult Intelligence Scale Digit Span and Coding, Judgement of Line Orientation test, Wechsler Abbreviated Scale of Intelligence, Beck Depression Index, and the Positive and Negative Affect Schedule).

Before participants within our experiment were brought in to test, the following was asked of them to screen for any potential cognitive dysfunction that could exclude them from the study:

“I will read you a list of health conditions, some of which are physical, and others are emotional conditions. To protect your privacy, please indicate at the end of the list with a yes or no that you have had any of the conditions without indicating specific ones. Please let me know if you have any questions about these conditions. Type I Diabetes; heavy drug or alcohol use; history of stroke; history of brain tumor; severe depression or anxiety necessitating inpatient psychiatric treatment; or a traumatic brain injury that resulted in a loss of consciousness that exceeded 10 minutes?”

Once the participants were brought in for the initial neuropsychological screening, they were administered a health screening by a health professional to assure that there were no major health concerns that could exclude them from the study.

**Fraud Susceptibility**

It is important to note that older adults are put under stressors that many younger persons are not. Some of those stressors include, but are not limited to, death of spouses and
friends, medical complications, financial complications, etc. With these stressors come difficult decisions that can be severely detrimental if they are not made accurately. If an older adult makes a poor financial decision, such as one seen in older persons affected by fraud, it can be crippling to their standard of living. Knowing that the older adult does not have as much time as a younger adult to make up for these decisions it can go on to affect their loved ones as well. It is because of this that it is important for us to understand how older adults make decisions, and the mechanisms that put them at risk for disadvantageous and advantageous decisions (Denburg, 2015).

Methods of Neuroscience

For this experiment, we used E-Prime software to track the participants’ behavior throughout the Coin Flip task. The different behaviors included those who chose to gamble, those who sometimes gambled, and those who never gambled during the experiment. We know from past decision-making tasks such as the IGT, that the behaviors of the participants are related to how the participants reacted to their results. Psychophysiological responses such as the galvanic skin response (GSR), also known as electro dermal activity (EDA), and heart rate can be used to measure a person’s reactions towards making decisions. GSR is a result of the autonomic sympathetic nervous system being rooted in a person’s emotional state (Critchley, 2002). Sympathetic nerves innervate a human’s sweat glands, and when a person is more emotionally aroused the sweat glands are activated and the skin in turn becomes more conductive (Critchley, 2002). In order to measure the skin’s GSR, we utilized a Biopac machine in parallel with the E-Prime software and a higher GSR was marked by a higher voltage amplitude. This system allowed for a participant’s emotional reactions to be measured in accordance with
their decision-making. This data was not included in the discussion of this paper; however, after further analysis it will be used in the future.

**Neuroanatomical (sMRI)**

In this study, a T1 MRI machine was used to collect in vivo data on older adults. Structural images were collected in order to measure the cortical region of their brains. Because loss of cortical thickness, and therefore synapses, has been correlated to older persons decreased cognitive abilities, the PFC cortical thickness was examined in each adult (DeKosky, 1990). One hypothesis states that there is asymmetry in the brain of the aging population and is known as the Hemispheric Asymmetry Reduction in Old Adults, or HAROLD (Cabeza et al, 2002). This occurs through the natural atrophy that occurs in the aging brain and could explain why there are differences in how older and younger adults process information and make decisions. In this study, all around trends in how the aging brain atrophies were observed.

**Interface between Engineering and Neuroscience**

Engineering is a discipline that challenges its personnel to solve issues that plague the human race through their innovation and novelty. Neuroscience aims to understand how the human brain functions, both healthily and diseased, and aims to solve problems associated with the human brain. Together, engineering and neuroscience can create techniques, medicines, devices, etc. that can improve humanity and assure the longevity of the human mind.

By exploring anterior brain regions and their cortical thicknesses in relation to the Coin Flip task, we plan to see positive correlations between the participants’ performance and retention of cortical thickness.
Methods

Participants

In this study, 55 healthy older adults (aged 65-90 years; mean age = 74.6 years; 49% female) participated, and all were considered to be cognitively healthy per performance on a neuropsychological battery (see Table 1 for more details). Participants were additionally screened for any outstanding medical and psychiatric conditions that would indicate that they were not aging normally. All participants were consented throughout the study with approval from the IRB.

Procedure

The study was broken into multiple visits in which different tasks were administered to the participants. On Visit 1, participants received a neuropsychological examination of three-hours duration. On Visit 2, they completed the Coin Flip Task and several paper and pencil questionnaires. Finally, on Visit 3, participants completed a 1-hour magnetic resonance imaging (MRI) scan of the brain, which included structural measurement of the brain (hereafter referred to as sMRI).

Neuropsychological Examination (Visit 1)

For the first visit, following completion of the IRB consent form, participants completed a three-hour neuropsychological battery. For additional description about the instruments described below, the reader is referred to Lezak, Howieson, Bigler, and Tranel (2012). Each task is described below and the cognitive domain that it measures is noted in capitals.

First, participants received a health interview administered by a health care professional to ensure all individuals met the inclusion/exclusion criteria. Some criteria
that excluded participants included outstanding medical (e.g., major stroke) or psychiatric (e.g., schizophrenia) conditions. Participants were included if they were living independently in the community, had the ability to independently give consent, had normal hearing and vision, had cognitive performances that were within the normal range for their age and level of education, and had no issues (e.g., metal in body, pacemaker insertion) that would exclude them from the MRI task.

The first cognitive task administered was the Mini-Mental State Examination (MENTAL STATUS), which provided a brief examination of overall mental ability. The Rey Auditory-Verbal Learning Test (AVLT) (ANTEROGRADE VERBAL MEMORY) was then administered. The AVLT consists of fifteen words read to the participant before the participant must repeat them back, from memory. The list is read a total of five times and after each reading, the participant is asked to recall as many of the words as they can. After thirty minutes, without the participant knowing, the administrator asks the participant to again recall as many of the words on the original list as possible. The task ends with the administrator reading a long list of 30 words and the participant must identify which words were on the original list and which words were not.

The Rey Complex Figure Test (CFT) was then administered.

Figure 1. Image of the Rey Complex Figure used in testing.
The CFT consists of a complex figure that the participant must draw with the stimulus exposed (VISUOSPATIAL) within ten minutes. After thirty minutes (ANTEROGRADE VISUAL MEMORY), and without the stimulus in sight, the participant is then asked to recreate the figure to the best of their ability, taking note that any portion of the figure completed will earn them partial or full credit towards their total score. Please see Figure 1 for the CFT stimuli.

The Wechsler Adult Intelligence Scale (WAIS) is an intelligence test made up of more than 10 subtests. For our study, we utilized the Digit Span (ATTENTION/CONCENTRATION) and Coding (PSYCHOMOTOR SPEED) subtests. In WAIS Digit Span, the administrator reads a string of numbers, before asking the participant to repeat the numbers back to them. As the participant gets spans correct, the strings of numbers get longer. When a participant gets a series of two spans incorrect, the task is over. During the first portion of this subtest, the participant must repeat the numbers in the exact order they have heard them (known as the forward order). This is followed by backwards Digit Span, in which the participant must repeat the string in backwards order (e.g., if examiner says 2-8-7, participant must say 7-8-2). In WAIS Coding, the participant is asked to match a series of numbers with their corresponding symbol. The participant is asked to write the matching symbol to as many of the numbers as possible in the given time span.

The Judgment of Line Orientation test (VISUOSPATIAL) asks participants to correctly determine the orientation of two lines that are offset in two-dimensional space given a comparative chart to base their decisions.
The Wechsler Abbreviated Scale of Intelligence-II (INTELLECT) consists of four subtests: Vocabulary, Similarities, Block Design, and Matrix Reasoning. Collectively, the four subtests combine to give a participant’s IQ score, while adding together just two provides a Verbal IQ (Vocabulary plus Similarities) and a Performance IQ (Block Design plus Matrix Reasoning). The Vocabulary subtest requires the participant to define words that are read aloud to them, and the more accurate the definition given the more points the participant is awarded. The Similarities subtest asks participants to find the commonalities between two given nouns, and their score can change depending on their ability to connect the two subjects given. The Block Design subtest requires participants to create a given pattern with cubes containing three patterns (two solid red sides, two solid white sides, and two half red/white sides). As the participant completes patterns in the time allotted, the more difficult the patterns become. The patterns start by requiring two blocks, then four, before ending in nine blocks. The final subtest, Matrix Reasoning, asks participants to determine the most logical choice that completes a given series or matrix. The matrix or series presented is incomplete and the participant must choose from a list which choice best finishes the matrix or series. As the participant moves through the matrices, they become more difficult.

The Boston Naming Test (LANGUAGE) involves a series of simple drawings that participants must be able to name. Participants are allowed two chances to name the image presented to them but receive no credit if the sound prompt is needed and provided.

The Beck Depression Inventory (MOOD) is a 21-item multiple choice self-report measure given to participants to measure mood experienced during the previous two
weeks. If participants indicated they were at risk for hurting themselves, administrators were instructed to report the suicidal ideation to the principal investigator.

Finally, the Positive and Negative Affect Schedule (PERSONALITY) is a 20-question self-report index that uses a one to five Likert scale (one being not at all and five being extremely) to describe how they are feeling at the present moment. The PANAS measures a person’s positive and negative affect in relation to their personality.

**Coin Flip Task (Visit 2)**

On a separate day, participants that were not excluded in the initial neuropsychological examination, were invited to return to complete the Coin Flip (CF) task visit. Before the participants were asked to start the CF task, the administrator recorded the date, time, temperature, and humidity of the room. Participants were then sat in front of a computer monitor and the administrator attached sensors to their person.

The two forms of sensors used were galvanic skin response (GSR) and heart rate sensors. A GSR sensor was attached to both the index and middle fingers of the participant, while the three heart rate sensors were attached to the inside of the wrist and one on the inside of each ankle. The sensors were connected to a Biopac machine that allowed the researcher to see in real time the reactions the participant was having as they performed the CF. The participant was then instructed as to what the task was going to consist of and given two practice trials of the CF before the series of 20 trials began.

The Coin Flip task is comprised of a series of 20 coin flips in which the user must decide between three options: heads, tails, or do not gamble. The participant was explained before the task began that they were completing a decision-making test in which they would have a 50/50 chance of winning or losing. They were then informed
that they at the end of the task that one of their decisions would be played out for real and
that they would be able to win an additional $5, $6, or $7.50 (lose, no gamble, and win
respectively). The participant then began the task. They were first presented with two
practice trials. A screen would ask the participant to put in their choice by using the
computer keyboard and pressing the H key for heads, the T key for tails (Figure 2), or the
space bar for the choice of not wanting to gamble. Once they had indicated their choice,
the program would automatically begin to show a computer-generated coin flip that
would end up showing either the tails or heads side when finished flipping.

Figure 2. Coin image that rotated as participant anticipated decision result

The screen would then present the participant with their results for that trial. If the
participant had chosen the correct side (i.e., the coin came up heads and the participant
had chosen heads) they were presented with a screen that indicated their win and they
would be awarded $7.50 for that trial. If the participant had incorrectly chosen the side of
the coin (i.e., the coin came up heads and the participant had initially chosen tails) then
they were presented with a screen that indicated a loss and they would only be awarded
$5.00 for that trial. If the participant had chosen not to gamble for the trail, the screen
would show a screen indicating that they had chosen not to gamble and that they would
be awarded $6.00 for that trial. Once the first two practice trials were done the researcher
would ask the participant if they had any other questions before beginning the task. The
participant would then start the first ten trials, or coin flips. After ten trials, the participants were given the option to take a break for as long as they needed before they started the next ten trials. When the participant had completed the task they were detached from the BIOPAC machine and given a 20-sided die to roll. The number that the participant rolled corresponded to the trial number that would be ‘played out for real’ and would determine what the participant’s pay out for the CF would be. If the die gave a winning trail the participant was awarded an additional $7.50 for the day. If the number corresponded to a losing trial, the participant was awarded an additional $5.00. Finally, if the number on the die corresponded to a trial in which the participant chose not to gamble then they were awarded $6.00.

Data from the CF task were initially analyzed as patterns or approaches to the task, that we termed clusters. To illustrate the cluster manner of analyzing the data, please see Figure 3. The three clusters were defined as (1) those who selected heads, tails, and no gamble interchangeably throughout the task (H-T-NG); (2) those who chose to gamble between heads and tails throughout the task (H-T); and (3) those who chose to gamble on either heads or tails throughout the task (Always H/T). The three clusters can be further explained as H-T-NG being the least advantageous group, as they not only switched throughout the task, but also chose not to gamble at certain points. H-T as the moderately advantageous group, because they chose to always gamble, but also chose to switch between heads and tails. Finally, the most advantageous group was Always H/T, as they chose to gamble and did not choose to switch.

Directly following the CF, the participant was asked to answer a short two-question math battery that had them determine probabilities of flipping a coin. Then the
participant was asked to answer an 11-question numeracy questionnaire by Lipkus, to assess their ability to understand and use numeric information (Lipkus et al., 2001).

The participants were then asked to fill out a series of behavioral and achievement measures: State-Trait Anxiety Inventory (STAI), NEO Personality Inventory Revised (NEO-PI-R), and the Wide Range Achievement Test 4 (WRAT-4). The State Trait Anxiety Inventory is a 40-question self-report measure that allows the participant to rank their agreement, or disagreement with a given prompt. The first page measures the participant’s level of anxiety in regard to their current state, while the back page measures the participant’s anxiety as a general trait of their person. The first 20 questions of the measure ask the participant to rank their agreement on the given prompt (from not at all, to very much so) based on how they are currently feeling. The second 20 questions ask the participant to rank their agreement or disagreement with a prompt (from almost never, to almost always) for how they generally feel on a month-to-month basis. The next battery given was the NEO Personality Inventory Revised in which participants are asked to self-report how much they agree or disagree with a given prompt (with one being strongly disagree and five being strongly agree). There are 240 prompts that the participant must answer. Finally, the WRAT-4 reading battery was administered to the participant. The WRAT-4 consists of a series of words the participant must simply read aloud to the administrator. Performance on the WRAT-4 is a proxy for verbal intellect.

**MRI 3T Scanner (Visit 3)**

On the third visit, 40 of the original 55 participants participated in a brain MRI scan in a T1 scanner with a 12-channel head array. Some of the original 55 participants declined to participate in the sMRI portion of our study or met exclusionary criteria for
Correlates of Decision Making with the Coin Flip Task

MR imaging (e.g., pacemaker). Participants were laid supine with a head coil to minimize head movement. A T1-weighted 3D MPRAGE sequence with 256 x 256 x 256mm volume (voxel size = 1 mm³, T1= 909 ms, TR= 2,530 ms, TE= 2.8 ms, Flip angle= 10 degrees, slice thickness= 1mm, scan time= 5 min and 36 s) was used to collect images on the coronal plane of each participant. Using a T1 weighted echo-planar sequence, the blood oxygen level dependent signal (BOLD) was measured. The scan parameters used were as follows: TR= 2,000, TE= 30, flip angle= 90 degrees, FOV= 220mm x 220mm, in plane resolution= 64 x 64 pixels, slice thickness= 4mm). Using an oblique transverse orientation with 20 degrees to the anterior commissure/posterior commissure line, thirty-one slices were taken. The total scan time was 12 minutes and 14 seconds and 367 volumes were collected, with the first two volumes discarded to eliminate saturation effects (adapted from Halfmann et al., 2014).

In order to analyze the sMRI data, a free online software program called FreeSurfer was utilized. Amongst its vast and robust abilities, the FreeSurfer software is able to map the thickness of cortical grey matter (Fischl, 2012). The average anatomist using similar non-programmed methods can take days to analyze the cortical thickness of just one patient, while the FreeSurfer software takes only a few hours (Fischl & Dale, 2000). FreeSurfer utilizes a series of algorithms that smooth the brain surface, distinguish the gyri and sulci from one another by assuming voxel size produced by the MRI is smaller than the curvature of surface and thickness of tissue, triangulation for vertices from white to grey matter, before calculating the thickness of the grey matter as an average of the distances computed from each surface in a region to another (Fischl & Dale, 2000). Vertex-wise analysis was then used using FreeSurfer’s QDEC program that
allowed for a correlation between the continuous variables of Coin Flip and the brain cortical thickness with the general linear model.

**Results**

**Neuropsychological Battery**

The neuropsychological characteristics of the sample, as shown in Table 1, indicated that the participants in our study were very high functioning (see Table 1). For example, this sample of older adults were highly educated at over 16 years on average. Another example would be their group IQ, which was on average over 120 which corresponds with high average intellect. Performances in the cognitive domains of visuospatial, language, memory, attention/concentration, psychomotor speed, and executive function were consistent with this above average level of intellect. Finally, on average, self-reported mood, as measured by a depression instrument, was minimal, with the group average falling in the normal range.

**Table 1.** *Demographic and Neuropsychological Characteristics of the Sample.*  

<table>
<thead>
<tr>
<th>Category</th>
<th>Measure</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Demographics</strong></td>
<td>N</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>74.58 (5.8)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sex</td>
<td>49% Female</td>
<td></td>
</tr>
<tr>
<td><strong>Mental Status/Intellect</strong></td>
<td>MMSE</td>
<td>29.25 (1.02)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Full Scale IQ</td>
<td>120.3 (9.9)</td>
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</tr>
<tr>
<td></td>
<td>WRAT Reading</td>
<td>112.53 (14.9)</td>
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</tr>
<tr>
<td><strong>Visuospatial</strong></td>
<td>Judgment of Line</td>
<td>25.16 (3.6)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rey-O Copy</td>
<td>29.05 (4.3)</td>
<td></td>
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<tr>
<td><strong>Language</strong></td>
<td>BNT</td>
<td>57.40 (3.4)</td>
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Correlates of Decision Making with the Coin Flip Task

<table>
<thead>
<tr>
<th>Category</th>
<th>Test</th>
<th>Mean</th>
<th>SD</th>
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</thead>
<tbody>
<tr>
<td>Memory</td>
<td>AVLT Delay</td>
<td>10.1</td>
<td>2.9</td>
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<td></td>
<td>Rey-O Delay</td>
<td>15.76</td>
<td>5.4</td>
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<tr>
<td>Attention/Concentration</td>
<td>Digit Span-F</td>
<td>10.16</td>
<td>3.1</td>
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<td></td>
<td>Digit Span-B</td>
<td>11.86</td>
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<td>Psychomotor Speed</td>
<td>TM A (Time)</td>
<td>40.42</td>
<td>16.7</td>
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<tr>
<td>Executive Function</td>
<td>TM B (Time)</td>
<td>91.38</td>
<td>30.1</td>
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<td>Mood</td>
<td>BDI</td>
<td>4.85</td>
<td>4.7</td>
</tr>
<tr>
<td>Personality</td>
<td>PANAS Positive Affect</td>
<td>33.25</td>
<td>7.5</td>
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<tr>
<td></td>
<td>PANAS Negative Affect</td>
<td>11.38</td>
<td>2.2</td>
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<tr>
<td></td>
<td>NEO-Conscientiousness</td>
<td>137.47</td>
<td>18.0</td>
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<td>NEO-Neuroticism</td>
<td>78.45</td>
<td>20.3</td>
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<td>NEO-Extraversion</td>
<td>115.69</td>
<td>19.2</td>
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<td>NEO-Agreeableness</td>
<td>134.31</td>
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<tr>
<td></td>
<td>NEO-Openness</td>
<td>111.58</td>
<td>16.3</td>
</tr>
</tbody>
</table>

MMSE = Mini-Mental State Examination; BNT = Boston Naming Test; AVLT = Rey Auditory-Verbal Learning Test; BVRT = Benton Visual Retention Test; TM = Trail Making Test; BDI = Beck Depression Inventory; PANAS = Positive and Negative Affect Schedule.

**Coin Flip Task**

For the Coin Flip Task, there were three main approaches that participants took while completing the task. These approaches were then put together into three clusters. Approaching the coin flip, there are two types of approaches that are considered advantageous: to gamble and to not switch between your choices of heads, tails, and no gamble. The first group (H-T-NG) performed the most disadvantageously and chose to
not gamble at times as well as switched between all three options. The middle advantageous group (H-T) chose to always gamble, but also chose to switch between heads and tails. The advantageous group (H/T) chose to always gamble and did not switch between heads and tails. The H-T group had the most participants in it with 51% (n = 28) of the participants, with the H-T-NG group coming in second largest with an 33% (n = 18 ) of the participants, and finally, the Always H/T had an 16% (n = 9) of the participants (Figure 3).

![Graphs showing behavioral clusters](image)

**Green -- Head**  
**Orange -- Tail**  
**Purple -- Not Gamble**

Figure 3. This outlines the different behavioral clusters found in the participant data set: those that chose not to always gamble and switched (H-T-NG; n = 18), those that always gambled and switched (H-T; n = 28), and those that always gambled and did not switch (Always H/T; n = 9).
Correlates of Decision Making with the Coin Flip Task

**Coin Flip – Cognitive Measures**

The results from the Coin Flip task showed that participants in the H/T cluster, the group who performed most advantageously on the coin flip task, performed significantly better than the H-T-NG cluster in the Tower Test. Knowing that the Tower Test aims to measure a person’s spatial planning, rule learning, and establishment of instructional set, we can establish that the H/T cluster retain their cognitive abilities in the areas of executive functioning better than those in the H-T-NG cluster. It was also observed that the Always H/T group performed significantly better on the AVLT 30 min recall as compared to the H-T cluster. This shows that the cluster who performed the best on the coin flip battery, has the best anterograde verbal memory.

**Coin Flip – Emotional Measures**

An interesting find showed that the H/T cluster scored higher on the STAI-T than either the H-T-NG or the H-T clusters. This indicates that the H/T group was more anxious as a general personality trait than either of the other clusters. This indicates that participants who are generally more anxious on a day to day basis score better on the Coin Flip task.

**Coin Flip – Behavioral Measures**

On the NEO, the H/T cluster showed to have a higher sense of neuroticism than either of the other clusters. This indicates that participants who behaved most advantageously on the Coin Flip task had more neuroticism in their personality than their peers. However, the H-T-NG and H-T clusters scored higher than the H/T cluster on the NEO-Conscientiousness, indicating that the participants who exhibited these traits performed disadvantageously on the Coin Flip task.
Figure 4. Shows the cognitive tasks that had significant findings between the three clusters. On the Tower total score, the Always H/T cluster scored significantly better than the H-T-NG cluster. On the AVLT 30 min recall, the Always H/T cluster scored significantly better than the H-T group.

Figure 5. The emotional tasks showed significant finding in the STAI battery. For the STAI Trait task, the always H/T cluster scored significantly higher than both the H-T-NG and H-T clusters.
Correlates of Decision Making with the Coin Flip Task

Figure 6. For the NEO, there were three personality traits that were significant to the clusters: neuroticism and conscientiousness. It was found that the Always H/T cluster scored higher than both the H-T-NG and H-T clusters. The H-T-NG and the H-T clusters scored significantly higher than the Always H/T cluster for conscientiousness.

**Structural MRI**

Because of the varying sample sizes (ranging from 9 to 28) for the cluster approach to data analysis, an additional variable was calculated from the CF task to allow for comparison between CF performance and sMRI cortical thickness. This variable, termed *Gamble*, was a count of how many times a participant chose to gamble during their CF session. The higher the Gamble score, the better a participant was thought to have performed on the task, as choosing to gamble is considered an advantageous approach during the CF task.

The FreeSurfer QDEC program showed a strong positive correlation between the Coin Flip Gamble variable and several brain areas, with a tendency toward anterior brain regions. We illustrate below some of the most significant findings, indicating a positive association between Gamble and several left hemisphere brain regions on the lateral surface of the brain. Of note, when we utilized a correction to control for Type I error
inflation (i.e., false positive findings), such as the false discovery rate, the aforementioned findings were no longer significant.

Table 2. Lists the brain regions positively correlated with the Gamble variable associated with figure 7 and their corresponding cortical thickness measured in mm$^2$.

<table>
<thead>
<tr>
<th>Brain Region (PC)</th>
<th>No Max</th>
<th>Size(mm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inferiorparietal</td>
<td>3.2785</td>
<td>60.11</td>
</tr>
<tr>
<td>Middletemporal</td>
<td>2.8365</td>
<td>55.78</td>
</tr>
<tr>
<td>Superiorfrontal</td>
<td>2.5539</td>
<td>65.66</td>
</tr>
<tr>
<td>Supramarginal</td>
<td>2.532</td>
<td>24.33</td>
</tr>
</tbody>
</table>

Figure 7. This image shows the QDEC results with the variable Gamble. The image shows a positive correlation between Gamble and cortical thickness in several brain regions. Panel A shows the inferiorparietal, supramarginal, and middletemporal regions; Panel B shows the superiorfrontal region.

**Discussion**

Our study demonstrated that a new decision-making task, entitled Coin Flip, has significant relationships with cognitive variables and personality/emotional variables, and
to a lesser degree, with morphometric brain variables, in a sample of healthy older adults. For the cognitive variables, more advantageous decision-making performance on the CF task was associated with stronger cognitive performance for the domains of anterograde verbal memory and executive functioning. By contrast, for the personality/emotional variables, more advantageous decision-making performance on the CF task was associated with higher levels of trait neuroticism and trait anxiety, and lower levels of trait conscientiousness. Finally, the morphometric aspect of this study involving structural brain MRI showed that cortical thickness was positively associated with a more advantageous approach to the Coin Flip task. That is, as a group, older individuals who displayed more advantageous decision-making performance also had thicker cerebral cortices. However, these decision-making and brain morphometry associations did not survive a correction for multiple comparisons.

A dissociation between cognition and emotion (e.g., where one is positively associated while the other is negatively associated) in relation to performance on a decision-making task is not uncommon. For example, a study by Lauriola and Levin (2001) demonstrated that higher scores on Neuroticism were associated with an advantageous approach for decisions where loss was imminent. Also, there is a positive (albeit complicated) relationship between intellect and decision making (Austin et al., 1997).

Memory plays an important role in decision making. As a person works to make an advantageous decision, they utilize their mPFC to recall appropriate actions and emotional responses from past experiences, making the PFC adaptive in its quest for making the best decisions (Euston, 2012). Similarly, executive function is tied closely to
Correlates of Decision Making with the Coin Flip Task

decision making in that it controls how decisions are chosen and can be seen through the use of VM and DL lesion patient studies (MacPherson, 2002). Memory, executive function, and decision making are all found in the frontal lobe, and more specifically are in part medicated through the PFC. Knowing this, it is clear that they all tie together to help the brain make choices on a second to second basis.

The results of the QDEC analysis of the structural MRI scans with the Coin Flip Gamble variable showed a strong positive correlation in cortical thickness in multiple areas of the brain. One of the major areas of interest was the superior frontal region’s positive correlation with the Gamble variable. The superior frontal region hosts part of the PFC and is in charge of high level decision making (Heekeren, 2004). This supports our hypothesis that participants who performed better on the Coin Flip task would have greater cortical thickness in high level decision making brain regions. The other areas highlighted by the QDEC system as positive correlations with the Coin Flip Gamble variable were found on the lateral side of the brain closer to the parietal and temporal regions.

As humans age, there are morphologic characteristics that researchers can study to observe the atrophy and how it affects the functionality of the brain. Some of these characteristics include the cortical thickness of the brain as well as the volume of the brain, two characteristics that are positively correlated with one another (Lernaitre, 2012). It should also be noted that these characteristics atrophy with age causing changes in cognitive function, decision making, memory, etc.

In terms of future directions, if I were to study decision making ability in the future, I would choose a different decision-making task than Coin Flip. For example, the
well-known Iowa Gambling Task has a single, clearly advantageous behavioral approach to “winning.” And, furthermore, Iowa Gambling Task performance provides a single, dependent variable or score that is continuous in nature (i.e., individuals can receive a single score from a low of -100 to a high of +100). Also, in terms of future directions, we plan to analyze the SCR data at some point following graduation.

In closing, as neurologists and scientists work to understand the human brain, they are also working to improve human aging and all-around quality of life. Understanding how the brain works, and more specifically how the brain ages, allows engineers and scientists to better tailor devices, medicines, and solutions to people and their unique needs. There is a correlation with the aging brain and a decrease in cortical thickness and knowing this can help scientists to better understand how the aging brain makes decisions. In the future, more tests will need to be administered to fully understand how the aging brain changes structurally, and what that means for its cognitive, emotional, and behavioral abilities.
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Correlates of Decision Making with the Coin Flip Task


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Acknowledgements

I would like to thank Professor Natalie Denburg for her guidance and support throughout this project. Without her mentorship none of this would be possible. I would like to thank Professor William Hedgcock for his help and willingness to let our lab utilize his creation the Coin Flip Task. I would like to thank Yixiang Xu for his help in our understanding of the Coin Flip task and the participant behavior. Lastly, I would like to thank Sean Chen for this help with the structural brain imaging analyses.