THE IMPACT OF CRITERION SHIFTS ON EVIDENCE ACCUMULATION IN THE INFERIOR TEMPORAL CORTEX

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THE IMPACT OF CRITERION SHIFTS ON EVIDENCE ACCUMULATION IN THE INFERIOR TEMPORAL CORTEX

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SUMMARY

Decision-making is a cognitive process that occurs in stages and can be conceptualized by variations of sequential sampling models which suggest that, for the options in a binary forced-choice decision-making task, there are opposing thresholds that the amount of evidence accumulated must cross before a selection is made (Ratcliff, 1978; Ratcliff & McKoon, 2008). That process is often influenced by prior knowledge that has the potential to bias an individual towards or away from given options, thereby changing the amount of associated sensory evidence processed over time (Dunovan & Wheeler, 2018). Meaning, when a criterion shift (prior knowledge) biases an individual toward the correct choice (a valid trial), younger adults have a propensity to take less time to respond, be more accurate in their responses, and show decreased BOLD activity in the inferior temporal cortex (ITC). Alternatively, the option biased against (an invalid trial) will take more time, produce poorer accuracy scores, and is associated with increased BOLD activity in the ITC. However, little is known about how well such results carry across the lifespan because current literature focuses mostly on younger adults. Older adults have a propensity to take their time during decision-making tasks and perform well, and it is believed they do so by behaving inflexibly when presented with prior knowledge. Younger adults are more likely to incorporate informative cues, while older adults tend to disregard them in favor of taking their time (Starns & Ratcliff, 2010). This fMRI work aimed to examine these conclusions from a lifespan perspective using a Posner-like cued face/house discrimination task. Special attention was paid to controlling for age-related sensory confounds. Contrary to the hypothesis that only younger adults

would incorporate cues into their decision-making process, both age groups performed similarly and responded faster/more accurately for valid trials relative to invalid trials. However, the underlying trends in the ITC BOLD data were not consistent across age groups, suggesting that there are different neural mechanisms underlying the same behavioral outcomes as a function of age.

CHAPTER 1:
INTRODUCTION

Probabilistic prior knowledge is a critical and necessary component of the perceptual decision-making process. For example, understanding the approximate likelihood that an approaching shopping cart will be around the corner helps people navigate the grocery store safely. Knowing the odds that a potential travel companion will be reliable can help a person decide if they should accept a pricey cruise invitation. Accounting for the probability that social security funds will be disbursed on time may help a person determine if they should agree to arrange automatic billing for their monthly mortgage payments. These, along with countless other examples, show that humans do not make decisions in a vacuum. Rather, we function in the context of cues and other prior knowledge provided by our environment. These overall decision-making processes and the incorporation of associated biases are illustrated by a variety of sequential sampling models which, based on the findings from a large body of literature, hold that the amount of evidence needed to reach a choice may be influenced by pre-defined outcome probabilities (Ratcliff & Smith, 2004; Smith & Ratcliff, 2004; Forstmann, Ratcliff, & Wagenmakers, 2016; Dunovan & Wheeler, 2018). Sequential sampling models generally formulate evidence as a variable that can increase or decrease over time, with a decision being reached when the amount of sensory evidence processed and incorporated (i.e. accumulated) over time passes a threshold. However, precisely if or how such results translate at the neural level for older adults relative to younger adults is poorly understood.

Therefore, the current work uses younger adults and older adults to examine both behavioral performance and neural measures of evidence accumulation. Neural measures will focus on the inferior temporal cortex (ITC) because, when breaking down a perceptual decision-making task into its components, the evidence accumulation aspect is associated with the rate of change of activity in this area (Ploran et al., 2007; Tremel & Wheeler, 2015; Dunovan & Wheeler, 2018). There is also past work with exclusively younger adult samples which describes how expectations can likewise shift patterns of accumulated activation in the ITC in an informative manner (Tremel & Wheeler, 2015; Dunovan & Wheeler, 2018). In this write-up, the conceptual framework of decision-making, sequential sampling models, and some of the relevant age-related differences in decision-making are explained. Then, pilot work aimed at determining how the intended procedure can be properly implemented in both a younger and older adult sample is reported, the current experimental procedure is described, and findings are described using both behavioral and neuroimaging data.

1.1 Decision-Making and Sequential Sampling Models

Perceptual decision making is the basis of countless cognitive outcomes and is operationally defined as selecting an option from a set of alternatives given the available sensory information (Heekeren, Marrett, & Ungerleider, 2008). Past work has shown that the process is also hierarchical, time-dependent, has both bottom-up and top-down components, and can be divided into stages (Figure 1; Wheeler, 2014). First, sensory information, such as visual or auditory input, is collected and processed (Wheeler, 2014; Gold & Shadlen, 2001; Shadlen & Newsome, 2001; Ratcliff, Cherian, & Segraves, 2003; Platt & Glimcher, 1999). Then, while that sensory information continues to be

incorporated, evidence is gathered that pertains to the available choices (Wheeler, 2014; Ratcliff, 1978; Hanes & Shall, 1996; Dunovan & Wheeler, 2018; Huk & Shalden, 2005) and, eventually, a commitment to a choice is reached and accumulation ceases (Wheeler, 2014; Gold & Shadlen 2007; Heekeren, Marrett, Bandettini, & Ungerleider, 2004; Philiastides, Ratcliff, & Sajda, 2006; Philiastides & Sajda, 2005; Cisek & Kalaska, 2005). All the while, this dynamic flow of information is dependent upon the characteristics of the decision itself, including the available choices, task difficulty, and the influence of prior knowledge on choice criterion. There is also a feedback loop which assists in monitoring performance (Ploran, et al, 2007; Ploran, Tremel, Nelson, & Wheeler, 2011; Wheeler, 2014).

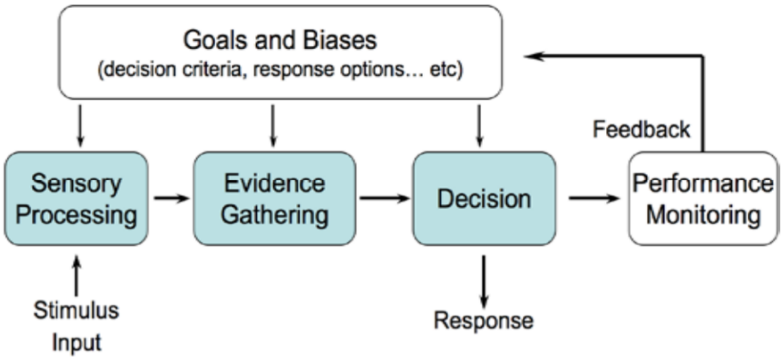


FIGURE 1: The 3 stages of decision making (blue): sensory processing, evidence gathering, and making a decision occur over time towards a response. Environmental factors and system feedback influence the process (white). This figure is from Ploran, Tremel, Nelson, & Wheeler, 2011 & Wheeler, 2014.

Within the context of this decision-making framework, the evidence gathering component is time-dependent and quantitatively moves directionally towards various options as evidence is gathered (Ratcliff, 1978; Bogacz et al., 2006; Ploran et al., 2007). If all of the options for a given choice each have an equal probability of being correct, then, theoretically speaking, it can be assumed that the amount of information that needs to be sampled from the environment should be consistent across outcomes. However, decisions are rarely this simple. In part, this is because what we know before embarking on the decision-making process can manipulate how much confuting/disproving information we require. The nature of that manipulation and associated trends is often characterized using accumulators. Accumulators are functions that describe a time-dependent operation and, in this circumstance, that operation serves to describe the gathering of decision-relevant evidence.

This framework is illustrated well by variations of sequential sampling models which hold that the choices in perceptual decisions have opposing thresholds. Evidence is represented by a variable that begins at a starting point and changes over time, moving toward a boundary. A binary choice is made when the amount of evidence passes one of two thresholds (Ratcliff, 1978; Ratcliff & Rouder, 1998; Ratcliff & McKoon, 2008; Krajbich & Rangel, 2011; Mulder, Wagenmakers, Ratcliff, Boekel, & Forstmann 2012; Winkel et al., 2012). “Sequential” means that the process is continuous over time, and “sampling” refers to the act of collecting information from the environment. Some examples of these models include the drift diffusion model (Bogacz, Brown, Moehlis, Holmes, & Cohen, 2006; Ratcliff & McKoon, 2008; Bogacz, Wagenmakers, Forstmann, & Nieuwenhuis, 2010), the linear ballistic model (Brown & Heathcote, 2008; Donkin,

Brown, Heathcote, & Wagenmakers, 2011), and the race model (Vickers, 1970; Bogacz, 2007). They all vary slightly in regard to their underlying mechanisms and mathematical principals, but share many common features. For example, the linear ballistic model is based on a race between simultaneous accumulators posed towards different options while, alternatively, the drift diffusion model uses a single accumulator pulled bidirectionally via a moving average. However, taken together and regardless of the variations in their specifics, these perspectives provide a strong body of converging evidence that sets the framework for the current study.

Mainly, this work focuses on the shared concept of a starting point (Figure 2). It has a location that depends upon the presence or absence of bias. Meaning, if each choice is equally likely (no bias), then that starting point will be centralized between the opposing thresholds and the amount of evidence and time required to make a selection should be the same. However, if the bias of prior knowledge suggests that a given option is more likely, then that starting point will shift towards that option and, therefore, less evidence accumulation is needed to reach the closer threshold and selections can be made quickly. Likewise, the more distant threshold will require more evidence accumulation than a standard 50/50 probability and take more time.

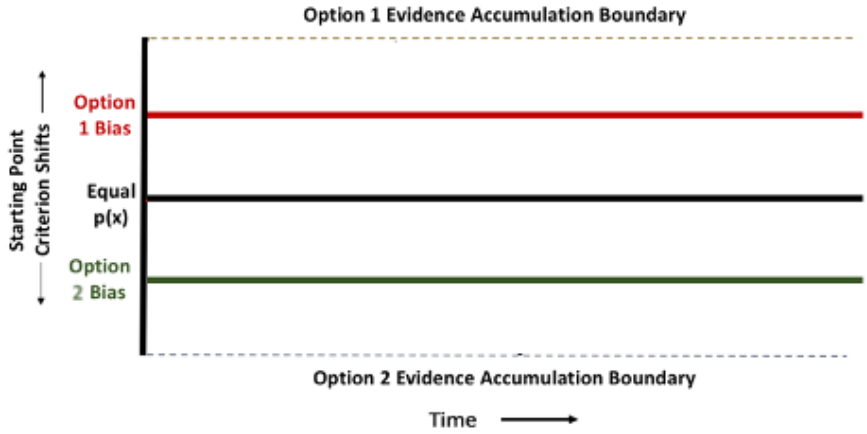


FIGURE 2: For simplicity, a binary choice is used as an example. There are evidence accumulation thresholds for option 1 and option 2 (dotted lines). This process begins at a starting point: equally likely (black), biased toward option 1 (red), biased toward option 2 (green).

1.2 Trends Across the Lifespan

Within the context of perceptual decision-making, there are also potential age-related differences in cognition that can be used to explore how shifts in criterion and evidence accumulation translate to behavioral and neural outcomes. For example, older and younger adults have a propensity to favor different ends of speed-accuracy tradeoffs (Starns & Ratcliff, 2010). Past work has shown that older adults have a propensity towards conservatism in their cognitive strategies relative to younger adults, and thus may be resistant to incorporating new knowledge into their decision-making (Braver, Paxton, Locke, & Barch, 2009; Fein, McGillivray, & Finn, 2007). Inflexibility in the face of environmental cues may thereby result in less efficient decision-making strategies because the starting points for older adults are less flexible than younger adults. Therefore, even though prior knowledge from the environment has the potential to bias

certain options, speed up the process, and reduce the amount of evidence that must be accumulated (assuming that the provided prior knowledge is valid), older adults may not make those adjustments to the same degree as younger adults. Older adults approaching decision-making in this inflexible manner is beneficial in terms of accuracy, but often at the expense of significant time and cognitive effort (Rabbitt, Cumming, & Vyas, 1979; Ratcliff, Thapar, & McKoon, 2001; Starns & Ratcliff, 2010; Hertzog, Vernon, & Rypma, 1993; Salthouse, 1979). However, ultimately, the direction of optimality for such speed-accuracy tradeoffs depends upon the nature and consequences of the task itself.

A study by Ratcliff, Thapar, and McKoon supports this framework (2001). These researchers used a simple signal detection theory paradigm, during which participants were presented with arrays of asterisks. The number of asterisks for each trial was randomly generated from either a high-mean normal distribution or a low-mean normal distribution. The participants were then tasked with classifying each array as being derived from a sample with either a "high" or "low" mean. They found that older adults, in general, presented longer and more variable reaction times than younger adults. They then replicated the findings using a different type of cognitive task (distance between items, rather than number of items) and examined the findings using a sequential sampling model analysis. They again found longer reaction times for older adults relative to younger adults. Furthermore, they also concluded that these age-related trends can likely be explained by differences in conservatism of choice because, even though reaction times varied by age, the rate of evidence accumulation (i.e. the rate of the accumulator drift function) was constant. Essentially, older adults locked their starting point in place, required more evidence than their younger adult counterparts, and failed to

adjust to starting point biases during this difficult and transient decision-making task. Another study by Ratcliff, Thapar, and McKoon (2007) came to similar conclusions when comparing signal detection task performance, visual discrimination performance, recognition memory, and lexical decision-making task performance for younger and older adults.

Regardless of the cognitive or metacognitive mechanisms behind these age-related differences in the utilization of prior knowledge or how they might play out between specific models, these and other examples provide an opportunity to test at a broad level how well the accumulation-to-boundary perspective of perceptual decision-making holds at the neural level with age as a factor. Meaning, those who are theorized to be more conservative (older adults) should present consistent percent change BOLD activation levels in the ITC, accuracy scores, and RTs that are independent of informative priors. While, on the other hand, their more liberal younger adult counterparts should show differences in these dependent variables that are consistent with the provided prior knowledge. This is a neurological perspective which is not addressed in the literature, as studies of this nature rarely include older adult samples or fMRI data. Therefore, this work may permit a more encompassing examination of decision-making than what younger adult behavioral data alone can provide. To accomplish this, the following study uses a Posner-like cue phase+task phase paradigm in which a cue establishes a probabilistic expectation about the nature of the stimulus appearing in the subsequent task (Posner, 1980). How quickly those individuals respond, how accurate they are, and the associated change in BOLD signals within the ITC under the context of these biases are then examined for both younger and older adults.

1.3 Hypotheses

There are several hypotheses that cover a variety of behavioral, cognitive, and neuroimaging domains. They are as follows:

1.3.1 Hypothesis 1

Older and younger adults 'accuracy during the task phase (overall, not yet broken down into levels based on the cue phase) will not differ significantly from one another. This analysis aims to test if the current protocol successfully controlled for an important confound—visual noise processing ability. This step in the analyses is important because the task-phase involves classifying images that are visually noisy and older adults tend to have collectively poorer visual acuity relative to younger adults. Thus, there are a few potential confound-related risks in protocols like this: older adults could perform at floor because they simply cannot see the stimuli, younger adults could perform at ceiling because they can see the stimuli too easily, or findings that conclude older adults perform worse could simply be driven by age-related changes in vision. To assess these concerns, a 1-up-3-down double interleaved staircase psychophysical thresholding task was implemented to control for the amount of visual noise prior to the decision-making task. That procedure is described later in the section "Chapter 2: Pilot Study." Perceptual thresholding on a subject-by-subject basis in this manner aims to control for these complicated individual differences. A lack of a significant difference between groups' overall accuracy would indicate that the thresholding procedure may be working properly, while a significant difference would be indicative of a serious age-related confound that should be considered when drawing conclusions about subsequent results.

The analysis will be accomplished using a two-sample t-test. Age is the independent variable, and accuracy is the dependent variable.

1.3.2 Hypothesis 2

Overall, older adults will have longer reaction times than younger adults due to general slowing and/or their relative conservatism. Again, this stage of the analysis does not assess differences based on factors like task phase validity. This is a quality-assurance step that serves to explore broad trends in the data. If, for example, older adults were faster than younger adults, that would be highly unusual and require additional consideration in regard to the representativeness of the samples. The analysis will be accomplished using a two-sample t-test. Age is the independent variable, and mean overall reaction time is the dependent variable.

1.3.3 Hypothesis 3

Older adults' accuracy will be more variable across individuals when compared to younger adults, as will their reaction times and visual noise thresholds. Again, this will provide general information about how the different age groups compare to one another moving forward. Older adults tend to lean towards being more variable than younger adults on a wide variety of physical and cognitive metrics for a plethora of potential reasons (Hultsch, Strauss, & Hunter, 2008; Newell, Mayer-Kress, & Liu, 2009). If they are found to be significantly less variable, then that should be considered when drawing conclusions from these samples. The analyses will be accomplished using F-tests for equality of variance. Age is the independent variable, and the dependent variables are variance in reaction time, variance in accuracy, and variance in visual noise threshold values.

1.3.4 Hypothesis 4

Younger adults will utilize the probabilistic cues more effectively because they will shift their criterion in a more flexible manner, which will be reflected in shorter reaction times for valid (cue and image match) trials and longer reaction times for invalid (cue and image do not match) trials relative to the neutral control. However, older adults will not use the cues as effectively and, because of the inflexibility in their starting points, they will not show as substantial of a difference in reaction time between valid and invalid trials. The analysis will be accomplished via a 2 (AGE: younger adult, older adult) X 3 (VALIDITY: valid, invalid, neutral) mixed ANOVA, with reaction time as the dependent variable.

1.3.5 Hypothesis 5

In regard to the imaging data during the task phase (which occurs prior to the probabilistic cue phase), younger adults will present the largest percent change in face and house ITC ROIs during invalid trials. This will be followed by the neutral condition, then the valid condition. These results will occur because the amount of activity tracks the amount of evidence, and invalidity, which means that prior knowledge is biased against the correct response, requires relatively more evidence accumulation than uninformative (neutral) or correctly biased (valid) cues. Larger percent change values are indicative of more work being conducted in a given set of voxels, and that is reflected by changes in hemodynamic response. Meanwhile, older adults will show consistent BOLD signal percent change across both valid and invalid trials due to their expected inflexibility.

During the cue phase, younger adults will likely show increased BOLD activity in the ITC relative to older adults because, again, they will attend to and engage with cues more readily. However, for the younger adults, any of those effects are expected to be qualitatively less pronounced (lower percent change values than during the task phase) and/or be reflected in fewer ITC regions. Cue-phase activity is likely top-down and anticipatory in nature, while task-phase activity is more perceptual and bottom-up. That perspective suggests that these are distinct processes. Based on the findings of previous work by Dunovan & Wheeler in 2018, the ITC responds differently in accordance. That study found that only face regions showed anticipatory activity and did so at a reduced BOLD signal magnitude.

The localizer task will be used to establish face and house ROIs. Within each of those ROIs, the cue and task phases will be considered separately. The task-phase analysis will be accomplished via a set of 2 (AGE: younger adult, older adult) X 3 (VALIDITY: valid, invalid, neutral) mixed ANOVAs, and the cue-phase analysis will utilize 2 (AGE: younger adult, older adult) X 3 (CUE: face, house, neutral) mixed ANOVAs. Percent BOLD signal change is the dependent variable.

1.3.6 Hypothesis 6

An additional hypothesis is that there will be a strong negative linear relationship between scores on the Mars Letter Contrast Sensitivity test (MLCST) and participants' visual noise threshold values because both acuity and contrast sensitivity are likely components of sensory processing in visually noisy environments. This analysis is exploratory and not directly related to the main goals of the study. Rather, this step aims to understand how the double staircase thresholding relates to other measures for the

purpose of informing future work. For instance, finding a 1:1 relationship may warrant an additional set of studies that test the efficacy of using the MLCST as an alternative to complicated thresholding tasks. It is also worthwhile to consider further applications of the MLCST in general, collect additional data that relates to underrepresented older adults, and get a feel for general trends in studies of this nature. The analysis will be accomplished using a correlation, with Mars Letter Contrast Sensitivity scores and visual noise threshold values as the variables.

1.3.7 Hypothesis 7

A final exploratory hypothesis is that older adults will provide higher mental demand, physical demand, temporal demand, effort, and frustration scores on the NASA-TLX inventory than the younger adults due to age-related trends in physical and cognitive factors. Self-reported performance estimates will not differ between age groups because difficulty is being controlled by the current design. Again, this step is not directly related to the main goals of the study and serves as an informative guide for potential studies in the future. The analysis will be accomplished via one-way MANOVA, with age (younger, older) as the between-subjects factor and scores on the 5 scales as dependent variables. ω^2 will be used to calculate effect sizes.

CHAPTER 2:
PILOT STUDY

The current study is a replication with extension that is based on a previous study conducted by Dunovan & Wheeler in 2018. That study used an exclusively young adult sample and tested whether expectations influenced the neural accumulation of evidence. The general method involved presenting participants with a binary forced-choice task, during which images of faces and houses overlaid with Gaussian visual noise were presented. The noise was similar to static on a television screen and made the task difficult, thereby extending the reaction times to the scale needed for fMRI. The participants were then tasked with classifying each image as either a face or a house. In this context, it was reasonable to control for task difficulty by setting the amount of visual noise overlaying the images at 67% for everyone. That strategy worked well for a younger adult sample. However, when including an older adult sample in the current protocol, controlling for visual noise in this fashion was no longer appropriate. This is because, as will be explained later in this pilot study's results section, there is less variability in younger adults' noise thresholds. Simply put, there were several instances where older adults indicated that they simply could not see images at all when they were obscured with 67% noise and, therefore, that inability to see the stimuli caused a significant floor effect for task performance that is unrelated to the variables of interest.

There are several reasons why this may be the case, all of which may present significant confounds which were not previously an issue with younger adults. These may include (but are not limited to): variability in visual acuity and contrast sensitivity decline, age-related cognitive changes, and increased difficulty handling visual noise over

time. The proposed solution to this issue involved identifying each individual's visual noise threshold which is associated with 80% accuracy in a face/house identification task, then changing the stimuli to match that threshold for each person. 80% was the value chosen because it is neither a ceiling nor floor effect, and it provides flexibility in case performance dips when participants transition from the computer-based training environment to the loud, dark, and restricting scanner environment. Therefore, this pilot study explored three psychophysical thresholding techniques—a hand-coded double staircase, the method of constant stimuli, and a 1-up 3-down double interleaved staircase. After obtaining thresholds using these techniques, the participants then completed a run of the experimental task that is also implemented in the current fMRI study. Additional goals of this preliminary work were to minimize technical difficulties, address ceiling and floor effects, and ensure a reasonable distribution of response times across 6-second trials (with a TR of 1.5 seconds) for translation into an fMRI environment.

2.1 Pilot Study Method

2.1.1 Participants

16 participants were recruited from the greater Atlanta, GA community via signage posted on the MARTA transit system and the Georgia Institute of Technology Sona subject pool website. The young adult group consisted of 12 individuals ranging in age from 18-25, with a mean age of 21.01. The older adult group consisted of 6 individuals ranging in age from 60-70, with a mean age of 65.75. Two younger adults were excluded due to technical difficulties and one elected to leave the experiment early. One older adult was excluded due to issues understanding the instructions. Before participation in this study, all potential subjects were pre-screened over the phone for

right handedness, proficiency with the English language, natural or corrected 20/20 vision, and a lack of any diagnosed psychological disorders. Participants received either 1.5 Sona class credits or $30.00 in exchange for their time.

2.1.2 Face/House Stimuli

For both the pilot and current studies, decision-making was examined in the context of criterion shifts using a face/house paradigm. This paradigm was used because, for later exploration using fMRI, the face-selective (fusiform gyrus) and place-selective (parahippocampal place area) evidence accumulation regions of the ITC are spatially distinct, and thereby permit examinations of non-overlapping stimulus-specific evidence accumulation (Heekeren, Marrett, Bandettini, & Ungerleider, 2004; Tremel & Wheeler, 2015; Dunovan, Tremel, & Wheeler, 2014; Dunovan & Wheeler, 2018). The current version of the face-house paradigm is a two-alternative, forced-choice task wherein participants were presented with images of faces and houses obscured with noise. Participants were instructed to identify each as a face or a house. The noise was like static on an old TV screen. The focus of pilot testing was to best determine the level of noise required for each participant to approximate an overall similar level of performance. All stimuli were built in PsychoPy version 1.80.03 and presented on an LCD screen. The house images were collected from real estate websites based in the immediate Pittsburgh, PA area, and the face images were provided by the MacArthur Foundation Research Network on Early Experience and Brain Development in Boston, MA. All stimuli were cropped to remove backgrounds, are black and white, and are 560 x 560 pixels in size (Figure 3).

FIGURE 3: Examples of face and house images.

2.1.3 Visual Noise Thresholding Task Procedures

As an initial step toward identifying an adequate thresholding procedure, one older adult participant's threshold was assessed using a hand-coded double staircase. For this task, the participant was first shown 6-second videos of faces and houses obscured with gradually increasing levels of noise. The participant then indicated verbally when the image was no longer visible. The process was then reversed, the participant was shown images with gradually decreasing levels of noise, and indicated when the image became visible. The highest (and most difficult) level was 73.25% occluded with visual noise. The lowest (and least difficult) noise level was 58%. Each step moved in increments of .25%. The process was repeated for a total of 6 rounds for faces and 6 rounds for houses. The obtained threshold values were all noted and subsequently averaged by hand, and a just noticeable difference threshold was identified. This procedure has been implemented by past researchers and has proven problematic, so it

was done once in order to generally understand and identify the issues for exploratory testing purposes.

The remaining older and younger adult thresholds were identified using both method of constant stimuli and the 1-up 3-down double interleaved staircase tasks. For the method of constant stimuli procedure, individuals were shown a randomized series of 6-second videos containing faces and houses obscured with varying levels of visual noise. Participants were instructed to indicate if the image they viewed was a face or a house via button presses on a keyboard. Each person's performance plotted across the different noise levels produced a linear function, and the point on that line associated with each person's 80% accuracy was documented. The participants then completed the 1-up 3-down double interleaved staircase thresholding task which also involved showing 6-second face and house images obscured with different levels of noise. However, this tool adjusted the amount of noise based on performance, with each mistake decreasing noise by .75% and each correct response increasing noise by .25%. Trials were repeated with different face and house images until 80% accuracy in the identification task was replicated at the same noise level 3 times for faces and 3 times for houses. If they were unable to categorize the image within the 6-second timeframe, they were instructed to guess for both tasks.

After the threshold identification tasks were complete, the intent was then to have the participants complete two runs (i.e. sequences) of the decision-making task that were going to be used in the fMRI study, and each would incorporate one of the two identified noise thresholds. Then performance would be compared across both procedures in order to determine which technique most closely resulted in 80% accuracy. However, the

techniques produced the exact same threshold values for each person and, as a result, the participants only completed 1 run of the decision-making task.

2.1.4 Decision-Making Task Procedure

In the Posner-style decision making task (Figure 4), trials began with a three-second cue phase in which participants were presented with one of three probabilistic cues: 80H (80% chance of a house in the task phase), 80F (80% chance of a face in the task phase), or 50N (50% chance of a face in the task phase). Participants were informed that the cue probabilities were accurate, and were asked to explain each to the researcher in order to confirm understanding. Each cue phase was followed by a 6-second task phase in which they saw a video of a building or human face obscured with dynamic noise calculated from the individual's thresholding task(s). Here, dynamic noise means that the noise mask updated regularly throughout the 6 sec trial, maintaining the same level of noise but shifting the spatial distribution over time.

Trials were separated by jitter periods comprised of face and house images obscured with 100% noise. These jitter periods were on screen between 1.5-6 seconds (uniform distribution in increments of 1.5 seconds), and their purpose was to separate overlapping activation across trials during later analysis. Participants were responsible for indicating via a left- or right-hand button press if they were viewing a face or house during the task phase (Heekeren, Marrett, Bendettini, & Ungerleider, 2004). If they were unable to decide before the six-second response period had elapsed, they were instructed to guess. There were 40 trials in each run, 25% of which were catch-trials consisting of the cue phase only. This trial type, which does not include a task phase, was used to

permit the later deconvolution of BOLD signal activation in the cue phase from activation in the task phase (Ollinger, Shulman, & Corbetta, 2001).

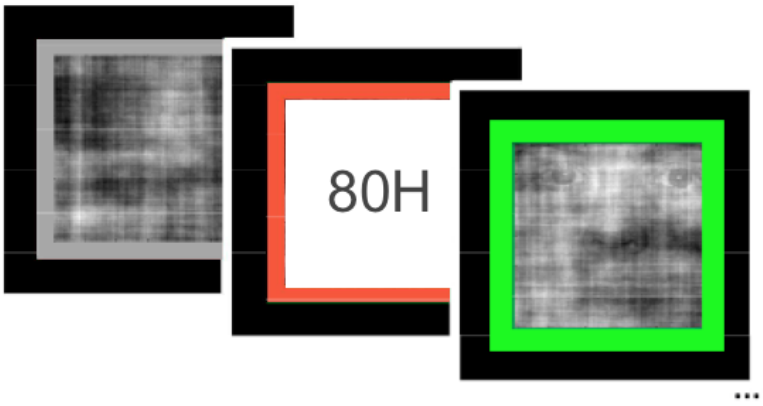


FIGURE 4: Example of stimuli consisting of a jitter (gray border), 3-second cue (red border), and 6-second face or house image (green border). The amount of noise overlaying the face or house image is associated with the participant's threshold.

2.2 Pilot Study Results

The one older adult who completed the hand-coded staircase (n = 1) had an identified psychophysical threshold of 63.25% noise and presented an overall accuracy of 96.11% for the task phase. All of the face images were identified correctly, only 3 out of 90 total house trials yielded incorrect responses, and the participant noted that those errors only occurred because the face button was pressed by mistake. This thresholding method produced a notable ceiling effect in the task data. Likewise, the reaction times presented a distribution which is far from uniform or near-uniform, with nearly all trials located within the 1.5-3 second increment of the 6-second trial (Figure 5). Exclusively

short reaction times are not suitable for fMRI analyses. This version of a threshold determination task, in addition to producing unusable performance data, also took over 40 minutes to complete and was frustrating for the participant.

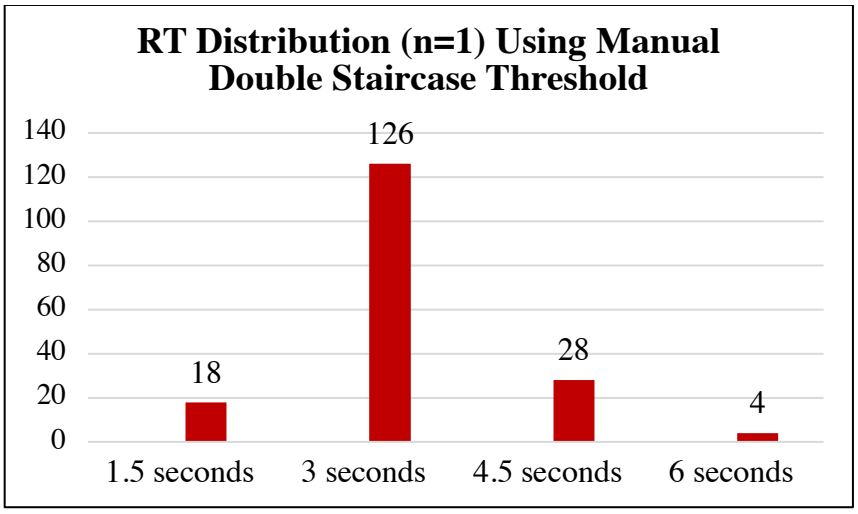


FIGURE 5: Reaction time distribution of experimental task for the older adult who completed the manual double staircase

For the remaining younger and older adults who completed the method of constant stimuli and 1-up 3-down double interleaved staircase thresholding tasks (n = 12), there was an overall mean threshold of 69.28% noise with a standard deviation of 1.4%. The mean overall accuracy for all participants during the task phase was 82.82% with a standard deviation of 4.25%. These results were far closer to the desired 80% performance level. Likewise, there was a more even and statistically usable distribution of scores across the increments of TR (Figure 6). A flat distribution is desirable because fMRI analyses bin trials by RT, and a flat distribution produces an equal number of trials

per RT bin. It is highly unlikely that one would ever obtain a perfectly uniform flat distribution, but, even with a small sample, reaction times are sufficient for the necessary analyses in this context.

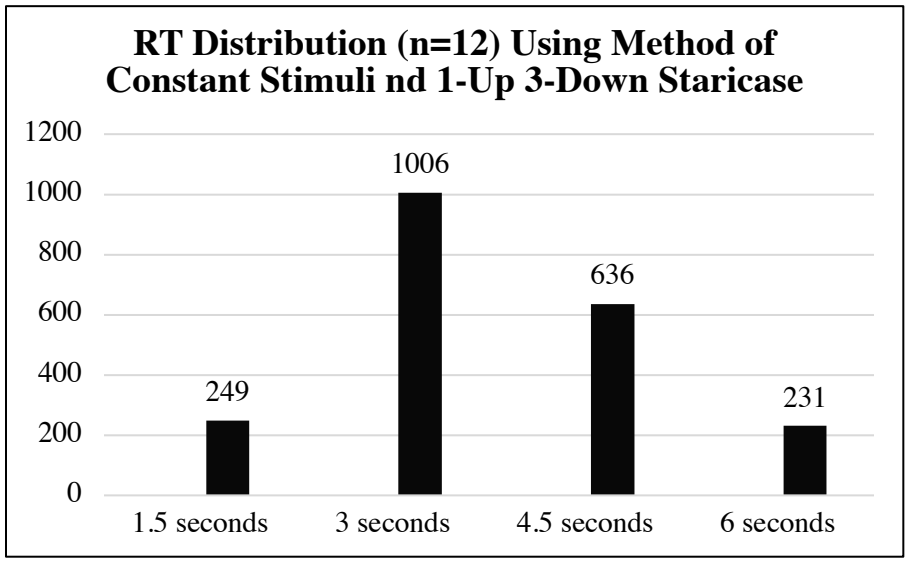


FIGURE 6: Reaction time distribution of experimental task for all participants using the thresholds identified by the method of constant stimuli and 1-up 3-down staircase techniques.

When splitting the data by age into the older adult (n = 2) and the younger adult samples (n =10), the results were likewise promising. The younger adult group had a mean threshold of 69.77% noise (*SD* = 0.73%) and a mean task accuracy of 82.66% (*SD* = 4.45%). This accuracy measure was close to the desired accuracy of 80%. The reaction time distribution was also sufficiently uniform based on qualitative inspection (Figure 7). The older adult group had mean threshold of 67.17% (SD = 2.14) and a mean accuracy of 82.44% (SD = 4.32) during the task phase. The result was also close to the desired

accuracy of 80% and is similar to the results for younger adults. The older adult reaction time distribution (Figure 8) is also sufficiently uniform, albeit skewed more than the younger adult group with a marked increase in RTs.

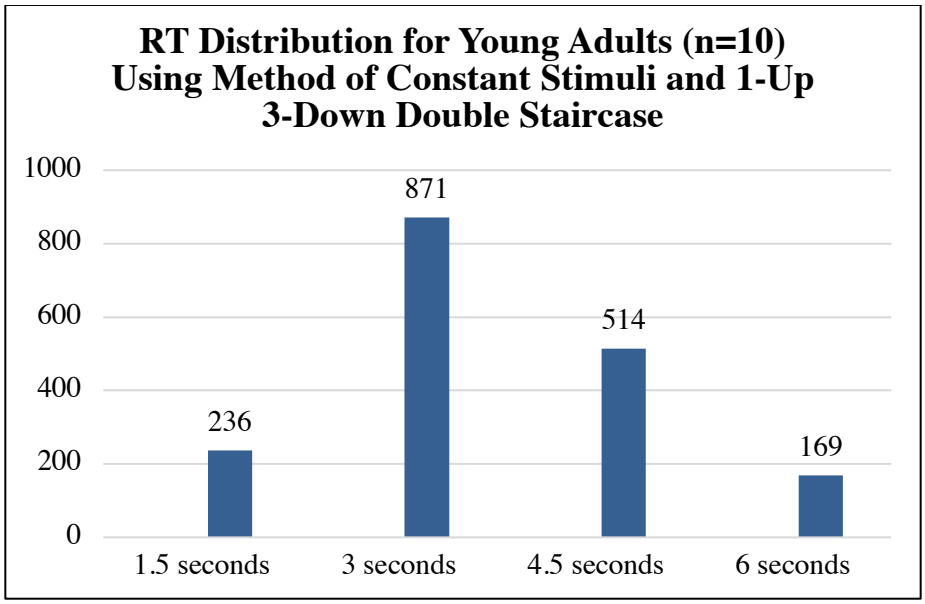


FIGURE 7: Reaction time distribution of experimental task for younger adults, using the threshold identified by the method of constant stimuli and 1-up 3-down staircase techniques.

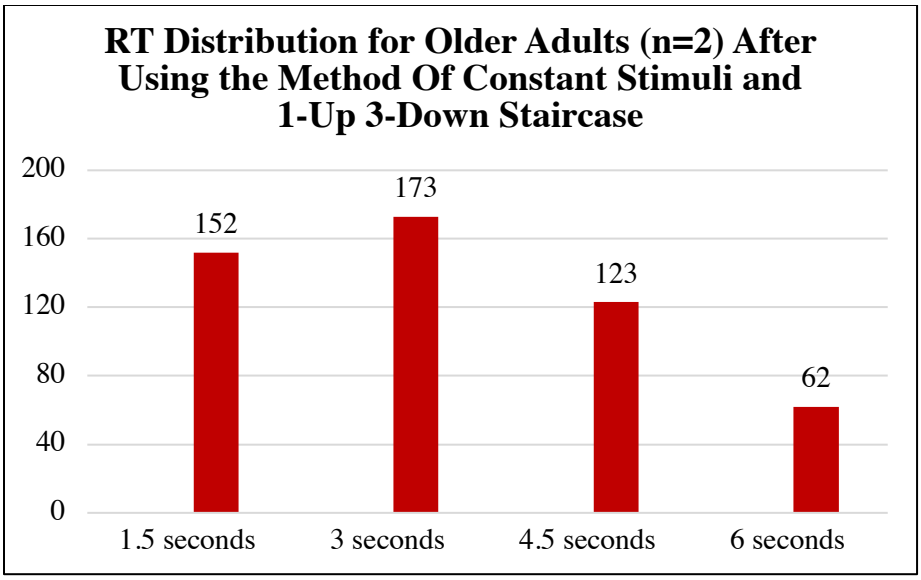


FIGURE 8: Reaction time distribution of experimental task for older adults, using the threshold identified by the method of constant stimuli and 1-up 3-down staircase techniques.

2.3 Pilot Study Discussion

Identifying visual noise thresholds was critical for the current study because the inclusion of an older adult sample has the potential to introduce additional cognitive and sensory confounds. Some methods may be better than others based on the characteristics of a given task, including the number of options or increments, the sensory modality, and the equipment or techniques being implemented.

In this case, a hand-coded double staircase was not sufficient. Part of the issue was that this version of the task is identifying an individual's least noticeable difference threshold, rather than a specific accuracy threshold. These are two entirely different concepts, and the former was not of interest for this study. Secondly, this method did not flow well, felt awkward to use in practice, and took over an hour to complete due to the

large number of noise levels available. The excessive duration also made this task susceptible to fatigue effects, which may have gradually pulled down the participant's actual threshold over time. That would have made the decision-making task easier because the noise level is reduced, and could be the reason a pronounced ceiling effect was found. Staircase tasks of this nature, because they are not interleaved, are also highly susceptible to the influence of the expectations established by previous trials (Cornsweet,1962; Leek, 2001).

Fortunately, the method of constant stimuli and the 1-up 3-down double interleaved staircase have proven to be more reliable techniques, as both appear to have successfully addressed issues faced by previous researchers attempting to identify each participant's appropriate visual noise threshold. Given that both of these techniques produced the same threshold values, the 1-up 3-down double interleaved staircase was chosen for use in the current fMRI study because it took less time to complete (5 minutes) than the method of constant stimuli procedure (20-30 minutes). It also appeared that using this tool would assist in mediating floor effects and ceiling effects, as well as produce a sufficient reaction time distribution for use in fMRI.

The results also illustrated why thresholding is necessary when older adults are considered, but not always necessary for exclusively young adult populations. The younger adult sample presented a higher noise threshold and a much smaller standard deviation (.73%), while the older adults sample presented a lower noise threshold and a larger standard deviation (2.14%). At a glance, the differences between these standard deviations may seem negligible, but the shifts in difficulty are notable when viewing video stimuli (Figure 9). As a whole, the older adults tended to require easier, less noisy

images and were more variable in their responses which, if not controlled for, is potentially confounding. It was anticipated that there would be a drop in performance across all individuals when translated from a mock fMRI/computer environment to an fMRI environment. However, controlling for difficulty should also assist in holding potential declines constant.

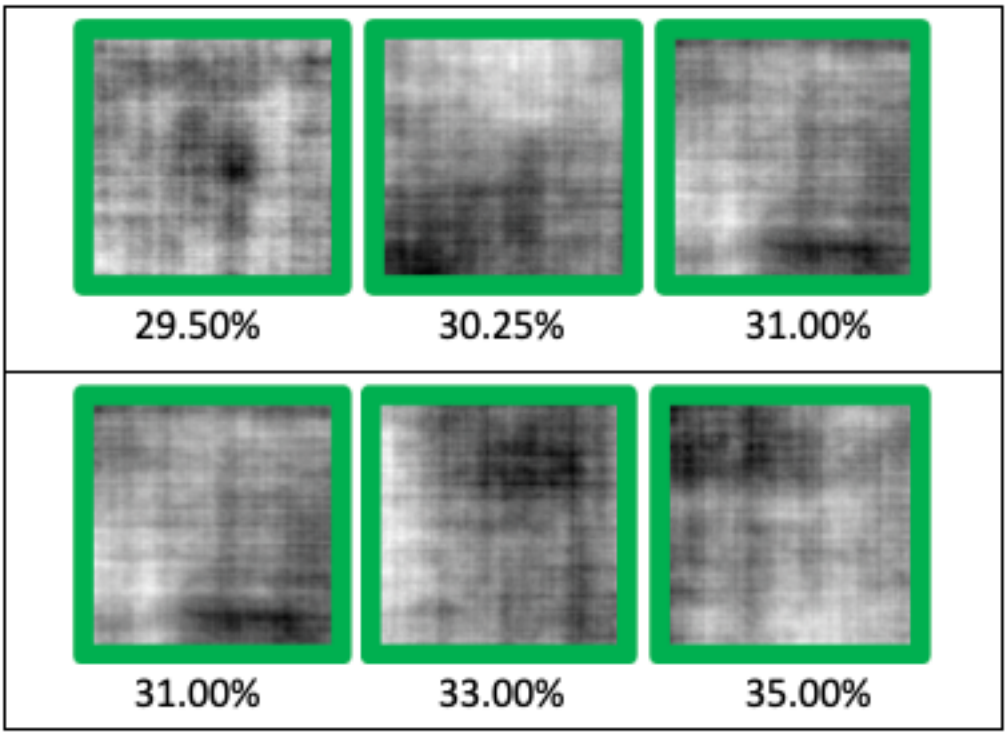


FIGURE 9: Example of a face image from the stimuli set, overlaid with the noise levels associated with young and older adults' 80% threshold. Noise percentages are rounded to the nearest .25%. The stimuli are dynamic in practice and the task is challenging in general, so differences are difficult to see in static images. *Top row (left to right):* 1 SD below the mean noise level, the mean noise level, and 1 SD above the mean noise level associated with 80% accuracy in the young adult sample. Differences appear negligible. *Bottom row (left to right):* 1 SD below the mean noise level, the mean noise level, and 1 SD above the mean noise level associated with 80% accuracy in the older adult sample. Differences are more pronounced.

CHAPTER 3:
METHODOLOGY

Given the results of the aforementioned pilot work and by implementing the 1-up-3-down double interleaved staircase, this work now goes on to address the study's primary goals and hypotheses that relate to aging, prior knowledge, and decision-making.

3.1 Participants

3.1.1 Sample Size

The younger and older adult groups consisted of individuals ranging in age from 18-35 and 60-75, respectively. The a priori sample size goal was 48 full data sets with 24 in each age group. The value was based on previous work (Dunovan & Wheeler, 2018). Unfortunately, due to scheduled maintenance and imaging equipment upgrades and a weather emergency severely constricting the timeline for data collection, the sample size was reduced. 47 participants were recruited for this study, and a total of 13 were excluded: 5 from attrition between the first and second days of the experiment, 2 due to claustrophobia, 2 due to excessive movement while inside of the scanner, 3 due to technical issues with the fMRI scanner, and 1 elected to leave early for personal reasons. A total of 18 older adults with a mean age of 66.6 (10 male, 8 female) and 16 younger adults with a mean age of 27.9 (6 male, 10 female) were included in subsequent analyses (Table 1).

TABLE 1: Sex, age, and racial breakdowns for the younger and older adult samples.

		Older Adults (n=18)	Younger Adults (n=16)
Sex	male	10	6
	female	8	10
Age	$\bar{x}$	66.61	27.88
	s^2	4.88	3.84
Race	Black	8	10
	White	8	3
	Asian	0	0
	Hispanic	0	1
	Native Am	0	0
	>1/Unkn	2	2
	No answer		

3.1.2 Recruitment and Pre-Screening

Participants were recruited from the greater Atlanta, GA community via signage posted on the MARTA transit system, in the local newspaper, on Craigslist, and on fliers posted in and around the Georgia Institute of Technology campus. Older adults were also contacted using Georgia Tech's Aging Participant Recruitment Pool, and several individuals reached out to the lab through online interest forms. All participants were first pre-screened over the phone before entering the laboratory (Appendix A). Inclusion criteria included: right-handed, normal or corrected-to-normal vision, lack of psychological or significant medical disorders, proficient in the English language, free from claustrophobia, and meeting the required fMRI safety criteria (no implants, certain tattoo inks, etc). Additionally, upon entering the laboratory, all individuals completed a

battery of standard cognitive and neuropsychological tests: Edinburgh Handedness Questionnaire, Mini Mental State Examination (MMSE), Trails A & B, 15-Item Short Form Boston Naming Test, and Clock Drawing Task.

The Edinburgh Handedness Questionnaire is a measure of left- versus right-preferentiality for common household activities (Oldfield, 1971). It consists of a list of 10 activities, and participants were tasked with indicating if they use their left or right side to complete them. Individual scores were then converted into a laterality quotient ($LQ = \frac{[R-L]}{[R+L]} * 100$) and put on a spectrum from -1 "pure right" to 1 "pure left." Those who scored below 0 were classified as some degree of left-handed, and those who scored above a 0 were classified as some degree of right-handed. The cutoff score for the current study was a highly conservative +0.85, and those individuals were classified as "strongly right-handed." The MMSE is a test of cognitive function commonly given to members of the older adult population (Folstein, Folstein, & McHugh, 1975). It consists of 30 questions that cover the domains of memory, awareness of time and location, language, orientation, and others. Each answer was worth one point and those points were summed into a single score. The scores range from 0 to 30, with lower values indicative of poorer cognitive functioning and higher values indicative of better cognitive functioning. The cutoff score for inclusion in the current study was >26. Trails A & B are inventories of perceptual and motor skills that tend to be associated with visual attention abilities and task switching (Reitan, 1958). They required participants to connect dots without lifting up their pen in numeric (A) and alphanumeric (B) order as quickly as possible. The seconds required to complete each task were then recorded. Faster times are indicative of better visuomotor skills, and slower times are indicative of poorer visuomotor skills. The

cutoff score for inclusion was <78 seconds for A and <273 seconds for B. The Boston Naming Test is a measure of picture-naming ability (Goodglass, Kaplan, & Weintraub, 1983). It consists of a series of 15 images on white backgrounds. Participants were shown the images, asked to identify them by name, and the number of correct responses is summed into a score. Higher values are indicative of better picture naming abilities, and lower scores are indicative of poorer picture naming abilities. The cutoff score for inclusion was at least 13 correct. The Clock Drawing task is an additional measurement of cognitive dysfunction (Shulman, 2000) in which participants draw an image of a clock depicting the time "10 after 11" with no visual references. There are several ways this measure can be scored, but this protocol used a range of 1 to 10. Lower values are indicative of poorer cognitive functioning and higher values are indicative of better cognitive functioning. The cutoff score for inclusion was >8.

No additional participants were screened out at this cognitive battery stage (Table 2). None were found to be left-handed or scored below the .85 "strongly right-preferential" requirement. All individuals scored within the normal adult range on Trails A & B. All individuals also scored at or near perfect on the Mini Mental State Exam, Clock Drawing Task, and Boston Naming Test.

TABLE 2: Pre-screening inventory results for the younger and older adult age groups. All results are within the normal range and all individuals are right-handed. Therefore, no participants were excluded at this stage.

		Older Adults (n=18)	Younger Adults (n=16)
Mini Mental State Examination	$\bar{x}$	29.30	29.60
	s^2	1.06	0.70
Clock Drawing Task	$\bar{x}$	9.70	10.00
	s^2	0.48	0.00
Edinburgh Handedness Questionnaire	left	0.00	0.00
	right	18.00	16.00
Trails A	$\bar{x}$	36.06	28.29
	s^2	15.04	13.80
Trails B	$\bar{x}$	76.73	60.77
	s^2	30.23	34.78
Boston Naming Test	$\bar{x}$	14.04	14.70
	s^2	0.97	0.48

3.1.3 Compensation

In exchange for their time, individuals were compensated at a rate of $25 per hour up to $75. Payments were provided in the form of either a check or pre-paid Visa card. The duration of this study was approximately 3 hours.

3.2 Equipment

fMRI data was collected using a 3T Siemens TIM Trio MR scanner located at the GSU/GT Center for Advanced Brain Imaging in Atlanta, GA. The functional scans were collected using a gradient pulse echo sequence (31 transverse slices starting at the base of the cerebellum, inferior to superior order, interleaved acquisition, TR of 1.5 seconds, 3.2x3.2x3.2 mm voxels). A T1-weighted magnetization-prepared rapid acquisition gradient echo (MPRAGE) scan and a T2-weighted scan with a fluid attenuated inversion recovery (FLAIR) sequence were collected for the structural series. Structural data were used primarily for atlas transformation and data visualization. Data were analyzed using Fidl version 7.1.1 and JMP version 15.2.1.

Stimuli inside of the fMRI scanner were presented on mirrors that reflect LCD screens with a resolution of 1024x768 pixels per inch. The display screens were connected to a 13-inch 2015 Macbook Air. Participants indicated their responses using MR-compatible button boxes, one for each hand. Each button was .43 inches in diameter, and all were arranged in alignment with the natural curve of the left and right fingertips. The thresholding task prior to the scanning session was designed in MATLAB R2016A version 9.0.0.341360 and was presented on a 13-inch Macbook Air LCD screen with a resolution of 1024x768 pixels per inch. The decision-making task was designed in PsychoPy version 1.80.03.

3.3 Stimuli

See the "Face/House Stimuli" portion of the "Pilot Study Method" section.

3.4 Procedure

The study took place in 2 sessions that were, initially, going to be at least 48 hours apart (Appendix B). That timeline allows sufficient time to cancel scanner timeslots without financial penalty in case participants discover they are claustrophobic, do not achieve the necessary scores on the pre-screening tasks, cannot reach a consistent accuracy threshold via the staircase technique, or miss their first session entirely. However, it should be noted that several participants were lost due to attrition (no-showed second session) in rapid succession. From that point forward in the interest of efficient and timely data collection, individuals were given the option to do both sessions on the same day with a break in between. All participants chose the latter option going forward. There are not enough individuals in the 2-day session group (5) to include timing as a covariate for later analyses. However, the change is likely inconsequential because the first session consists mainly of pre-screeners and the participants are not asked to carry over any information between sessions as one might do in, for example, a long-term memory task or cognitive training study. Throughout the entirety of the experiment, researchers read the instructions to the participants from a script to ensure consistency. Researchers also asked the participants to confirm their understanding each time new information was presented, there were opportunities for participants to ask questions, and instructions were repeated several times with the help of visual aids that included sample stimuli.

The first session took approximately one hour. Upon arrival, participants first completed the consent process (Appendix C) and were given a general overview of what to expect. They then completed the National Science Foundation (NSF) standard demographics questionnaire, which is used for reporting and collection of basic sex and

ethnicity data. This was also a requirement for one of this study's funding sources. The participants then completed all of the prescreening inventories outlined in the above section "3.1.2 Recruitment and Pre-Screening." Those inventories were scored as they were completed and no individuals were excluded based on those criteria.

The pre-screeners were followed by a visual acuity and contrast sensitivity test known as the Mars Letter Contrast Sensitivity Test (MLCST). The MLCST is similar to a traditional Snellen Eye Chart which features letters gradually decreasing in size (Arditi, 2005). However, in this context as participants identified the letters on the MLCST chart, the letters decreased in both size and contrast simultaneously. This inventory was used because the current protocol relies on a visual perception task wherein participants identify images overlaid with visual noise. Therefore, these results may prove interesting when examining how combined visual acuity and contrast sensitivity results compare to noise thresholds.

After the eye test, participants then completed a 1-up 3-down double interleaved staircase task designed establish each individual's noise threshold. As was described in "Chapter 2: Pilot Study," this step titrated the stimuli difficulty to each person's visual processing abilities. The only difference is that participants completed this task inside of a mock fMRI scanner using the same type of button boxes that will be used inside of the actual scanner, rather than on a computer using a keyboard. The mock fMRI was used in order to screen out individuals who are claustrophobic, and to attempt to match the scanner's visual environment as much as possible.

The response keys were also counterbalanced for handedness so the majority of motor activity related to the physical execution of button presses can be averaged out

across individuals. Once the thresholding task was finished, participants completed one half of the face/house localizer task so the researcher could confirm that they understood how to follow task instructions. The localizer task was a simple 1-back task that involved showing participants a series of face or house images. They were responsible for indicating when they saw the exact same face or house twice in a row by pushing the assigned button. Each image was on screen for 0.75 seconds, and each presentation within a block was separated by a 0.25-second fixation. There were a total of 6 blocks of stimuli (3 face, 3 house), and each was separated by a 15-second fixation period. This 1-back task format was used to encourage attention to the stimuli throughout the scan. The localizer was used to identify regions of interest for fMRI analyses. The participants then exited the mock fMRI scanner, the table was cleaned, and they were given their Session 2 Instruction Sheet (Appendix D) and fMRI safety paperwork (Appendix E) to complete.

For the second session, after safety paperwork was reviewed and those with glasses were given an fMRI-safe pair that matched their prescription, each individual completed 1 run of the localizer task and 1 run of the decision-making task. Practicing before they entered the scanner served several purposes: it confirmed that the participant remembered which hand was associated with which response, ensured that he or she understood all instructions, and permitted additional time for questions. Once the participants confirmed that they understood the task and appeared to be responding properly, they were brought to the fMRI suite and set-up for their scan (fitted with ear plugs, provided with pillows and blankets, etc). Next was the structural portion of the scan that took approximately 15 minutes wherein participants were told to relax, remain still, and view a silent fish tank video (Cat Trumpet, 2015).

After the structural series, the participants first completed 12 blocks of the localizer task (6 face, 6 house). Then participants were then given a reminder about the instructions for the decision-making task and completed 7 runs that were each approximately 8 minutes in length. There were a total of 280 trials across these 7 runs. 25% of these were the cue phase-only catch trials. The 210 remaining trials were compound trials consisting of a cue and a task phase, divided into three conditions based on cue validity: valid, invalid, and neutral. Valid trials occurred when the cue phase matched the subsequent task phase. For example, when a person was shown 80H during the cue phase and a house image during the task phase, they completed a valid house trial (the phases do not conflict). Invalid trials occurred when the cue phase did not match the subsequent task phase. For example, when a person is shown 80F during cue phase and a house image during the task phase, they completed an invalid house trial (the phases conflict). Neutral trials are 50/50 probabilities with a 50N cue shown before either a face or house image. Participants were correctly informed that the probabilities were accurate.

Taken together, there were a total of 7 types of conditions across the 240 trials: 60 catch trials, 48 valid face, 48 valid house, 12 invalid face, 12 invalid house, 30 neutral face, and 30 neutral house. These trial counts were selected to maintain the meaningfulness of the cues and maintain a scan/set-up time of approximately 90 minutes. Time in the scanner is a particular concern for older adults who are more likely to experience physical discomfort from extended periods of stillness. In hindsight, 12 trials in the invalid face and house conditions was insufficient for meaningful imaging analysis of those trials because the fMRI signal-to-noise ratio was too low (and, as a result, the standard error for percent change is excessively high). As such, though still important to

consider in terms of behavioral data, the invalid condition is excluded from all subsequent imaging analyses. The entire scan time (not including set-up) is approximately 75 minutes.

After the scan was complete, the participants were removed from the scanner and immediately completed a National Aeronautics and Space Administration Task Load Index (NASA TLX). The NASA TLX is a measure of cognitive load and includes questions about self-reported performance, stress, and demand on Likert scales (Hart & Staveland, 1988). That inventory took approximately 1 minute to complete. The participants were then thanked for their time, provided with a debriefing form (Appendix F), given instructions about how to use their brain image disk, and paid.

3.6 Functional Magnetic Resonance Imaging Pre-Processing

Imaging data were first pre-processed using proprietary scripts developed by Avi Snyder in the Departments of Radiology and Neurology at the University of Washington in St. Louis (Dunovan & Wheeler, 2018, Ollinger, Shulman, & Corbetta, 2001; Ollinger, Corbetta, & Shulman, 2001). Preprocessing included correction for slice timing differences across interleaved slices, motion correction, and normalization to a mode of 1000 in order to support inter-subject comparisons (Dunovan & Wheeler, 2018; Ojemann, et al., 1997). The functional images were then transformed to a common atlas space using a custom template based on a combination of older and younger adult whole-brain images for group analyses.

3.7 General Linear Models

Pre-processed imaging data were first analyzed using single-subject general linear models in Fidl (Ollinger, Shulman, & Corbetta, 2001; Ollinger, Corbetta, & Shulman, 2001). For each "compound trial" consisting of a cue and task phase, each phase was coded as a separate event of interest. The cue phase events for each cue type (80F, 80H, 50N) were combined with catch trial events of the same type (80F, 80H, 50N). Thus, the model included the following cue phase events collapsed across catch and compound trials: 80F cue, 80H cue, 50N cue. The model also included the following task phase events: valid trial, neutral trial. Note again that the invalid trials were excluded from the model. The cue phase and task phases are distinguished from one another in the hemodynamic response functions by coding them as separate regressors in the general linear model: 80H cue, 80F cue. 50N cue, valid response period, and neutral response period. Catch trials were included in the cue regressor, and that helped distinguish overlapping signals associated with the cue and task periods. The hemodynamic responses were modeled using a finite impulse response function that estimates effects across 18 time points (TR=1.5 seconds). This approach allows us to evaluate how each condition uniquely influences the shape of the hemodynamic response.

3.8 Inferior Temporal Cortex Regions of Interest

To address the imaging hypotheses, BOLD response functions were analyzed within the context of regions of interest in the ITC. Using the face/house localizer task scans, a 2 (STIMULUS: face, house) x 18 (TIME: 1-18) group level repeated measures ANOVA was calculated in each voxel for the whole brain image in 222 space. This analysis produced a set of uncorrected and corrected images for each term in the model,

which included the main effect of time and the interaction of stimulus and time. A main effect of time is present when the time series deviates from the GLM baseline term during the task (regardless of condition), and an interaction of stimulus with time occurs as a function of the stimulus type (face versus house) over time. The main effect of stimulus type was discarded because it does not yield useful time information. Each statistical image included a voxelwise F value from the ANOVA transformed to a Z-statistic. The corrected images included corrections for sphericity and for multiple comparisons using Monte Carlo simulations. The result is a face vs. house two-tailed uncorrected z-map, and a Monte Carlo corrected and sphericity adjusted z-map. Next, regions of interest were derived from the stimulus x time image. The uncorrected z-map image was smoothed using a Gaussian kernel to 4mm width at half maximum. Then, using the corrected and sphericity adjusted image as an exclusion mask, a distinct region was classified as such if it was at least 10 mm in size, at least 10 mm away from neighboring regions (if closer, they are clustered as the same), had a z-score value that is greater than 1.65 or less than -1.65, and was also present in the corrected image. Thus, the final ROI included only voxels that passed corrections for multiple comparisons and sphericity. From that output, a region is only retained if it was at least 45 voxels in size, based on the voxel extent used in the Monte Carlo corrections. This approach yielded a total of 13 regions of interest.

An additional data quality assurance check was also conducted on the timeseries data within these 13 regions before proceeding to formal a-priori hypothesis testing. This process involved visually reviewing the timeseries data and looking for abnormally high, low, or noisy percent change values. Particular attention was paid to regions located near

the edge of the brain because, even though the images are transformed into atlas space using the same template, sometimes individuals' data can still be cut off if it is too close to the skull. An additional 3 regions were removed at this stage because, due to the fact they were close to the edge of the brain, the timeseries data for more than half of the participants was completely flat or noisily high (600%+ signal change with sawtooth-like fluctuations). 10 regions were included in the subsequent analyses and will be examined individually (Figure 10, Table 3).

Regions were then classified as either face or house preferential using a series of two-sample two-tailed t-tests with unequal variances assumed. Time series data was first extracted using the same procedure outlined in section "3.7 General Linear Models." Then, mean peak percent signal change for the house trials was compared to the mean peak percent signal change for the face trials within each ROI. ROIs that have a significantly higher percent signal change for face trials are labeled "face preferential," while ROIs that have a significantly higher percent signal change for the house trials are labeled "house preferential." Those that did not differ as a function of stimulus type were labeled "neither."

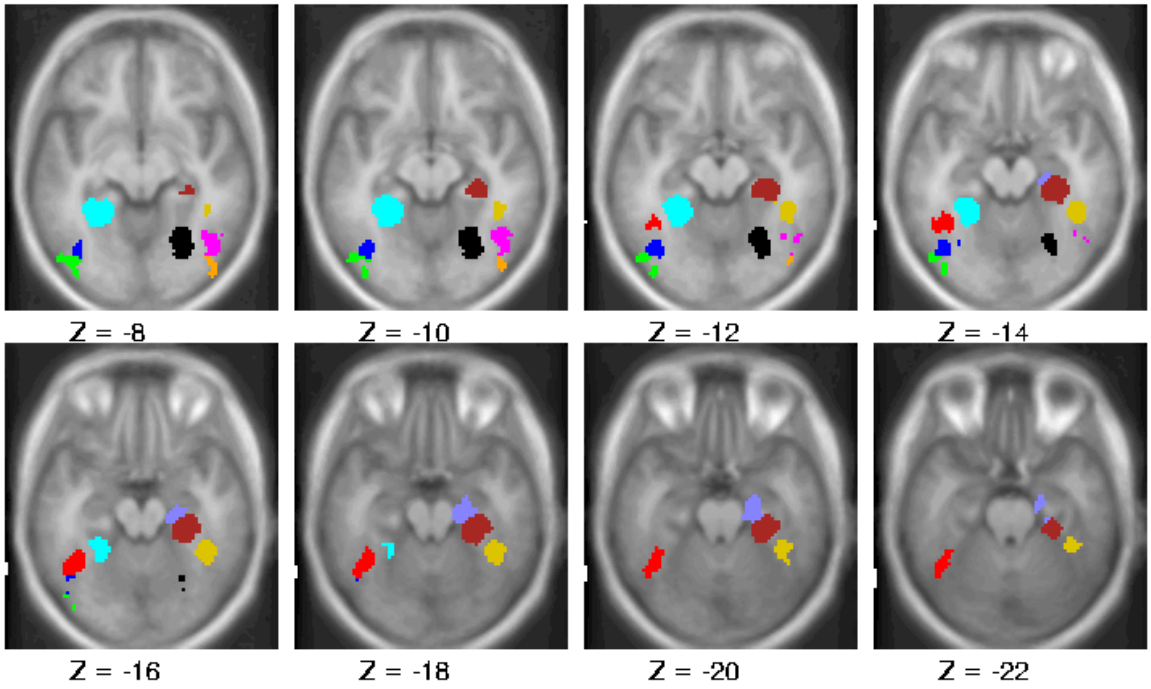


FIGURE 10: Regions of interest identified via the localizer task.

TABLE 3: Characteristics of ROIs identified via the localizer task: the associated coordinates, voxel numbers, preferentiality classifications, anatomical structures, and Broadman areas (BAs).

region	x	y	z	voxels	potential preferentiality	anatomical structure	Broadman area (BA)
1	41	-46	-17	241	face	fusiform face area (R)	31
2	-42	-54	-20	249	face	fusiform face area (L)	37
3	-43	-79	-8	165	neither	extrastriate cortex (L)	19
4	-39	-69	-11	90	neither	fusiform face area (L)	19
5	45	-81	-5	92	neither	extrastriate cortex (R)	19
7	45	-66	-8	110	neither	fusiform face area (R)	19
9	-26	-46	-10	441	house	parahippocampal place area (L)	37
10	29	-34	-17	365	house	parahippocampal place area (R)	37
11	26	-66	-8	351	house	parahippocampal place area (R)	37
12	20	-21	-19	137	house	parahippocampal place area (R)	36

CHAPTER 4:
RESULTS

Using the data collected via the protocol above, this write-up now addresses the specific hypotheses of interest. This starts with a review of the thresholding and MLCST scores, followed by behavioral data, following by imaging data, and ending with the NASA-TLX and strategy post-survey.

4.1 Psychophysical Thresholding and Contrast Sensitivity Scores

As stated previously, the noise level of the mask was adjusted on a subject-by-subject basis to be more or less noisy. That difficulty adjustment aimed to produce 80% discrimination accuracy across all individuals. Broadly, the stimuli for this experiment are comprised of 2 simultaneously operating visual components— face/house image and dynamic Gaussian noise. Noise levels could vary from 0-100%. For example, a score of 33.5 means having stimuli that are 33.5% image and 66.5% dynamic Gaussian noise. Higher scores are associated with less visual noise and are easier to see, and lower scores are associated with more visual noise and are more difficult to see.

In the interest of understanding the age group thresholding data overall, it is first worthwhile to determine if there are any overarching differences between the group threshold score means and variances. As is reflected in a set of box plots divided by age (Figure 11), there were no statistical outliers in this dataset for either age group. The scores for the older adults were quantitatively higher overall, though there was some overlap around the grand mean. Unsurprisingly, the sample mean threshold for the older

adult group (M = 32.08, SD = 1.34, range: 30.39-34.54) was higher than that of the younger adult group (M = 30.28, SD = .80, range: 28.61-31.63).

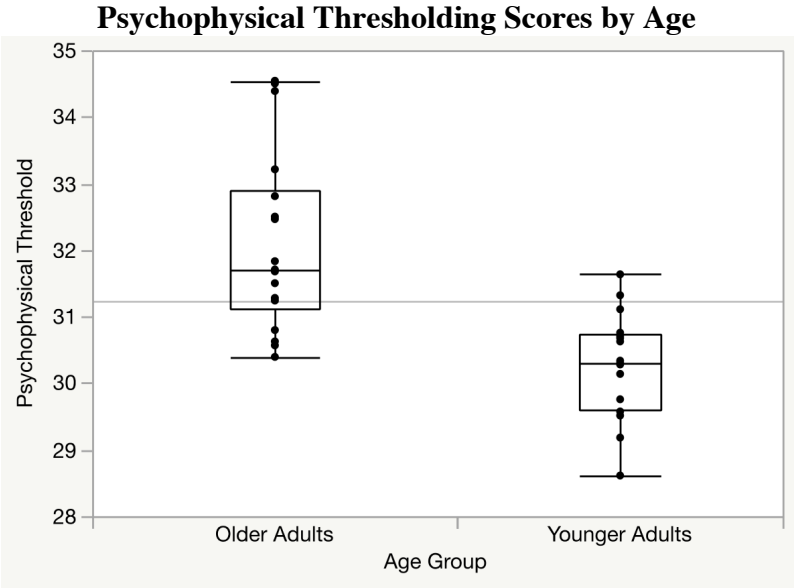


FIGURE 11: Box and whisker plots for Psychophysical Threshold Scores indicated that no groups have any statistical outliers. A qualitative review indicated that older adults appear to have higher scores and be more variable than the younger adult group.

A two-sample two-tailed t-test with equal variances not assumed was conducted to determine if the age groups' threshold scores differed significantly. This test revealed that older adults scored significantly higher than younger adults overall ($t(28.25) = -4.81$, $p < .0001$). A Levene's F-test for equality of variances confirmed that older adults were also more variable than younger adults ($F(1, 32) = 4.76$, $p < .05$). Though the approximately 2% difference between the mean values for these groups may seem small upon first glance, the difference can be appreciated when reviewing the stimuli side-by-side (Figure 12).

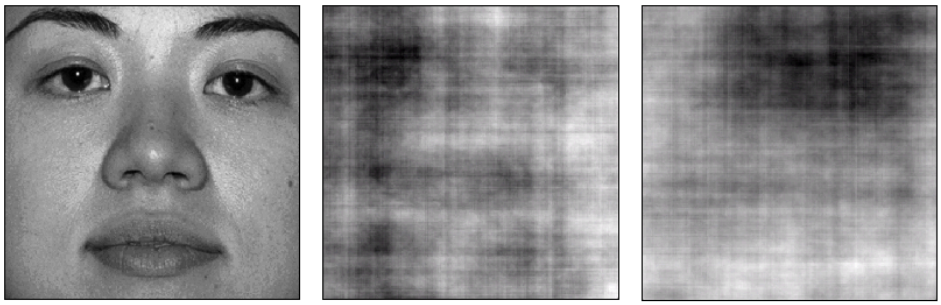


FIGURE 12: From left to right: An example of a face image that is comprised of 100% image/0% noise, that same face configured with older adults' average of 32.00% image/68% noise, and again configured with the younger adults' average of 30.25% image/69.75% noise. The stimuli comprised of the older adults' average threshold score is easier to see in this static viewing, and even more so when the noise is dynamically presented during the experiment.

The next step was to test for age effects in MLCST scores. Higher scores on this test were indicative of better visual acuity and contrast sensitivity, and lower scores were indicative of relatively poorer visual acuity and contrast sensitivity. As was reflected in a set of box and whisker plots divided by age (Figure 13), there were no statistical outliers in this dataset for either age group. The sample mean for the younger adult group (M = 1.79, SD = .07, range: 1.64-1.88) was higher than that of the older adult group (M = 1.51, SD = 0.22, range: 1.20-1.80). The older adult group also appeared to have scored so lowly and so variably that the grand mean has been pulled downwards, creating a situation in which no younger adult scored at or below it.

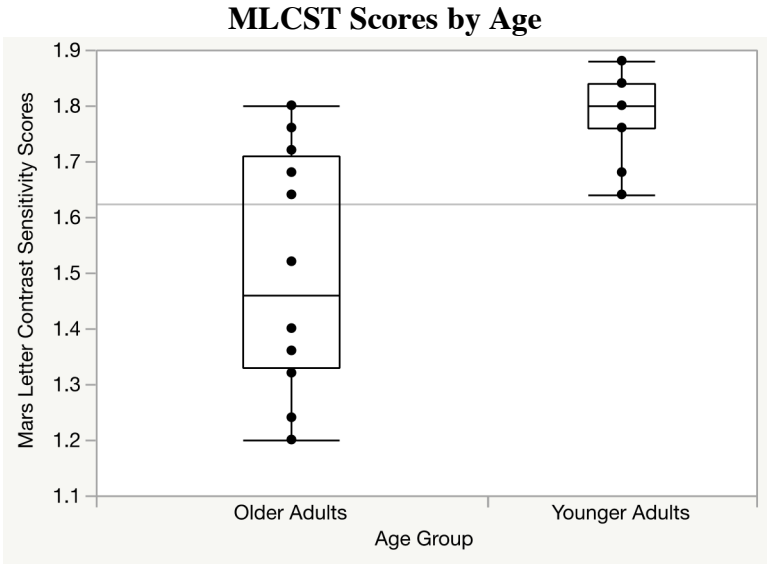


FIGURE 13: Box and whisker plots for Mars Letter Contrast Sensitivity scores indicated that no groups have any statistical outliers. A qualitative review indicated that older adults appear to have lower scores and be more variable than the younger adult group.

A two-sample two-tailed t-test with equal variances not assumed was conducted to determine if the age groups' MLCST scores differed significantly from one another. Older adults scored significantly lower than younger adults ($t(20.04) = 4.82, p < .0001$). A Levene's F-test for equality of variances confirmed that older adults were also more variable than younger adults ($F(1, 32) = 20.83, p < .0001$).

Given these age-related findings across two seemingly independent measures of visual ability, the next step was to test the hypothesis that the thresholding task and MLCST might actually be measuring related concepts. In order to get at this question in a broad manner using the data available, a bivariate correlation was computed between these scores. When collapsed across age groups, the two variables have a statistically

significant negative linear relationship with one another ($r(32) = -.45, p < .05$). The strength of this relationship is moderate (Figure 14).

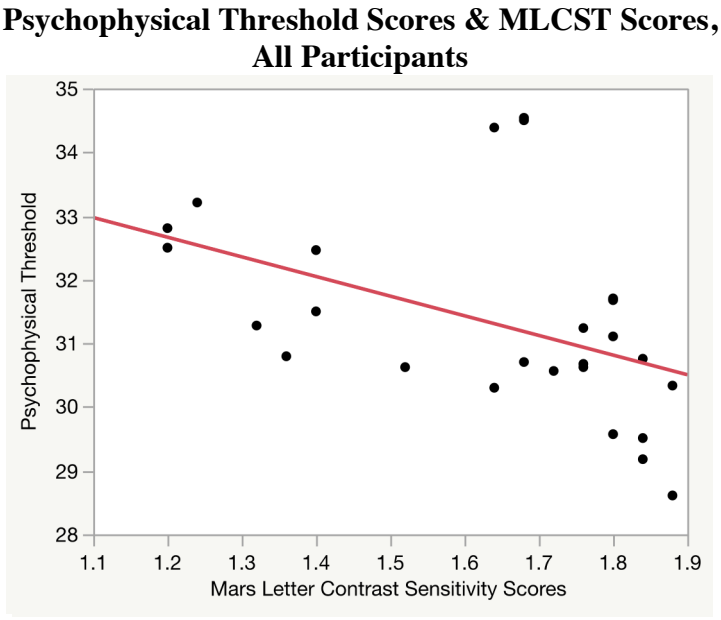
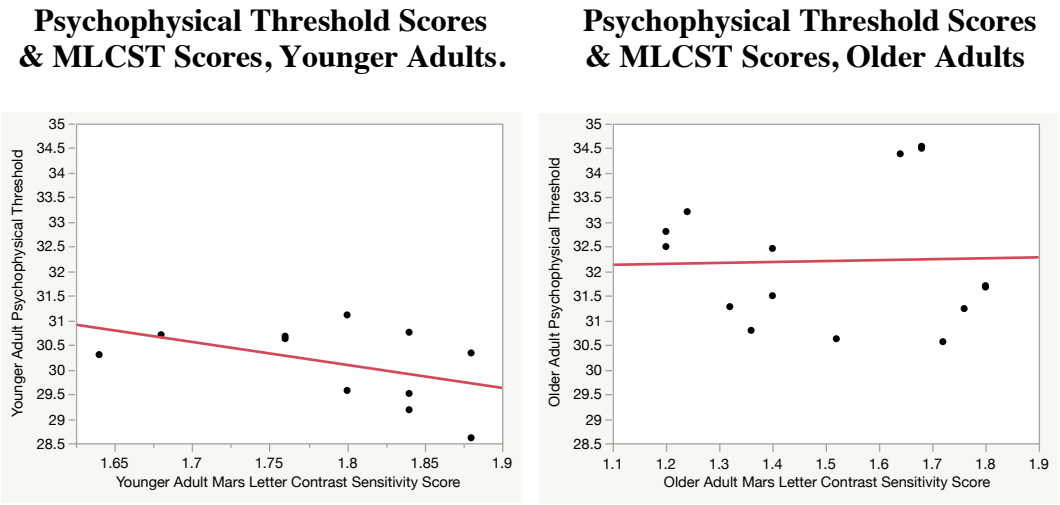


FIGURE 14: There was a moderately strong negative correlation between Mars Letter Contrast Sensitivity scores and Psychophysical Thresholds when collapsed across the age groups.

For exploratory purposes, this relationship was also tested within each age group (Figure 15). There was a moderately negative non-significant correlation between threshold values and MLCST scores in the younger group ($r(14) = -.46, p = .15$), and no correlation between threshold values and MLCST scores for the older adult group ($r(16) = .03, p = .91$). After transforming the r values into Fisher's z values and conducting a z-test to compare the correlations, it was determined that the linear relationships within each age group were not statistically different from one another ($z = 1.11, p = .13$).



A B

FIGURE 15: There was a moderately negative correlation between MLCST and Psychophysical Thresholds for the younger adult group (A). There was no correlation between MLCST scores and Physical Thresholds for the older adult group (B). Neither finding was statistically significant.

4.2 Face-House Classification Task: Behavioral Results

Now that the presence of an age-related sensory confound has been established and explored, the next step is to assess how well the psychophysical thresholding task worked when controlling for visual noise levels in the fMRI design. The pilot experiment touched on this question, but the older adult sample used at that stage was small. Scores were also applied in a non-scanning environment with fewer trials. To assess the current protocol, it was important to first get a general sense of how age groups compare in terms of overall accuracy and variability.

The first dependent variable from the decision-making task was overall percent correct collapsed across all conditions within age groups. The influence of cue validity will be described in subsequent analyses. The older adults ($M = 71.58$, $SD = 3.00$) had an

approximately 3.90% higher mean percent correct than the younger adults (M = 67.99, SD = 3.18). However, both of the means were still hovering around approximately 70% (Figure 16). This was lower than the 80% target accuracy of the thresholding task, though not unexpected when transitioning to an fMRI environment. A two-sample two-tailed t-test with equality of variances not assumed showed that older adults and younger adults' overall accuracy did not statistically differ from one another ($t(31.36) = -.62, p = .53$). A Levene's F-test for equality of variances likewise found no difference between age groups ($F(1, 32) = .17$, p = .67).

Overall Accuracy Collapsed Across Validity Conditions, Main Effect of Age

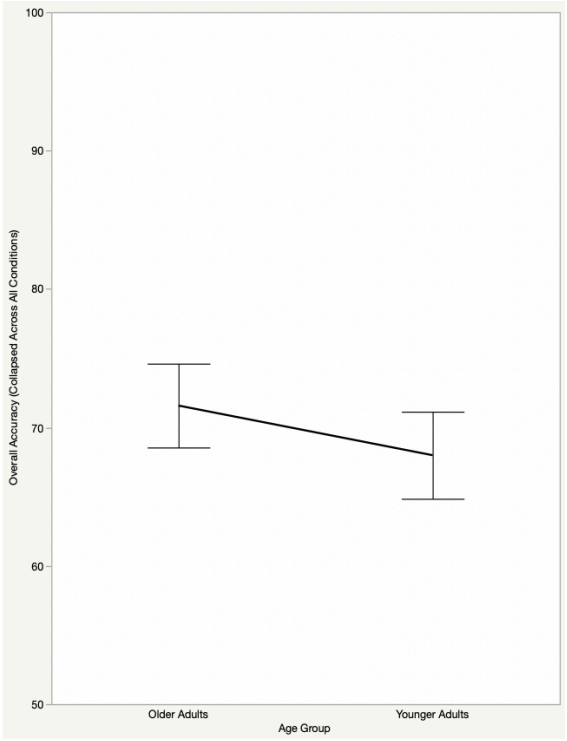


FIGURE 16: The means plot for older and younger adults' overall accuracy scores. Accuracy is collapsed across all conditions.

Next, that percent correct dependent variable is examined on the basis of both age and cue validity. This is done to assess if individuals appear to be responding to the cues in an informative manner. Past work with a similar design suggests that younger adults should attend to the cues, but it is unclear if or how that is the case for older adults (Dunovan & Wheeler, 2018). A 2 (AGE: younger, older) x 3 (VALIDITY: valid, invalid, neutral) mixed univariate ANOVA with a Greenhouse-Geisser correction for sphericity indeed found a significant main effect for validity ($F(1.25, 40.13) = 30.61, p < .0001$). There was no main effect of age ($F(1, 32) = .76, p = .39$), and the age x validity

interaction ($F(1.25, 40.13) = .74, p = .35$) was also not significant. Within the main effect of validity, a series of post-hoc Bonferroni corrected paired t-tests for multiple comparisons were conducted. In alignment with previous work, participants had the highest percent correct for valid condition, followed by neutral, followed by invalid (Figure 17),

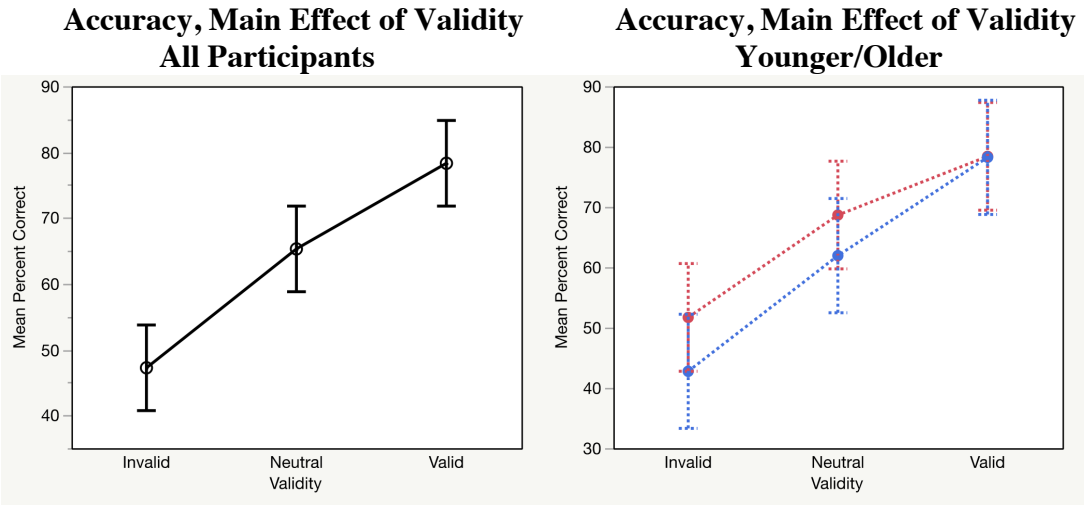


FIGURE 17: For all participants (black), the invalid condition is associated with the lowest percent correct, followed by neutral, followed by valid. All are statistically different from one another. This is the case for both age groups, as younger adults (blue) and older adults (red) did not statistically differ from one another.

Now that accuracy has been addressed in relation to age and validity, the next step was to determine if these groups differed in overall reaction time. This information is useful because, in addition to gaining insight into overarching data trends, there are some expected findings that are important to consider. For example, the concept of age-related general slowing suggests that older adults should not have shorter mean RTs than

younger adults on the same task. Opposite findings would suggest that there might be something unusual about these samples.

The dependent variable was overall average RT in seconds collapsed across all conditions within age groups. The influence of cue validity will be accounted for in subsequent analyses. The younger adults ($M = 2.58$, $SD = .63$) had an overall RT sample mean that was approximately .14 seconds faster than that of older adults ($M = 2.72$, $SD = .75$; Figure 18). A two-sample two-tailed t-test with equality of variance not assumed indicated that older adults and younger adults did not differ significantly ($t(31.92) = -.59$, $p = .56$). A Levene's F-test for equality of variances showed that the group variances also do not differ ($F(1, 32) = .88$, $p = .35$).

Overall RT Collapsed Across Validity Conditions, Main Effect of Age

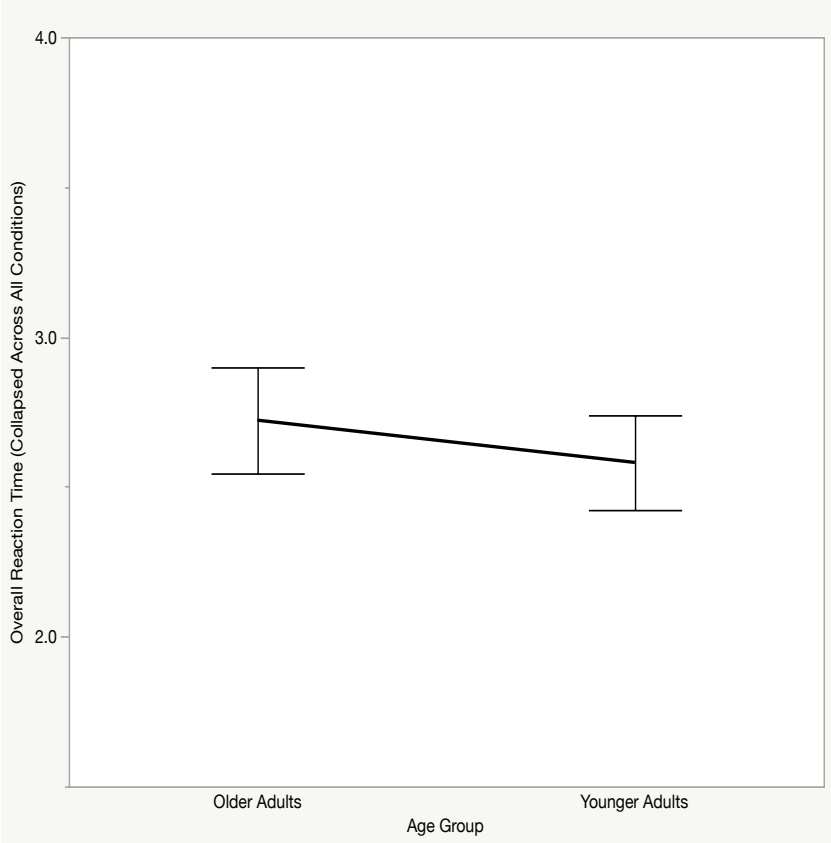


FIGURE 18: The means plot for older and younger adults' overall accuracy scores. Accuracy is collapsed across all conditions.

These results showed that both younger and older adults are responding at similar speeds during the task overall, so the next step was to consider the influence of validity on RT. Based on previous research and the theoretical framework provided by evidence accumulation models, it was hypothesized that younger adults would utilize the cues more readily and respond most quickly to valid trials, followed by neutral trials, followed by invalid trials. Meanwhile, the older adults would hold their RTs constant across

conditions. A 2 (AGE: younger, older) x 3 (VALIDITY: valid, invalid, neutral) mixed univariate ANOVA with a Greenhouse-Geisser correction for sphericity and mean RT as the dependent variable found a main effect for validity ($F(2, 63.09) = 6.8, p < .05$). The main effect of age ($F(1, 32) = .46, p = .51$) and age x validity interaction ($F(2, 63.09) = .96, p = .39$) were not significant. A series of Bonferroni-corrected post-hoc paired t-tests for multiple comparisons were conducted. For the younger adults, valid trials resulted in significantly shorter RTs than invalid trials. The neutral condition was in between valid and invalid, but not statistically different from either. For the older adults, the neutral and valid conditions mean RTs did not differ from one another, but both were associated with lower RTs than the invalid condition (Figure 19).

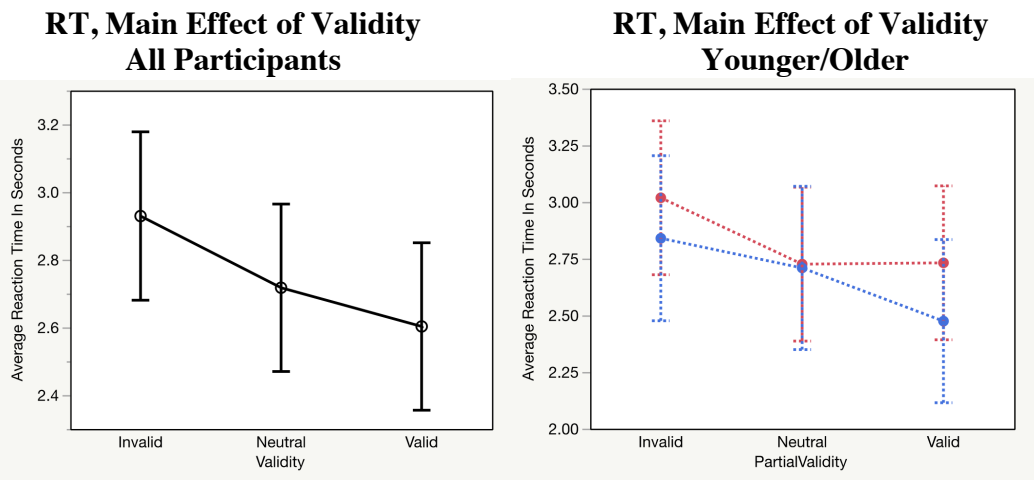


FIGURE 19: The means plots for all participants (black) show that the valid condition is associated with the shortest reaction time, followed by neutral, followed by valid. The valid condition is significantly shorter than the invalid condition. This is the case for both younger adults (blue) and older adults (red).

Next, RT distributions for each group were reviewed. For a relatively low-temporal resolution fMRI study to work properly, RTs should be distributed over many seconds instead of clustered around zero. The response window for the face-house classification task was six seconds, and that was further divided into four time bins in 1.5 TR increments. To qualitatively assess RT distributions, a histogram of RTs divided by TR time bin was generated for all participants combined, the younger adults, and the older adults respectively. Ideally, bins would contain the same number of trials (i.e., flat distribution across TRs). As illustrated in Figure 20, the RTs were spread out across the six-second response window with more responses in the first than second half of the trials. While not ideally distributed (flat), the spread is sufficient for fMRI analyses (i.e., enough trials in shorter and longer RT bins to yield sufficient power).

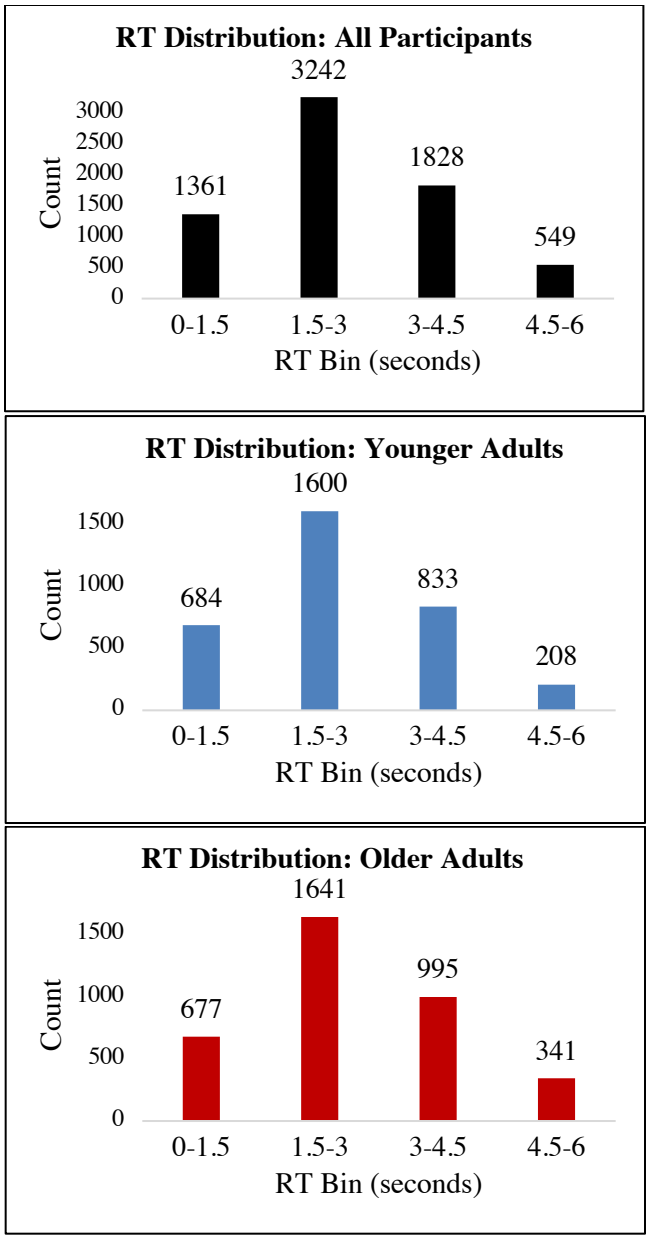


FIGURE 20: Overall reaction time distributions for the face-house classification task for all participants (black), younger adults (blue), and older adults (red). All are roughly normal and meet the standards of this quality control check.

4.3 Face-House Classification Task: Functional Magnetic Resonance Imaging Results

Thus far, these data show that a valid expectation increases accuracy and decreases speed, while an invalid expectation has the opposite effects. These findings were expected in the younger adult sample. However, both groups performed similarly and the predictions that older adults would disregard cues and favor conservatism over flexibility in choice criterion were not supported. The next stages of analyses aimed to determine how these trends held at the neural level in the ITC. First, trials were divided into 2 components for imaging analyses: the cue phase and the task phase. Each are modeled using the procedure outlined in section "3.7 General Linear Models." These components are examined separately in order to attempt to separate top-down anticipation and bottom-up evidence accumulation within the ITC, as well as maximize the catch-trial design that separates overlapping activation.

For the cue phase, it was hypothesized that there would be more BOLD activity in these regions for the younger adult group because they are more readily engaging with the cues, while older adults would show less BOLD activity because they are relatively inflexible to criterion shifts. 3 levels of the cue were compared: 80% face (80F), 50% neutral (50N), and 80% house (80H). A series of individual 2 (AGE: younger, older) x 3 (CUE: face, house, neutral) univariate mixed sphericity-corrected ANOVAs were conducted in each region with percent BOLD signal change as the dependent variable (Table 4). Multiple comparison tests were done with a series of Bonferroni-corrected paired t-tests.

TABLE 4: Imaging results for the cue phase using a 2 (AGE: younger, older) x CUE (face, house, neutral) mixed ANOVA. Percent change in BOLD signal magnitude is the dependent variable.

region	x	y	z	vox	FH prefer.	anatomical structure	BA	Age	Cue	Age x Cue
1	41	-46	-17	241	face	fusiform face area (R)	31	n.s.	n.s.	n.s.
2	-42	-54	-20	249	face	fusiform face area (L)	37	F=9.53*	n.s.	n.s.
3	-43	-79	-8	165	neither	extrastriate cortex (L)	19	F=9.73*	n.s.	n.s.
4	-39	-69	-11	90	neither	fusiform face area (L)	19	F=5.53*	n.s.	n.s.
5	45	-81	-5	92	neither	extrastriate cortex (R)	19	F=5.04*	n.s.	n.s.
7	45	-66	-8	110	neither	fusiform face area (R)	19	n.s.	F=3.83*	n.s.
9	-26	-46	-10	441	house	parahippocampal place area (L)	37	n.s.	n.s.	n.s.
10	29	-34	-17	365	house	parahippocampal place area (R)	37	n.s.	n.s.	n.s.
11	26	-66	-8	351	house	parahippocampal place area (R)	37	n.s.	F=9.01***	n.s.
12	20	-21	-19	137	house	parahippocampal place area (R)	36	n.s.	n.s.	n.s.

* = significant at the .05 level
** = significant at the .01 level
*** = significant at the .001 level
n.s. = not significant

Four ROIs presented a significant main effect of age during the cue phase and, unexpectedly, older adults had a higher BOLD signal change in all of them (Figure 21). Two ROIs were located in the extrastriate cortex (EC), which is an occipital visual

processing region rostral to the primary visual cortex. The remaining two ROIs were located within the fusiform face area (FFA)—a region often implicated in face processing, object recognition, and evidence accumulation.

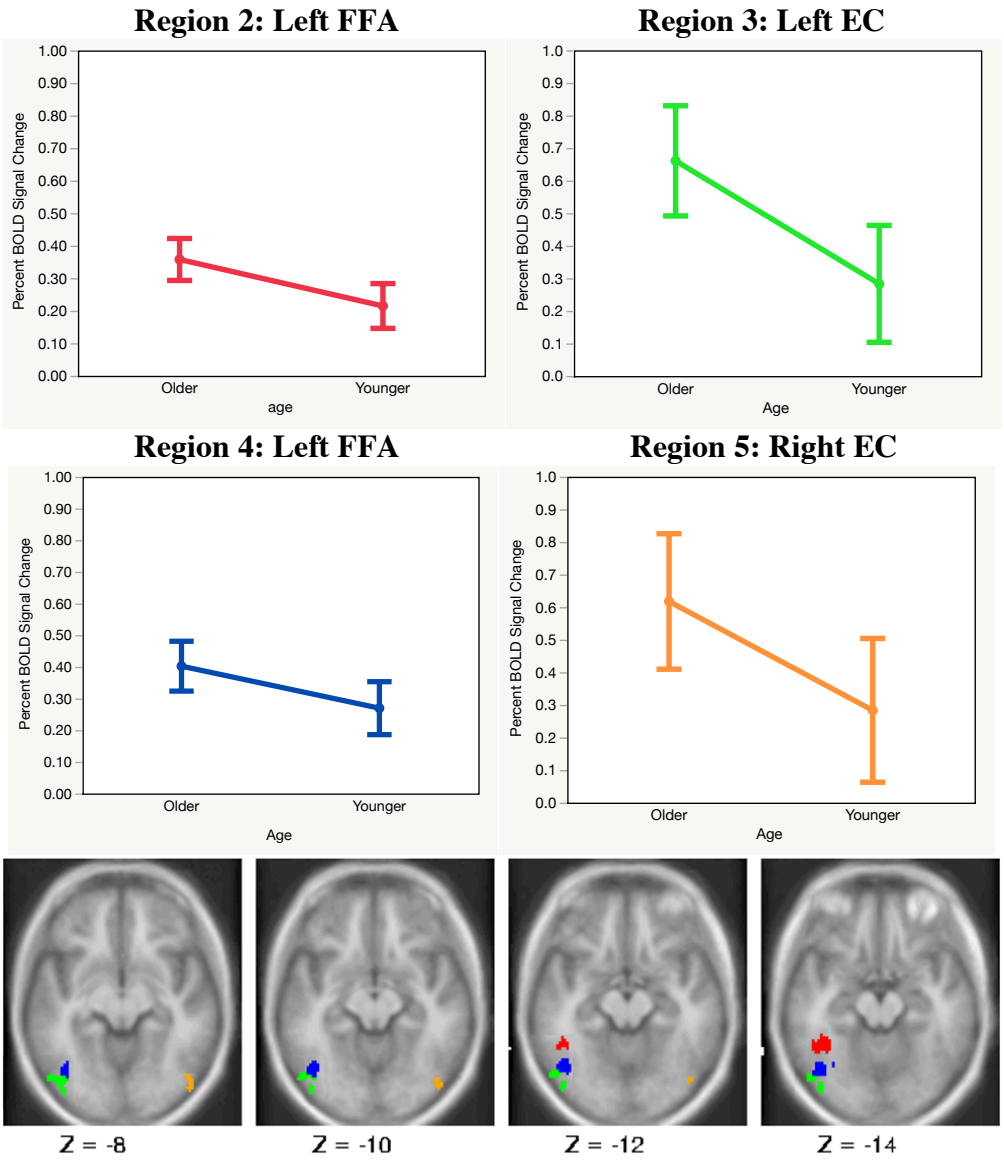


FIGURE 21: Axial slices of the extrastriate (green, orange) and FFA (red, blue) ROIs that show a main effect of age during the cue phase.

For the main effect of cue type (face, house, neutral), there were two regions that show statistically different activation (Figure 22). The first was located in the fusiform face area (FFA) and the second was located in the parahippocampal place area (PPA), and both presented higher activity for house cues compared to the face or neutral cues. There were no age x cue interaction effects during the cue phase.

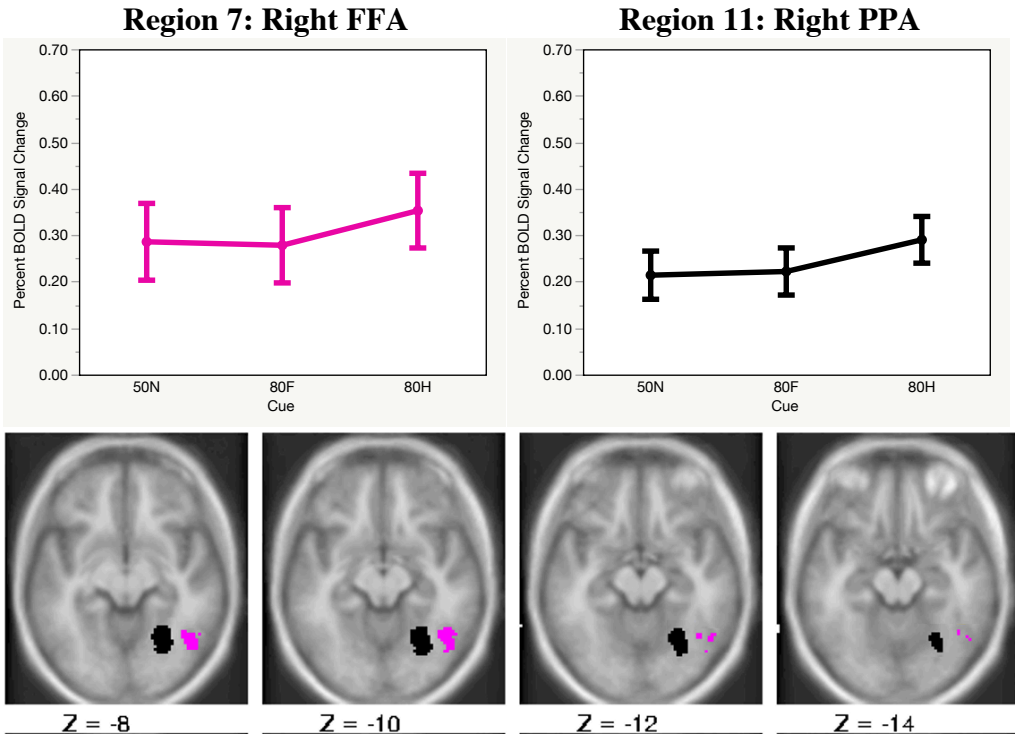


FIGURE 22: Axial slices of the FFA (pink) and PPA (black) ROIs that show a main effect of cue during the cue phase.

Now that the cue phase has been addressed, a similar analysis approach was taken for the task phase. A series of individual 2 (AGE: younger, older) x 2 (VALIDITY: valid, neutral) univariate mixed sphericity-corrected ANOVAs were conducted in each region with percent BOLD signal change as the dependent variable (Table 5). Multiple

comparison tests were done with a series of Bonferroni-corrected paired t-tests.

TABLE 5: Imaging results for the task phase using 2 (AGE: younger, older) x 2 VALIDITY: invalid, neutral) mixed ANOVAs. Percent change in BOLD signal magnitude is the dependent variable.

region	x	y	z	vox	FH	anatomical structure	BA	Age	Validity	Age x Val
1	41	-46	-17	241	face	fusiform face area (R)	31	n.s.	F=12.95**	n.s.
2	-42	-54	-20	249	face	fusiform face area (L)	37	n.s.	F=6.62*	n.s.
3	-43	-79	-8	165	neither	extrastriate cortex (L)	19	F=4.94*	n.s.	n.s.
4	-39	-69	-11	90	neither	fusiform face area (L)	19	n.s.	n.s.	n.s.
5	45	-81	-5	92	neither	extrastriate cortex (R)	19	n.s	n.s.	n.s.
7	45	-66	-8	110	neither	fusiform face area (R)	19	F=6.89*	F=8.10**	F=4.93*
9	-26	-46	-10	441	house	parahippocampal place area (L)	37	F=11.77**	F=23.61***	F=19.78***
10	29	-34	-17	365	house	parahippocampal place area (R)	37	n.s.	n.s.	n.s.
11	26	-66	-8	351	house	parahippocampal place area (R)	37	n.s.	F=7.26*	n.s.
12	20	-21	-19	137	house	parahippocampal place area (R)	36	n.s.	n.s.	n.s.

* = significant at the .05 level
** = significant at the .01 level
*** = significant at the .001 level
n.s. = not significant

A significant main effect for age was observed in 3 ROIs (Figure 23). The first was located in the extrastriate cortex, and, in alignment with the findings from cue phase data, older adults showed a higher percent BOLD signal change relative to younger adults. The second ROI was located in the right fusiform face area and showed more activity for younger adults relative to older adults. The third region was located in the parahippocampal place area and also showed more activity for younger adults relative to older adults.

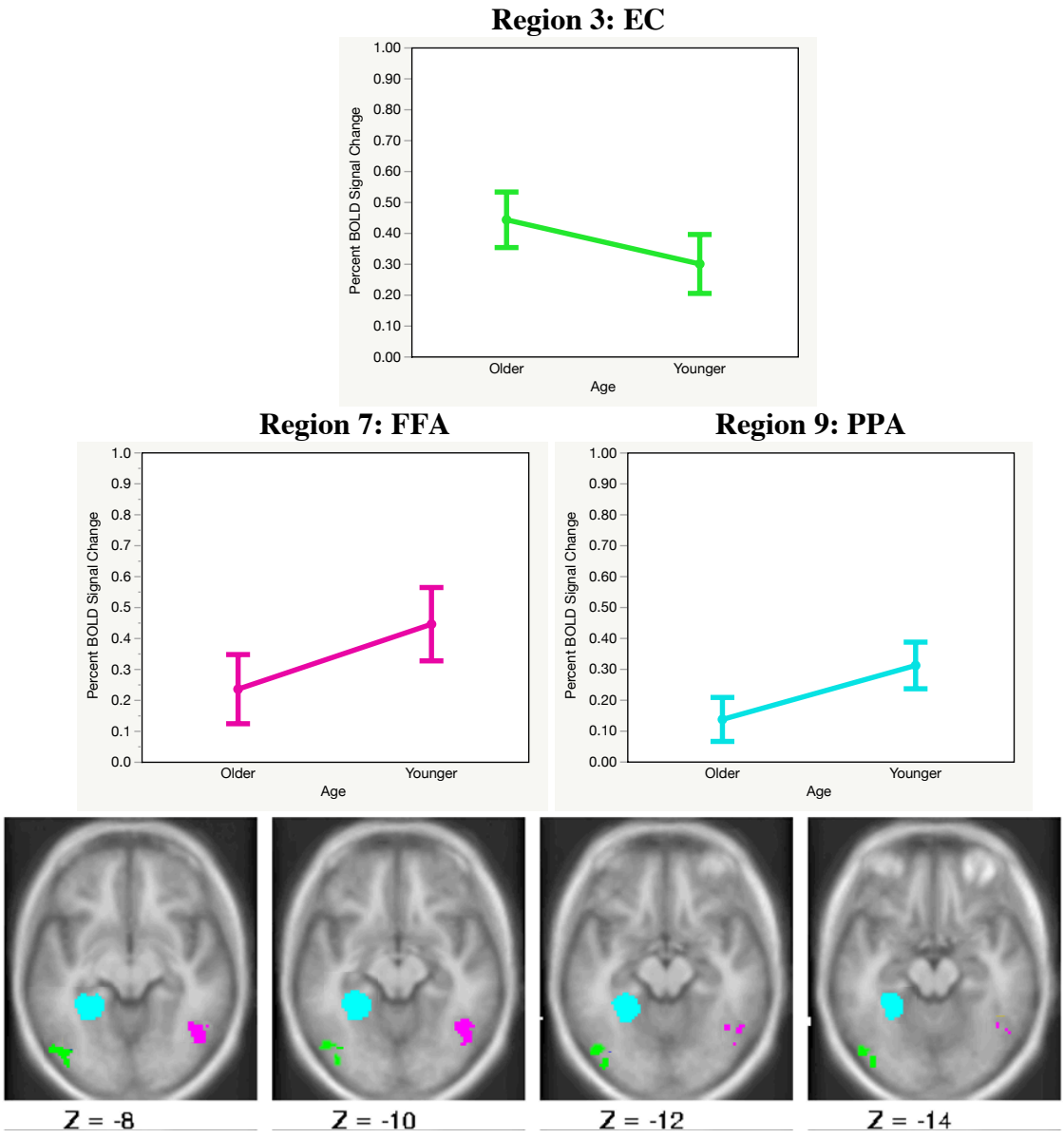


FIGURE 23: Axial slices of the regions that show a main effect age during the task phase in the EC (green), FFA (pink), and PPA (teal).

A significant main effect for validity was observed in 5 ROIs. These are located in the FFA and PPA (Figure 24). In all of these regions, the neutral condition is

associated with a higher percent change than the valid condition. These findings replicate the results of previous young adult work (Dunovan & Wheeler, 2018).

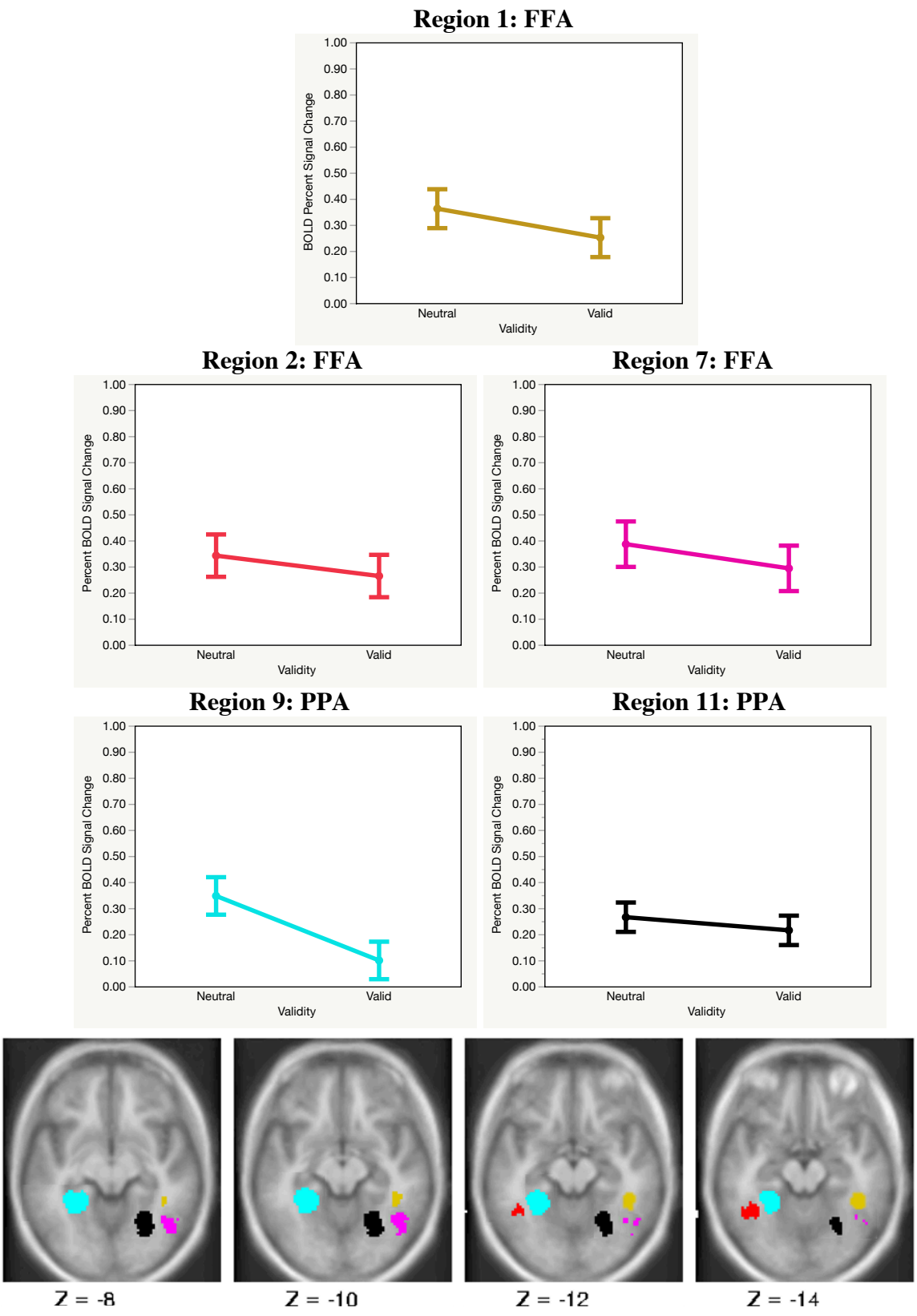


FIGURE 24: Axial slices of regions that show a main effect of validity in FFA (gold, red, pink) and PPA (teal, black) during the task phase.

There are also 2 ROIs which have a significant interaction effect (Figure 31). One was located within FFA and the other within the PPA. Younger adults showed increased BOLD activity for the neutral condition relative to the valid condition. Older adults' BOLD activity was constant across both levels of validity (Figure 25).

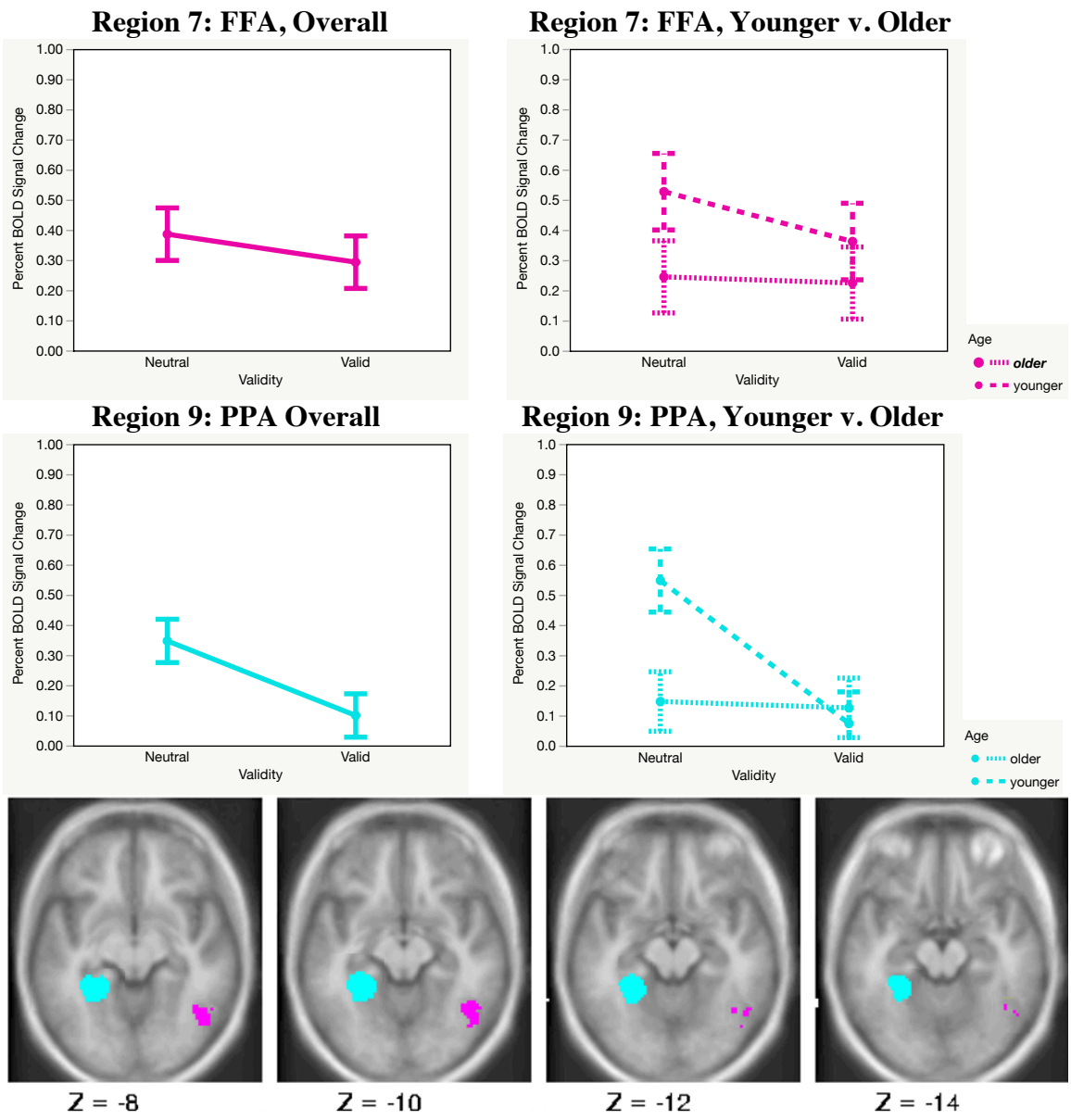


FIGURE 25: Axial slices of regions that show an interaction effect of age x validity in FFA (pink) and PPA (teal) during the task phase.

4.4 Face-House Classification Task: NASA TLX and Strategy Results

The final analysis step was to address the post-experiment surveys. For the NASA Task Load Index (NASA TLX) measure of cognitive load described in "Chapter 3: Methodology," it was hypothesized that, due to general age-related changes in physical

factors along with older adults' bias conservatism, older adults would present higher ratings on all scales (mental demand, physical demand, temporal demand, effort, and frustration). The only exception being the performance scale, as that factor would be controlled for across age groups by the psychophysical thresholding task. A one-way MANOVA was conducted to compare the older and younger adult groups on each of the six dependent variable scores, and the model was not significant ($F(6,27) = 2.09$, $p = .37$, Wilk's $\lambda = .64$, partial $\eta^2 = .37$).

After completing the NASA TLX, participants were given a survey in which they were asked to describe any strategies they used. This was not a validated measure, nor was it particularly detailed. It was simply a blank field that participants could use to indicate if they approached the task in any sort of systematic way. Many individuals left this question blank. But, for those who did respond, there were a few common themes (Figure 26). Most individuals indicated that they looked for the eyes when trying to identify a face, looked for rooflines to identify a house, and/or chose to approach the task completely as an acceptance or rejection of faces (in lieu of looking for rooflines or other house features). A few stated that they used the cues as a guide or default response. There were no notable qualitative differences in the nature of these responses between older adults and younger adults.

Please describe any strategies you used while completing the face/house idenification task inside of the fMRI scanner.

I would look for the eyes to identify a face.

For faces, I looked for eyes. Also, I generally trusted the likelihoods.

If I couldn't see anything vaguely resembling human eyes in the image, I clicked on House 95% of the time.

Looking for eyes or the outline of a roof when there was a 50/50 chance of either showing up

If no evidence of face i chose house

I looked for eyes first

Singing a song in my head to try to stay awake and focused

For the houses, I looked for shapes at the edge of the screen if I could not see any eyes. For faces, I looked at the top or middle part of the screen first to see if I could notice pupils.

looking for lines for houses, circles or lack of lines for faces

concentrating on the eyes for faces - no eyes? must be a house

Closing my eyes and opening them again, to get a reset image each time.

no face then must be house.

Looked for eyes

Those shared by many others: searching for eyes and straight lines to distinguish between the two objects.

I would look for the eyes on the faces and if I didn't see eyes then I assumed it was a house.

Looked for eyes

I looked for eyes first

Focused on seeing eye for face. Rooftop for house, but relied more on eye sighting.

Looked at the upper right quadrant for an eye, and used the presence/absence to make my decision.

I used the cues to guide where to look first. I would look for eyes near the top of the screen and if I didn't see eyes I looked towards the sides of the screen for sloping lines for the roof of a house.

I used the suggested possibility for my answer.

FIGURE 26: All of the responses to the post-task survey about strategy use.

CHAPTER 5:
DISCUSSION

Decision-making is a multi-stage process that takes place over time and involves the intake of sensory information from the environment, accumulation and processing of evidence, and the selection of a final option (Heekeren, Marrett, & Ungerleider, 2008; Ploran, et al, 2007; Ploran, Tremel, Nelson, & Wheeler, 2011; Ratcliff, 1978; Dunovan & Wheeler, 2018; Wheeler, 2014). All the while, a collection of environmental factors influences the process. One of those environmental factors is prior knowledge, and that is the primary focus of the current study—specifically, prior knowledge in the context of cognitive aging, behavioral outcomes, and BOLD activity in the ITC. Past work has shown that younger adults respond to probabilistic cues in an informative manner. This is reflected in increased accuracy, shortened RTs, and reduced BOLD activity in the ITC for valid trials relative to neutral or invalid trials (Dunovan & Wheeler, 2018). However, it is unclear if or how that relationship between behavior and neural activity holds across the lifespan. Based on current literature, we hypothesized that there would be age-related differences because older adults may not take cues into account and respond consistently irrespective of the prior knowledge provided (Ratcliff & Smith, 2004; Smith & Ratcliff, 2004; Forstmann, Ratcliff, & Wagenmakers, 2016; Wheeler, 2014). That prediction was not supported in this study. Instead, older and younger adults responded to informative cues in similar manners. However, at the same time, the underlying BOLD activity in ITC did differ between age groups, providing an instance where the outcomes are the same but the underlying neural substrates differ.

5.1 Older and Younger Adults Responded to Probabilistic Cues in a Similar Manner

Older and younger adults' overall accuracy, overall RTs, and variability of these dependent measures collapsed across all validity conditions (valid, invalid, neutral) did not differ. That is not surprising given that overall task difficulty was controlled for on a subject-by-subject basis. When breaking down trials by validity, both younger adults and older adults presented similar trends in both accuracy and reaction time. There were no main effects for age or interaction effects for age x validity for either dependent measure. Instead, both groups consistently responded faster and more accurately to valid trials compared to invalid trials. Neutral (control) trials tended to lie somewhere in the middle, though older adults' RTs may potentially plateau across the valid and neutral conditions. This was surprising given the expectation that older adults would remain relatively inflexible and respond consistently regardless of the cues provided. Rather, overall, these behavioral results suggest that both age groups are engaging with and incorporating prior knowledge into their decision-making processes in similar ways.

This preservation of ability across the lifespan could be a product of controlling for task difficulty. In this case, that difficulty confound was visual in nature. If, for example, visual ability had not been accounted for via psychophysical thresholding and the hypotheses about older adults' relative inflexibility had instead been upheld, it is possible that could have occurred simply because those older adults did not have the ability to allocate those resources towards processing cues because they were overwhelmed by struggling to see (Verhaeghen, in press). It would not be a matter of them not attending to cues because of some inherently conservative decision-making mechanism, but that the task was structured in a confounding way that prevents them

from taking advantage of additional information in the first place. Titrating task difficulty may have erased a potential age-related sensory effect, which is important to consider when studying decision-making in general. Alternatively, there may simply not be an age difference for the validity conditions during this task even with sensory confounds. Regardless of the reason, the take-away message is that criterion adjustment is a process that appears to be relatively conserved in aging.

5.2 Despite Similarity in Behavior, The Underlying BOLD Activity in ITC Differed by Age

Contrary to the behavioral results, these imaging data suggest that older adults' strategic use of the informative cues differed from younger adults. It was important therefore to determine whether older and younger adults utilizing cues in the same manner directly translates to differences in BOLD activity. Meaning, if we find bias-associated BOLD signal changes patterns in the ITC for younger adults (lowest percent change for valid compared to neutral), will we also find the same patterns in older adults? Finding the same activation patterns within the ITC between age groups would provide evidence for retention of function during this perceptual decision-making task. On the other hand, if activation patterns are different, then that would provide evidence for some sort of divergence, strategy, differentiation of function, or lifespan-based structural/functional change that should be addressed through additional research. Imaging data is divided into two stages going forward: 1) the 3-second cue phase and 2) the 6-second response window task phase.

Cue phase activation is anticipatory in nature. This is the point at which an individual is processing the cue information and incorporating bias. The participants do

not know if the subsequent task phase will be valid or invalid at this stage, but they have information and the behavioral results suggest they are about to use it. There were a few findings of note during these cue periods. First, there was a main effect for cue type (face, house, or neutral) in two ROIs, with both responding preferentially to house cues. The remaining eight ROIs showed no face- or house-preferential activation. There were also four regions that had a significant main effect for age. However, opposite to what was predicted, all showed higher activity for older adults relative to younger adults. Two regions were located within the left/right extrastriate cortex, which is a visual area implicated in the processing of dynamic motion. The cues are static text and nothing on screen is moving at this stage, but there still appears to be some potential anticipatory visual activity taking place for older adults. The remaining two regions were within the left fusiform face area which, again, is a region implicated in object recognition and evidence accumulation. The remaining six ROIs showed no age effects. There are no significant cue x age interaction effects in any ITC ROI. Taken together, these cue phase results provide further reinforcement that older adults were engaging with the cues, and suggests that they were doing so via a different neurological mechanism than younger adults.

The task phase is the response period during which individuals are applying their prior knowledge, viewing the noisy images, gathering and incorporating visual evidence, and reaching a decision. There are several findings of note from this phase. First, an ROI within the left extrastriate cortex presented larger BOLD signal changes for older adults relative to younger adults. This visual region behaved similarly during the cue phase, suggesting it had a more significant roll processing the stimuli for older adults. However,

aside from this single ROI, none of the other regions that showed more activity for older adults during the cue phase carried over to the task phase. Instead, there are two additional PPA/FFA regions which had a higher BOLD signal change for younger adults, suggesting these regions have a more significant role for this age group during the task phase. There is also an additional collection of five regions across the FFA and PPA that have a main effect of validity and show increased activity for the neutral condition compared to the valid condition, which replicates previous trends seen in younger adult data (Dunovan & Wheeler, 2018). Furthermore, within that collection of five ROIs, there are two regions—one within the fusiform gyrus and one within the parahippocampal place area—that present a main effect for age, a main effect for validity, and a significant age x validity interaction. The pattern of these relationships is as predicted: younger adults show increased BOLD activation for the neutral condition relative to the valid condition, and older adults show consistently lower and constant activity across both conditions. Aside from this selection, many ROIs showed no task phase effects. Overall, the direct relationship between neural work and outcome that was found for younger adults (in a selection of ROIs) was not seen in older adults. That does not mean older adults were not utilizing cues because the accuracy, reaction time, and cue phase imaging data suggests they did. Rather, the differences lie in how that information was processed in the brain while generating similar outcomes.

5.3 Other Findings: Mars Letter Contrast Sensitivity, Cognitive Load, and Strategies

The remaining analyses for this experiment were secondary and exploratory in nature, the first of which related to the relationship between psychophysical thresholding

scores and Mars Letter Contrast Sensitivity Test scores. At this stage of understanding, it is not clear exactly what the psychophysical thresholding task is measuring aside from accuracy and noise levels for these specific stimuli in this specific circumstance. However, it is possible that this tool is getting at some broader concept akin to individual differences in acuity and contrast sensitivity (which is what MLCST is designed to measure). From a practical perspective, a thresholding task like this is also difficult to script and understand. Therefore, it might also be beneficial to explore potential alternative visual ability measures. The scores on these two measures were found to have a moderate positive linear relationship with one another. However, this trend appeared to be driven mostly by the younger adults who are less variable and gets stronger with larger samples. Future studies could justifiably revolve around the idea that, either alone or together, these tools might be measuring different sensory characteristics as a function of age.

For the NASA TLX cognitive load measure, there were no age differences. This lack of an age effect for any of the cognitive load Likert scales (physical demand, temporal demand, mental demand, effort, performance, and frustration) could represent an additional reinforcement that task difficulty is being controlled for across age groups, as no one group is finding the task more disproportionately taxing than the other. However, though there is a possibility that is indeed the case, such a conclusion should be considered with caution given the fact that this sort of analysis typically requires a much larger sample size. For the self-report question about strategy use, there are no notable qualitative differences between age groups. There were some common responses overall, such as seeking out eyes or relying on cues. Although, it is also worth noting that this

technique is not the most in-depth or reliable way to measure metacognition and many individuals left the question blank. Going forward, taking a more systematic approach to teasing apart strategy use is preferable.

5.1 Future Research

Additional studies should consider alternative explanations for the age-related disparity between behavioral outcomes and BOLD activity. For example, a lack of corresponding BOLD signal change in the older sample could be a reflection of dedifferentiation of function. Dedifferentiation is a phenomenon whereby, as individuals grow older and their anatomy and experience levels change, cells and regions become generally less specialized in their function (Baltes & Lindenberger, 1997; Park & Reuter-Lorenz, 2009). For example, FFA and PPA could become less face and place specialized in late life, but serve more an overarching decision-making and evidence processing purpose irrespective of the stimulus type. Changes like these might be a product of natural cell death and reductions in white/gray matter, pruning to maximize function and reduce costs, or some combination of factors (Craik, 2006; Cabeza, 2002). It may also be worthwhile to step outside of the ITC in the future, focus on more frontal/pre-frontal areas, and take a compensation-related utilization of neural circuits hypothesis (CRUNCH) approach. The CRUNCH model holds that, because of declining neural efficiency, older adults can sometimes recruit more areas to meet demand (Reuter-Lorenz & Cappell, 2008). If that is the case during this task, then it would be worthwhile to include additional areas outside of what is pre-identified in the younger adult ITC

literature. Other possible explanations may also include age-related differences in metacognition and the use of optimally efficient strategies (Hertzog, 2016; Gandini, Lemaire, Anton, & Nazarian, 2008), individual differences in BOLD signal magnitudes (D'Esposito, Zarahn, Aguirre, & Rypma, 1999), and anatomical and cytoarchitectural changes (Fjell & Walhovd, 2010).

Aside from the primary goals of this work, this dataset is likewise rich and there are many opportunities to explore a wide variety of research questions using different analysis methods. For example, using hierarchal clustering of whole-brain scans for an object identification task, a paper by Ploran and collogues from 2007 classified certain decision-making ROIs as belonging to 1 of the 3 stages of decision-making: 1) sensory processing, 2) evidence accumulation, and 3) the moment-of-decision. That provides a systematic foundation to make stage-specific comparisons. The design of the current study does not directly distinguish between these overlapping processes, but future work could easily do so in that manner. The task phase response period in the current protocol includes all three because participants are looking at the stimuli, collecting information about it, and pushing the button to make a choice within that window. Having increasingly fine-grained regional specialization could serve as a guide when delving deeper into age-related differences. There are no staunch distinctions or claims being made about precisely what is happening in each of the localizer ROIs at this time, but making stage-related comparisons by age and validity in the future would be interesting. Such an approach could investigate if, for instance, the evidence processing stage is what is most effected by age or if older adults engage in additional sensory processing to accommodate to visual decline in order to maintain performance. There is also a growing

body of literature that uses whole-brain fMRI to examine age-related differences in cue/compound trial activity during executive control tasks, and the same analysis framework could be extended to include decision-making (Madden, et al., 2010).

5.2 Limitations

Due to equipment upgrades severely constraining the timeline for collection, the sample size for this experiment was less than desired. There are also approximately half as many trials in the current protocol compared to the study design being replicated (Dunovan & Wheeler, 2018). That decision was made in order to reduce the scan time to a more reasonable length for older adults. An unfortunate consequence of these limitations is that, for the imaging data, we are unable to include the invalid condition in the analysis due to having too few trials for some individuals. If we had simply excluded everyone who did not have enough invalid trials and moved forward, then we would consequently have too few participants to compare in the first place. For some perspective, comparing a 50/50 probability in the neutral condition to the 80% probability in the valid condition is only a 30% difference in expectation bias. Having a larger disparity might reveal more differences, and the lack of one has increased the risk of type II error on a ROI-by-ROI basis. Another concern is that age is treated as a 2-level discrete variable in this design. That approach can be useful at the early stages of inquiry, but lacks a true lifespan perspective. Future work should either include middle-aged adults and/or aim to treat age as a continuous variable because most of the spectrum is missing. Additionally, no education or socioeconomic status demographics data was collected from the participants so those factors cannot be considered.

5.3 Conclusion

Contrary to our prediction, older adults attended to the predictive cues in a similar manner to younger adults. Imaging data from ITC suggest that older adults use a different strategy to perform the task, which may be revealed by examining prefrontal and/or parietal brain areas. However, more conclusive evidence from invalid trials is likely needed to confirm this possibility.

APPENDIX A: PHONE SCREENING FORM

Participant Phone Screening Form

Hello, my name is _____ _____ and I am a researcher in the laboratory of Dr. Mark Wheeler at Georgia Tech. I understand that you have expressed interest in being a research participant for us. We are currently recruiting people to participate in a learning and memory study. Would you like to hear more?

YES NO {If No}: Thank you very much for your time.

{If Yes}: We do have some further requirements for participation in our study, so I would like to ask you some questions regarding your biographical and medical history. Before I do, I want you to know that your current and future status, if any, at Georgia Tech will remain the same whether you participate in this study or not. Your participation is voluntary and you can withdraw at any time. All of the information I receive from you now by phone, including your name, telephone number, and answers to my questions will be kept strictly confidential and will be stored in a locked filing cabinet in a locked office. If your answer to any question results in your ineligibility to participate in the study, we will discontinue the interview process and shred documentation.

In this study you will be asked to take a memory test while an MRI scanner records your brain activity. It will be held at the Center for Advanced Brain Imaging on campus. The full procedure will last up to 3 hours.

Are you still interested in being a participant in our study? If so, do I have your permission to ask some background questions?

YES NO {If No}: Thank you very much for your time.

{If Yes}: I'm going to ask you a series of questions pertaining to the biographical and medical requirements of this study. These are primarily yes/no questions; we do not require any great detail.

What is your age? _____.

What is your birthdate? _____.

Which is your dominant hand? _____.

If the answer to any of the following questions is "yes", then request a brief description and, if appropriate, reply at the end of the survey "Thank you for your time today. Unfortunately you do not meet all of the requirements of our current research study."

Do you have any history of hearing

loss?.....Yes/No

If yes, please describe._____

{If participant uses hearing aids, suggest that they bring them to the study.}

Do you have any history of vision impairment?.....Yes/No

If yes, please describe._____

{If participant uses glasses or contact lenses, suggest that they bring them to the study.}

Is English your first language?.....Yes/No

If no, please describe._____

Do you have any history of a learning disability?.....Yes/No

If yes, please describe._____

Do you have any history of a speech, language, or reading disorder?.....Yes/No

If yes, please describe._____

Do you have any history of a neurologic illness?.....Yes/No

If yes, please describe._____

Have you ever had a stroke, aneurysm, or severe heart attack?.....Yes/No

If yes, please describe._____

Do you have any history of psychiatric/mental

illness?.....Yes/No

If yes, please

describe._____

Are you currently taking any

medications?.....Yes/No

If yes, please

describe._____

Would you like to be considered for any future research

studies?.....Yes/No

If you agree to participate, you will be paid $25 per hour during times of your participation.

Are you still interested in being a participant in our study?

YES NO {If No}: Thank you very much for your time.

{If Yes}: I'm going to ask you a series of questions pertaining to your safety in the MRI scanner. These are primarily yes/no questions; we do not require any great detail.

Have you ever been in the MRI environment

before?.....Yes/No

If yes, please

describe._____

Are you claustrophobic or uncomfortable in confined

spaces?.....Yes/No

If yes, please

describe._____

Do you wear contacts or

glasses?.....Yes/No

If yes, please describe._____

{If the participant wears glasses please explain that they cannot be worn in the scanner because they have metal parts, but a non-ferromagnetic pair can be made for them if they know their prescription. They are encouraged to wear contacts if they have them.}

Do you have any metal in or on your body that you cannot remove?.....Yes/No

Do you weigh less than 250 pounds?.....Yes/No

Have you ever had a pacemaker?.....Yes/No

Before I schedule this appointment I need to obtain your contact information.

What is your name? _____.

What is your phone number? _____.

What is your email? _____.

What is your address? _____.

APPENDIX B: PROCEDURE LISTED IN STEPS

Session 1 (1 hour)

1. Informed Consent for Experiment
2. Informed Consent for Older Adult Database (if applicable)
3. Demographics Questionnaire
4. Edinburgh Handedness Questionnaire
5. Mini Mental State Examination
6. Trail Making Test A & B
7. Digit Span
8. Clock Drawing Task
9. Mars Letter Contrast Sensitivity Test
10. Set-Up in the Mock Scanner
11. 1-Up 3-Down Double Interleaving Staircase Thresholding Task
12. Explanations of Button Boxes and Face/House Responses
13. Practice for Localizer Task
14. Instructions for Next Session
15. Explanations for fMRI Safety Paperwork
16. Payment

Session 2 (2 hours)

1. Collection and Review of fMRI Safety Paperwork
2. Explanation of Button Boxes and Face/House Responses
3. Instructions for Localizer
4. Practice for Localizer Task
5. Instructions for Experimental Task
6. Practice for Experimental Task
7. Set-Up in fMRI Scanner
8. T1 Structural Scan
9. T2 Structural Scan with flair
10. Instructions for Localizer Task
11. Localizer Task
12. Instructions for Experimental Task
13. 7 Runs of Experimental Task
14. Removal from fMRI Scanner
15. NASA Task Load Index & Question about Task Strategies
16. Payment

APPENDIX C: INFORMED CONSENT

Consent Document for Enrolling
Adult Participants in a Research Study at the
Georgia State University - Georgia Institute of Technology
Joint Center for Advanced Brain Imaging
831 Marietta Street
Atlanta, GA 30318

Project Title
NEURAL MECHANISMS OF AGE-RELATED CHANGES IN PERCEPTUAL AND MEMORY DECISIONS

Investigators
Dr. Mark Wheeler, Principal Investigator
Dr. Kurt Braunlich, Postdoctoral fellow and Co-investigator
Rachel Boyd, Elyse Carlson, Jenny Walker, and Mary Bernhardt, Graduate Student researchers
Marvin Hoo, Post-Bac Researcher & Co-Investigator
Layla Abdullatif, Anaqa Faizer, and Aken Sanghavi, Undergraduate Student researchers

Contact
School of Psychology
Georgia Institute of Technology
654 Cherry Street NW
Atlanta, GA 30332-0170
404-894-3102

Introduction
You are being asked to participate in a research study. We are conducting a brain imaging study to learn more about the brain and its role in perception and memory. We will be using magnetic resonance imaging. MRI detects changes in brain function during mental activity. We examine changes in brain function while people make decisions based on their perceptions and memories.

This study is only diagnostic and does not involve treatment. Prior to starting the experiment, we will also ask you to fill out several questionnaires. In the experiment, you will be asked to view various images and make decisions based on how well you can remember and identify them.

The brain imaging is performed while you lie on a table that will be placed inside a large magnet. If you have never had an MRI brain scan before, you may be asked to spend about 20 minutes in a model of a real scanner in order to help you get used to the feeling of being in a real scanner. While in the MRI scanner, it is critically important that you remain *as still as you possibly can* throughout. Because we are interested in where activity occurs in specific places in your brain, movement in the scanner will blur and distort the data. Even moving your legs can make your head

move. If you feel that you are unable to remain still, please notify the experimenter. You will spend 60 to 90 minutes in the scanner, and approximately 3 hours in the experiment total.

Purpose
Approximately 240 individuals will participate in this research study funded by the Georgia Institute of Technology and the National Science Foundation. This study will help us to learn how the brain processes visual information, learn how brain activity changes when we make decisions about what we remember, and identify changes that occur in healthy aging.

Exclusion/Inclusion Criteria
You may experience nausea if you have certain conditions such as migraines, vertigo, anxiety or stress, fatigue, food poisoning or digestive disorders, fibromyalgia, concussion or brain injury, appendicitis, kidney or liver disorders, central nervous system disorders, brain tumors, some forms of cancer, or other illnesses. If you are currently experiencing nausea for any reason, you should not have an fMRI scan until your nausea has subsided.

It may not be safe for people with certain metals in their bodies or with certain medical conditions to undergo MRI, which uses a very strong magnet. The researchers will ask you to review a list of conditions and tell them if any apply to you. **If you have any of the following, you will be excluded from this study for your own safety:** Cardiac pacemaker; hearing aid; any other implant metal in your body or eyes, including pins, screws, shrapnel, plates, braces on your teeth, or dentures; Parkinson's; Alzheimer's or other dementia; sickle cell anemia; epilepsy; bipolar disorder; multiple sclerosis; or brain surgery.

If you have tattoos, you could experience some irritation and redness at those sites. Tattoos on the head, such as eye liner or other permanent makeup, may make it impossible to get clear and usable images. If you have tattoos or permanent makeup of any type, you should inform the researchers.

It may not be appropriate for people with the following conditions to participate. The researchers will ask you to review a list of conditions and tell them if any apply to you. **If you have any of the following, you will be excluded from this study for your own safety:** Claustrophobia; large frame; diabetes; heart disease; untreated high or low blood pressure; a history of stroke or seizure; loss of consciousness; brain damage; heart attack; epilepsy; bipolar disorder; untreated depression or anxiety; attention deficit disorder; history as a metal worker; untreated respiratory problems like emphysema; untreated cataracts; untreated glaucoma; macular degeneration; orthopedic issues; hearing difficulties; people who regularly use illegal drugs.

You must be between the ages of 21-35 or 60-75 to participate.

Procedures
- The study will take up to three hours and involve one or two visits.
- The study may include a study session in which you study items such as faces, names, and places. Your goal is to try to remember the items for a later test.

- The test will occur in the scanner. If you have never been in an MRI scanner, you may want to try out the simulator first. During the test you will see items appear on the screen and make a decision about their identity.
- While in the scanner, it is essential that you are as comfortable as you can be before sliding into the scanner. Even the slightest discomfort will magnify over time and encourage you to move.
- You will be given ear protection, and may be fitted with plastic lenses if needed.
- After entering the scanner, you will hear from the technician, who will begin making adjustments to the scanner. During this time, you will hear clicks and buzzes and intermittent periods of silence. When the task begins, you will receive further instructions and then the noise will increase to a loud beeping.
- You will wear gloves that will enable you to make responses for the experiment. You may also wear a small device on your finger that records your pulse.
- When the experiment is finished, you may be asked to take brief tests in the investigator's laboratory, and will have an opportunity to learn more about the study.
- Tell the technician if you need a break, are uncomfortable, or need to move.
- **You are free to quit the study at any time, and this will in no way affect the care you may receive.**

Risks or Discomforts

There are no known risks associated with the behavioral procedures. Some of the questions will ask you for personal information (e.g. medical history). You do not have to answer any questions that make you uncomfortable. **Women of childbearing potential who are considering being in this study should especially note that the risk to fetuses of exposure to MRI are unknown.**

This MRI is done for research purposes only. The MRI scan is designed to answer research questions, not to medically examine your brain. The MRI scan is not a substitute for one a physician would order. It may not show problems that would be picked up by a medical MRI scan. None of the researchers are medically qualified radiologists. However, if we see something unusual in your scan, we will inform you so that you can obtain a follow-up evaluation by your physician. Any follow-up evaluation or treatment that you seek will be at your own expense. Even if your physician rules out any problems, you may be unnecessarily worried if a problem is suspected.

The following risks or discomforts may occur as a result of your participation in this study. The energy levels used to make MRI measurements are far less than those used in a single X-ray. While MRI is painless and there are no significant risks from MRI as it is to be performed, participation may mean some added discomfort for you. In particular, you may be bothered by the beeping and hammering sounds made by the scanner as it collects measurements. Disposable earplugs will be provided to diminish the noise. The magnet is a small enclosure and some people feel claustrophobic inside it. You may also experience mild numbness or tingling in your fingers and toes. This feeling is similar to the feeling you get when your arm has fallen "asleep" – not the painful "needling" feeling, but the numb tingling you feel afterward. The room may be cold. You may ask for blankets. You may become tired or bored from lying in the scanner. Some people feel nervous while lying in the scanner. You may ask to leave the scanner at any time.

Because the MRI scanner attracts certain metals, it could move metallic objects within the MRI room during your examination, which could possibly harm you. Precautions have been made to prevent such an event from happening. Further, because of the high magnetic field, people with pacemakers, heart rhythm disturbances, or certain metallic implants in their body cannot participate in this study. You will be screened for these conditions.

Benefits
You are not likely to benefit in any way from joining this study. We hope that what we learn will help us improve cognitive function throughout the lifespan.

Compensation to You
You will be compensated $25 per hour for your time and effort. You will make one or possibly two visits to the laboratory, lasting approximately 3 hours in total. Your total compensation will be $75. You are free to quit at any time and will be compensated for time spent on the study at a rate of $25/hour.

U.S. Tax Law requires a mandatory withholding of 30% for nonresident alien payments of any type. Your address and citizenship/visa status may be collected for compensation purposes only. This information will be shared only with the Georgia Tech department that issues compensation, if any, for your participation.

Confidentiality
The following procedures will be followed to keep your personal information confidential in this study: The data collected about you will be kept private to the extent required by law. To protect your privacy, your records will be kept under a code number rather than by name. Your records will be kept in locked files and only study staff will be allowed to look at them. Your name and any other fact that might point to you will not appear when results of this study are presented or published. Your privacy will be protected to the extent required by law. To make sure that this research is being carried out in the proper way, the Joint Georgia State University and Georgia Institute of Technology IRB may review study records. The Office of Human Research Protections and/or the Food and Drug Administration may also look over study records during required reviews. One of the sponsors of this study, the National Institutes of Health, has the right to review study records as well.

We have obtained a Certificate of Confidentiality from the National Institutes of Health to help us keep your information confidential. This Certificate provides a way that researchers cannot be forced to disclose information that may identify you, even by a court subpoena, in any federal, state, or local civil, criminal, administrative, legislative, or other proceedings. The Certificate cannot be used to resist a demand for information from personnel of the United States Government that is used for auditing or evaluation of Federally funded projects or for information that must be disclosed in order to meet the requirements of the federal Food and Drug Administration (FDA). A Certificate of Confidentiality does not prevent you or a member of your family from voluntarily releasing information about yourself or your involvement in this research. If an insurer, employer,

or other person obtains your written consent to receive research information, then the researchers may not use the Certificate to withhold that information.

Costs to You
There are no costs to you, other than your time, for being in this study.

In Case of Injury or Harm
If you are injured as a result of being in this study, please contact Principal Investigator, Dr. Mark Wheeler, Ph.D., at telephone (404) 894-3102. Neither the Principal Investigator, nor Georgia Institute of Technology, nor Georgia State University has made provision for payment of costs associated with any injury resulting from participation in this study.

Participant Rights
- Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.
- You have the right to change your mind and leave the study at any time without giving any reason and without penalty.
- Any new information that may make you change your mind about being in this study will be given to you.
- You will be given a copy of this consent form to keep.
- You do not waive any of your legal rights by signing this consent form.

Questions about the Study
If you have any questions about the study, you may contact the Principal Investigator, Dr. Mark Wheeler by telephone (404) 894-3102 or email at mark.wheeler@psych.gatech.edu.

Questions about Your Rights as a Research Participant
If you have any questions about your rights as a research participant, you may contact Ms. Kelly Winn, Office of Research Integrity Assurance, Georgia Institute of Technology, Atlanta, GA 30332-0420. Voice 404-385-2175.

Signatures
Signing below indicates that you have read (or have had read to you) the information on pages 1-5 of this consent form, and you would like to be a volunteer in this study.

_____
Participant Name (printed)

_____ _____

Participant Signature **Date**

_____

Person Obtaining Consent (printed)

_____ _____

Signature of Person Obtaining Consent Date

APPENDIX D: INFORMATION SHEET FOR SESSION 2

fMRI Session Information Sheet

You are scheduled to come in _____.

When to Arrive and What to Bring

- PLEASE BE ON TIME. If you are late, we are unable to reschedule. If you have any issues, please contact your researcher as soon as possible at _____.
- Please bring your completed safety paperwork with you to your appointment.

Where to Go

- The gated entrances are open Mon-Fri from 8:00am-5:00pm. If your appointment is outside of these hours, your researcher will open the gate for you when you arrive.
- If you are driving, park in one of the parking spots labeled "Reserved."
- When you arrive for your scheduled appointment, please go to the side door of the building (facing Marietta Street) and ring the doorbell labeled "Wheeler." A researcher will be with you shortly.

Safety

- If you wore glasses during your first session, please wear contact lenses instead of glasses if possible for your second session. If you do not have any contact lenses, then you will be fitted with fMRI-safe glasses. If you did not wear glasses or contacts for your first session, please do not wear them during your second session.
- Do not use any heat protecting hair creams or sprays.
- Avoid placing any pins or metal in your hair.
- Be aware that you will need to remove your shoes, wigs, dentures, rings, piercings, watches, and other items from your person while in the scanner.
- Please avoid wearing clothes with metal in them. Some people prefer to bring sweatpants or pajama pants, so there is a changing room available if you need to use it.

During the fMRI session, we will be taking pictures of your brain, and it is important that you remain as still as possible for the entire duration of scan. Therefore, we want to ensure that you are comfortable. During the set-up process, please let the researcher know if you need a blanket or any of cushions need adjusting before the scan starts.

APPENDIX E: FMRI SAFETY PAPERWORK

Center for Advanced Brain Imaging
Georgia State University and Georgia Institute of Technology
831 Marietta St, Atlanta GA 30332, USA
Phone (404) 385-8619
Fax (404) 385-8620

Magnetic Resonance Imaging Contraindication Screening Form-Adult Version

If you answer YES to any of the questions on this page, you are NOT eligible to participant in a MRI study as your safety may be at risk. **Do not write on this sheet.**

MRI can be dangerous for people with certain conditions. MRI uses a very strong magnet that may cause metal objects in your body to move around and cause injury.
Please carefully read the following statements and *let us know if any apply to you.*
This information will help us determine whether you can safely enroll in the study.

Please do not write on this sheet.

SAFETY QUESTIONS

If the answer is YES to any of these four questions about you IT IS NOT SAFE for you to be in this study.

1. **Do you have any of the following: cardiac pacemaker, ferromagnetic aneurysm clip, neurostimulator, joint replacement, blood clot filter, hearing aids, cochlear implant, prosthetic, insulin pump or any other implant?** *{The high magnetic field interferes with the proper functioning of pacemakers. Metal implants may be bent, pulled out of place, and may cause internal damage.}*
2. **Do you have any metal in his/her body or eyes? This includes pins, screws, shrapnel, plates, and braces on his/her teeth, dentures, dental bridges, dental implants, and IUD.** *{Metal implants may be bent or pulled out of place. For instance, shrapnel from an old car wreck wound left lodged near vital organs may be pulled by the magnet. These effects could cause internal damage.}*
3. **Are you claustrophobic?** *{The MRI scanner is a very narrow enclosed space. It has been compared to a tanning bed or torpedo tube. The coil [or helmet like device your child's head is placed in] will be mere centimeters—possibly less—from the tip of his/her nose. Your child's head is placed in padding to help him/her hold it as absolutely still as possible. Although you can get out of the magnet at any time during the experiment if he/she feels seriously uncomfortable, you should be aware that this is an extremely confined space, and you will need to lie still for an hour or more.}*
4. **Do you have a large frame?** *{The Magnetic Resonance Imaging table can support up to 440 pounds. Because the space is so narrow, people who are extremely large or obese cannot participate}.*

STOP!
If the answer is YES to any of the above questions, please inform the experimenter.
It is not safe for you to participate in the study.

HEALTH QUESTIONS

Certain medical conditions may not be eligible for some studies.
The experimenter will tell you whether you need to answer the following four questions.

5. **Have you ever had brain surgery?** *{Note that un-retrieved device fragments may become dislodged and cause internal damage.}*
6. **Have you had any type of surgery in the last 3 months?**
7. **Do you have any of the following conditions? Sickle cell anemia, Bipolar Disorder, Schizophrenia, or Multiple Sclerosis**
8. **Do you have a history of stroke or heart attack?**

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Page 2
If the answer is YES to any of the following questions about yourself,
IT MAY NOT BE SAFE for you to be in this study.
You will need to discuss these points with the experimenter.

Do not write on this sheet.

1. **Do you wear a medicated adhesive patch?** *{Medicated adhesive patches with metal backing may heat up and burn the skin during MRI. If so, the experimenter may ask whether the patch can be removed during MRI.}*
2. **Do you have any non-removable jewelry, facial piercing, or permanent makeup?** *{Permanent makeup and metal jewelry made out of materials like surgical steel may heat up and become uncomfortably warm.}*
3. **Do you have any tattoos?** *{Some tattoo dyes contain metal fragments that may heat up and become uncomfortably warm or cause swelling.}*
4. **Do you have now (or ever had) any of the following? ADD/ADHD or any other neurological or psychological disorder?**
5. **Do you have now (or ever had) any of the following? Epilepsy, a seizure, loss of consciousness for more than a few seconds, or brain damage?** *{If so, the completion of a special seizure protocol by your child's doctor may be required before your child can be in this study.}*
6. **Have you ever been seen by a neurologist, psychiatrist or psychologist (not counselor)?**
7. **Do you take tranquilizers, sleeping pills, anxiety or depression medication, or other psychological medications?**
8. **Do you have now (or ever had) any of the following? Heart disease, anemia, untreated diabetes, or untreated high or low blood pressure?**
9. **Do you use recreational drugs?**
10. **Do you ever used or abused alcohol?**
11. **Do you have now (or ever had) untreated respiratory problems (e.g., severe asthma, emphysema)?**
12. **Do you have now (or ever had) any of the following vision conditions? Untreated cataracts, untreated glaucoma or macular degeneration?**
13. **Do you need glasses and cannot wear contact lenses?** *{Most studies require responses to visual cues or instructions, so normal vision is usually required. In these studies, contact lens corrected vision is considered the same as normal vision}.*
14. **Do you have any hearing difficulties?** *{If so, you might be asked about your hearing in each ear.}*
15. **Do you have any orthopedic issues such as arthritis or back pain that would make it difficult for you to sit or lie still for at least an hour or to use a keyboard?**
16. **Do you have any other physical or mental problems that you haven't mentioned so far?**

WOMEN OF CHILDBEARING POTENTIAL WHO ARE CONSIDERING BEING IN THIS STUDY SHOULD ESPECIALLY NOTE:
THE RISK TO FETUSES FROM EXPOSURE TO MRI ARE CURRENTLY UNKNOWN.

Please tell the experimenter about any safety concerns that you may have.
Thank you for your interest.

MAY 2012

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Georgia State University and Georgia Institute of Technology
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HEALTH SCREENING FORM

Name		Phone Number
Date of Birth	**Age**	**Gender**

Ethnic Category:

[ ] American Indian/Alaska Native [ ] Asian
[ ] Black/African American [ ] Hispanic/Latino
[ ] Native Hawaiian/Other Pacific Islander [ ] Caucasian

HANDEDNESS

What hand do you normally use? (Put "+" in the column if you usually use that hand, "++" if you always use that hand, or one "+" in each column if you use both hands equally.)

Experimenter: Score 1 for L++, 2 for L+, 3 for + in each column, 4 for R+, and 5 for R++ (> = 20 ok).

Activity	Left	Right
Writing a message		
Drawing a picture		
Using a toothbrush		
Throwing a ball		
Using a pair of scissors		

Do you have any immediate family members who write with their left hand? [ ] No [ ] Yes

EYESIGHT

Indicate which you use:	If you know your prescription, please write it here.	Is the prescription for one eye much stronger than the other?
[ ] Glasses		[ ] No [ ] Yes
[ ] Bifocals		
[ ] Reading glasses	*Left*	Do you have astigmatism?
[ ] Contacts		[ ] No [ ] Yes
[ ] None (normal vision)	*Right*	Are you color blind?
		[ ] No [ ] Yes

LANGUAGE / EDUCATION

Is English your first language?	List all other languages that you speak:	Starting with elementary school, how many years of education have you had?
[ ] No [ ] Yes		
If not, what language is?		

GENERAL HEALTH

How would you rate your general health?	List any serious medical conditions that you have had, and list all of your current medications.
[ ] Poor [ ] Fair	
[ ] Good [ ] Excellent	

For Experimenter Use Only:
Principal Investigator_____
Experimental ID_____
Subject ID_____
Screen Date_____
MRI Date & Time_____

June 2010

Participant ID :_____

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MAGNETIC RESONANCE SCREENING FORM- Adult Version

The MR suite contains a very strong magnet. Some metal objects can interfere with your scan or even be dangerous. Before you are allowed to enter, we must know if you have any metal objects in your body or have experienced any of the conditions listed below. Please answer the following:

Yes	*No*		*Yes*	*No*	
☐	☐	Metal fragments in your eye	☐	☐	Tissue expander (Breast)
☐	☐	Cardiac pacemaker	☐	☐	Aneurysm clip
☐	☐	Any type of internal electrode(s) Pacing wires, Cochlear Implant, etc...	☐	☐	Implanted insulin pump
☐	☐	Swan-Ganz catheter	☐	☐	Halo vest or metallic cervical fixation device
☐	☐	Hearing aid	☐	☐	Any type of intravascular coil, filter or stent
☐	☐	Implanted drug injection device	☐	☐	Any type of foreign body, shrapnel or bullet
☐	☐	Heart valve prosthesis	☐	☐	Any type of ear implant
☐	☐	Penile prosthesis	☐	☐	Any type of surgical clip or staple
☐	☐	Vascular access port	☐	☐	Intraventricular shunt
☐	☐	Artificial limb or joint	☐	☐	Dentures or braces
☐	☐	Diaphragm (in place), IUD	☐	☐	Latex allergies
☐	☐	Neurostimulator	☐	☐	Wire mesh
☐	☐	Any type of electronic, mechanical or magnetic implant	☐	☐	Implanted cardiac defibrillator
☐	☐	Any implanted orthopedic items *(e.g. pins, rods, screws, nails, clips, plates, wire, etc...)*	☐	☐	Medication patch
☐	☐	Tattoo or tattooed makeup, such as eyeliner	☐	☐	Amateur or prison tattoo
☐	☐	Sickle cell anemia/Parkinson/Dementia/Alzheimer's	☐	☐	Epilepsy/seizure

WARNING: ***Certain implants, devices, or objects may be hazardous to you and/or may interfere with the MR procedure. Do not enter the MR environment if you have any questions or concerns regarding an implant, device, or object. Consult with the MR Technologist BEFORE entering the MR environment if you have any concerns. The MR system is Always on.***

May 2012

Participant ID :_____

Page 2: Magnetic Resonance Screening Form	
[ ] Yes [ ] No [ ] N/A	If you are female: Do you suspect that you are pregnant?
[ ] Yes [ ] No	Have you ever had surgery?
[ ] Yes [ ] No	If you have had surgery, were any metal, metallic, and/or medical devices implanted?
[ ] Yes [ ] No	Have you ever been injured by any metallic foreign body {e.g., bullet, BB, shrapnel, etc}?
[ ] Yes [ ] No	Have you ever had an eye injury involving a metal object, such as metallic slivers, shavings, foreign body, etc.?

YOUR BIRTHDATE, WEIGHT, HEIGHT		
Date of Birth (MM/DD/YYYY)	Weight (Pounds)	Height (Feet, Inches)

IMPORTANT INSTRUCTIONS FOR YOUR SAFETY

Before entering the MR environment you must remove all metallic objects including hearing aids, dentures, removable partial plates, keys, beeper, mobile phone, eyeglasses, hair pins, barrettes, jewelry, body piercing, watch, safety pins, paper clips, money clips, credit cards, bank cards, magnetic strip cards, coins, pens, pocketknife, nail clipper, tools, shoes, clothing with metal fasteners (excluding pants & bra).

I attest that the above information is correct to the best of my knowledge. I have read and understand the contents of this form and have had the opportunity to ask questions regarding the information on this form and regarding the MR procedure that I am about to undergo.

Signature of Person Completing Form:	Date (MM/DD/YYYY)

Form Completed by: ☐ Participant ☐ Relative

_____ _____

If relative, print your name | State your relationship to participant

For Office Use Only
Notes on any checked items:

_____
_____
_____
_____

For Experimenter Use Only:
Name of Project: _____
Principal Investigator: _____
Researcher(s):_____
Person obtaining screening: _____
Screening date & time: _____

May 2012

APPENDIX F: DEBRIFING FORM

Debriefing Document for Enrolling Adult Participants in a Research Study through the Georgia State University - Georgia Institute of Technology Joint Center for Advanced Brain Imaging 831 Marietta Street Atlanta, GA 30318

Thank you for your participation in the "INDIVIDUAL AND GROUP DIFFERENCES IN DECISION MAKING" study at Georgia Institute of Technology. The purpose of this study is to help us gain valuable information about how adults in various age groups make decisions, as well as the factors that influence the decision making process. We are interested in examining such differences at both the individual and group level.

We greatly appreciate your assistance!

If you have any questions about your rights as a research participant, you may contact Ms. Kelly Winn at the Office of Research Integrity Assurance, Georgia Institute of Technology, Atlanta GA, 30332-0420 at 404-385-2175.

If you have any questions about the study you may contact Dr. Mark Wheeler, the Primary Investigator by telephone at 404-894-3102.

Thank you again for your participation!

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