THE INFLUENCE OF AGING ON THE NEURAL CORRELATES OF JUDGMENTS OF LEARNING

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A THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Arts
in the Department of Psychology
in the Graduate School of
The University of Alabama

TUSCALOOSA, ALABAMA

2022

ABSTRACT

Metamemory monitoring refers to the awareness of one's own knowledge and memory abilities. A common way to measure monitoring is to have individuals predict their current learning state via metamemory judgments such as judgments of learning (JOLs). JOLs are subjective ratings regarding whether information will be remembered later. Prior research in young adults (YAs) suggests that the medial prefrontal cortex (mPFC) is involved in making JOLs. Although older adults (OAs) often show spared monitoring via JOLs, they might be able to maintain this ability by recruiting additional brain regions to compensate for alterations in the mPFC. Alternatively, OAs might have preserved monitoring because their neural correlates remain intact. YA and OA participants made JOLs on a 1-3 scale (Likely, Maybe, Unlikely) after viewing picture pairs during Functional Magnetic Resonance Imaging (fMRI) scanning. We tested the extent that brain activity differed in OAs compared to YAs in the mPFC using region of interest analyses in prefrontal brain regions, which are often invoked as key sites for neural compensation. Behaviorally, no age differences were found, consistent with the sparing of metamemory in older age. However, OAs showed increased brain activity when compared to YAs for the accurate > inaccurate and maybe > inaccurate contrasts in the middle frontal gyrus. This supports the notion that additional regions besides the mPFC are recruited by OAs when making encoding-based metamemory judgments, which could be indicative of compensatory mechanisms.

LIST OF ABBREVIATIONS AND SYMBOLS

YA	Younger Adults
OA	Older Adults
JOLs	Judgements of Learning
DMN	Default Mode Network
mPFC	Medial Prefrontal Cortex
DLPFC	Dorsolateral prefrontal cortex
OFC	Orbitofrontal cortex
fMRI	Functional Magnetic Resonance Imaging
MELODIC	Multivariate Exploratory Linear Optimized Decomposition into Independent Components
ROI	Region of Interest
sHRF	Specific Hemodynamic Response Function
N	Sample size: the number of samples
BF	Bayes Factor: The ratio of the likelihood of one particular hypothesis to the likelihood of another hypothesis
t	Computed value of t test
p	Probability associated with the occurrence under the null hypothesis of a value as extreme as or more extreme than the observed value
≥	Greater than
=	Equal to
MA	Middle Aged Adults

ACKNOWLEDGMENTS

I would first like to express gratitude to my mentor, Dr. Ian McDonough, for his support and guidance throughout the course of this thesis. Your wisdom has been instrumental in shaping who I am becoming as a researcher. I would also like to thank my committee members, Dr. Sheila Black and Dr. Hyemin Han, for providing insightful criticisms and support throughout the entirety of this thesis project and beyond. Your eagerness to help me grow as a researcher is very much appreciated. I also want to thank Ansley Gilpin for being like a second mentor to me throughout my tenure in the program. Your consistent professional advice and support means more than you will ever know.

I would like to thank my two forever best friends, James Lawlor and Lacey Cagle, for always supporting me no matter the circumstances. I would not be the person I am today without the two of you in my life. I would also like to give special thanks to my graduate school best friend and partner in crime, Datlon Burchardt, for always having my back through the toughest of times. Your genuine friendship is something that will never be replaced. Words cannot describe the amount of love and appreciativeness I possess for my husband, Will Erwin, for his unwavering love, support, and encouragement throughout everything I attempt to accomplish. I would be lost without you. I would like to thank the two sweetest cat babies, Tink & Tiger-Lily. You always find a way to make every day better. I would like to thank my mom, Pamela Sharpe, and my late great-grandparents, Alf and Dot Hastings, for always wanting the best for me and inspiring me to chase my dreams, no matter how big or impossible they may seem. Finally,

I would like to thank all the many other individuals who have assisted and/or supported me throughout the course of my thesis work. Oops!.. I did it again. =)

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INTRODUCTION

Metacognition refers to the awareness of one's own knowledge and the ability to understand, control, and manipulate one's cognitive processes. This includes knowing when to use specific strategies for effective learning and problem solving, as well as how and why to use these tactics (Nelson, & Narens, 1990). A common way to measure metacognition is to have an individual predict their current learning state via metamemory judgments such as judgments of learning (JOLs), which are subjective ratings regarding whether information will be remembered later. Metacognitive ability is especially important in older adults (OAs), as being able to accurately predict memory outcomes may counteract memory deficits involved in daily decision making. That is, if an individual can recognize certain information they might remember or forget, attentional actions could possibly be utilized to increase remembrance, such as engaging additional cognitive resources (McGillivray & Castel, 2017). For example, an OA might realize that they have forgotten the date of a friend's birthday, but they are pretty sure it is in a certain month, such as July. Once the actual date is confirmed to them to be July 8th, one might make a mental note of the date by also remembering that 8 comes directly after 7 to help aid their memory for the next time they need to retrieve said information. Even though cognitive decline is observed as a function of aging, several studies regarding metacognition in OAs have concluded that metamemory abilities are spared during the aging process (Connor et al., 1997, Hertzog & Hultsch, 2000; Hertzog, Kiddler, Powell-Moman, & Dunlosky, 2002; Hertzog, Sinclair, & Dunlosky 2010; Hines, Touron, & Hertzog, 2009; Robinson, Hertzog, & Dunlosky, 2006). These findings suggest that OAs may make metamemory judgments similarly to that of

Younger Adults (YAs) in terms of metacognitive accuracy. Specifically, metacognitive accuracy was measured by gamma scores, in which large positive values indicated a high degree of accuracy, zero meant chance, and large negative values indicated a low degree of accuracy. Accuracy was whether yes or no predictions (JOLS) resulted in correct or incorrect responses respectively. A question of interest surrounding this metamemory sparing theory is whether OA metacognitive ability, specifically regarding JOLs, is secure because neural correlates involved in metacognition remain intact throughout the aging process or if different underlying neural correlate mechanisms are present to preserve the cognitive processes that underly metacognitive ability.

While behavioral studies regarding metamemory have been conducted regarding both YAs and OAs, few studies have investigated the neural correlates involved in the cognitive process of making metacognitive judgments such as JOLs using Functional Magnetic Resonance Imaging (fMRI). The investigation of the neural correlates that are involved when individuals give JOLs is important when aiming to understand underlying cognitive processes and why some individuals may make poorer metacognitive judgments than others. The small pool of prior research in young adults (YAs) suggests that the Default Mode Network (DMN) is involved when making JOLs (Do Lam et al., 2012; Kao, Davis, & Gabrieli, 2005; Yang et al., 2015). More specifically, the bulk of this research has consistently implicated the medial prefrontal cortex (mPFC) with evidence suggesting that greater mPFC activation is associated with higher JOL ratings. In terms of decision making, the mPFC is implicated in emotional, self-referential, and contextually appropriate responses (Bechara & Damasio 2005; Higgins, 2000; Matthews et al., 2010). Anatomical connections to the mPFC include other prefrontal regions such as the

dorsolateral prefrontal cortex (DLPFC) and the orbitofrontal cortex (OFC), along with the hippocampus (Parent, et. al., 2010) and the amygdala (Reppucci & Petrovich, 2016).

A previous preregistered study (https://osf.io/sp5hn) conducted in our lab was based off previous YA findings regarding neural correlates of JOLs and specifically investigated mPFC activation for Likely, Maybe, and Unlikely metamemory judgments. We attempted to adjudicate among three theoretical perspectives about the bases of JOLs using three different hypotheses; Somatic Marker (emotionally guided; Bechara & Damasio 2005), Feeling of Rightness (contextually appropriate; Higgins, 2000), and Task Engagement (self-referential processing; Matthews et al., 2010). Twenty YA participants made JOLs on a 1-3 scale (Likely, Maybe, Unlikely) after viewing picture pairs during fMRI scanning. All hypotheses predicted that mPFC activity would be greater for Likely than Unlikely judgments, which was replicated. However, each hypothesis made different predictions regarding the Maybe judgment, which were either higher than both Likely and Unlikely or mid-way between Likely and Unlikely judgments. Results revealed that brain activity for Maybe judgments fell between Likely and Unlikely judgments. These findings support the Feeling of Rightness Hypothesis, which suggests that participants could be relying on what feels right or more correct when making likely and unlikely judgments. To build upon these results in terms of cognitive aging, further exploration of activation in the mPFC and connecting regions of interest in OAs could help shed light on possible activation differences regarding cognitive processing while making more accurate metamemory judgments. Overall, these details could aid in understanding why the mPFC is activated when providing metamemory judgments and clarify what role the mPFC may play in terms of metacognitive ability.

A main reason regarding why OAs may show different activation levels when making accurate metamemory judgments when compared to YAs is due to compensatory mechanisms. Compensation has been defined as the utilization of additional brain regions to offset certain memory deficits. That is, “less wiring, more firing” occurs such that additional brain regions are over-recruited in OAs to compensate (Daselaar et al., 2015). Several compensatory models are present and are thought to aid in cognitive deficits. The Compensation-Related utilization of Neural Circuits Hypothesis presumes that OA brain sites that are seen to be overactive are working more diligently than other equivalent regions in YAs. More specifically, OAs make up for cognitive processing deficiencies with over activation of additional regions or networks (Reuter-Lorenz & Cappell, 2008). Additionally, the Posterior Anterior Shift in Aging theory added that recruited compensational regions may be associated with higher order functions, such as top-down processing, that are recruited in response to cognitive deficits to possibly reconstruct reduced brain signaling (Davis et al., 2008). The Scaffolding Theory of Aging and Cognition models suggest that the brain is engaging in compensatory scaffolding faced with declining cognitive function. That is, when additional regions are being recruited by OAs, increased activation in prefrontal areas is due to different neural circuits being used to achieve a certain goal in terms of cognition. from (Park & Reuter-Lorenz, 2009; Reuter-Lorenz, & Park, 2014). A review conducted by Festini, Zahodne, and Reuter-Lorenz (2018) regarding the five aforementioned compensatory models revealed a consistent argument for the presence of frontal lobe recruitment when individuals are engaged in compensation. Additionally, specific connectivity was revealed between the mPFC and the DLPFC in a study conducted by Lighthall, Huettal, and Cabeza (2014). Moreover, the compensatory response in the DLPFC is associated with use of more elaborative and successful memory strategies in OAs.

In contrast with these models that support the notion that compensation could possibly improves efficiency in terms of cognitive processes, Morcom and Henson (2018) argue that increased frontal activation is indicative of decreased efficiency in OAs rather than compensation. More specifically, increased prefrontal activation suggests less specific and/or efficient brain activation as opposed to proposed compensation mechanisms that are known for counteracting cognitive decline. In terms of mPFC activation during encoding, these compensation mechanisms could account for less mPFC in OAs when compared to YAs and this could be a product of OAs utilizing additional prefrontal regions besides the mPFC when making metacognitive judgments to possibly aid in cognitive deficits. Investigating whether or not OAs are successfully compensating in terms of activation while providing metamemory judgments could help shed light on whether these types of judgments are cognitively spared in OAs. More specifically, we could decipher whether OA metacognitive ability is spared because of successful compensatory mechanisms or if their activation levels are simply similar to those of YAs.

Hypotheses

Hypothesis 1. Based on previous literature regarding compensation, we predict that, in terms of mPFC activation, the OA distribution will be different when compared with the prior YA distribution.

Hypothesis 2. In terms of compensation, we predict that other frontal or mPFC connected area activations will increase in OAs. This supports the notion that OAs are recruiting other areas in addition to the mPFC when making metamemory judgements.

METHOD

Participants

Participants consisted of YAs (N = 20) and OAs (N = 32) that were recruited by newsletters, flyers, Facebook ads, and word of mouth in the Birmingham and Tuscaloosa areas. Data were collected as a part of the Alabama Brain Study on Risk for Dementia to investigate the influence of aging on the neural correlates of metamemory judgments. YA ages ranged from 20-30, with a mean age of 23 and 55% of participants being female. In terms of race, YA participants were 60% white, 5% African American, and 35% identified as other. Average years of education for YAs was 15. OAs ages ranged from 60-74, with a mean age of 66 and 52% of participants being female. In terms of race, 81% of OA participants were white and 19% were African American. Average years of education for OAs was 14. Exclusion criteria included being pregnant, having a prior diagnosis of dementia or another neurological condition, a medical history of stroke or traumatic brain injury, claustrophobia, history of substance abuse, or having metallic implants that are incompatible with MRI. In addition to exclusion factors already included in the Alabama Brain Study on Risk for Dementia, outliers due to movement were removed using MELODIC and any runs showing fMRI artifact via visual inspection at the first level were removed from subsequent analyses. In second level analyses, visual inspection was used to ensure outliers were not present in the data. Additionally, to ensure that outliers will not strongly influence our results, a bootstrapping procedure will be used within the ROI (Region of Interest) analyses. Behaviorally, if a participant did not have an adequate number of at least 7 encoding or retrieval task responses for each of the three metamemory judgments, specific

participant contrast data regarding this was excluded. Also, participants that provided metamemory judgments but had no recognition responses or vice versa were not included in the accuracy analyses, because knowing whether participants were accurate or inaccurate in terms of their judgements and recognition outcomes was imperative to determine metamemory accuracies and inaccuracies demonstrated by participants.

Procedure

The overall study consisted of three sessions, two of which were in person. The first session included a three-hour cognitive battery. Following successful completion of the cognitive battery, participants were provided with an online survey to complete that consisted of several questionnaires. If participants were unable to access the survey from their own location, we offered an on-site computer for them to take the survey in a separate session. The last session consisted of the fMRI scan which included a structural scan and several functional scans including two resting-state scans, a paired-associates memory encoding task, a memory recognition task, and a visual-motor checkerboard task to measure participant specific hemodynamic response function (sHRF).

Materials

Stimuli. The stimulus order was fixed for each counterbalance, and different orders of stimuli were implemented across eight counterbalances with each one randomizing the specific face-object or face-scene presented. The face stimuli used in the encoding and retrieval tasks were taken from the Chicago Face Database Version 2.0.3. This database contains high-quality photos of male and female faces from different ethnoracial categories ranging in age from 18 to 50 years old. Half of the faces chosen to be included were of men and half were of women. Within each sex, half were African Americans and half were non-Hispanic White. The

ethnoracial categories were chosen to represent the local demographics. Pictures of the objects and scenes were taken from http://cvcl.mit.edu/MM/stimuli.html and have been used in several memory studies.

FMRI Scan (Encoding). During the encoding scan, participants were asked to view a series of faces that were paired with either an object or a scene. These stimuli were divided into two trials, each consisting of 32 pairs, lasting around 8 minutes, and the paired pictures were presented randomly while participants were in the scanner. Immediately after viewing each face-object or face-scene pair, participants were asked to provide a judgment of learning (JOL) to estimate the likeliness of remembering the object or scene that was paired with the specific face on an upcoming memory test. JOL responses (Likely, Maybe, or Unlikely) were collected after each picture-object or picture-pair was presented during the encoding phases.

FMRI Scan (Recognition). During the recognition scan, participants were shown the faces they previously viewed and were asked to select the object or scene that was previously paired with that face out of four given faces and/or scenes out of four selections. These stimuli were divided into two trials, each consisting of 32 pairs of pictures and lasting around 8 minutes. Object and scene picture selection accuracy was collected during the recognition phase that was present after both encoding phases were completed.

FMRI Scan (Checkerboard Task). After the encoding and recognition phases, participants completed a checkerboard task that measured participant sHRF in the occipital cortex that was time-locked to the onset of the visual stimulation where they were asked to tap their pointer finger when the checkerboard was present on the screen and not tap their pointer finger when the checkerboard was absent.

Statistics

SPM Analyses. First level regression analyses using temporal and spatial derivatives were conducted at the individual level for all participants. After completion, these files were converted so we could utilize a more participant specific hemodynamic response function (sHRF). After completion of the first level analyses and sHRF conversion, the files were resliced to ensure that all files were aligned before conducting second level analyses. Second level group analyses consisted of paired samples t-tests that were conducted for each metamemory magnitude contrast and each metamemory accuracy contrast in order to produce activation averages or betas for ROI extraction.

ROI Activation Average Extraction. To extract Region of Interest (ROI) activation averages for the mPFC specifically, we conducted paired samples t-tests using SPM to examine the fit of each metamemory judgment magnitude condition (Likely, Maybe, and Unlikely) and accuracy condition (Accurate, Maybe, and Inaccurate) for OAs compared to the hemodynamic response function (HRF), which resulted in three beta-values per participant that represented brain activation averages for the medial orbitofrontal region (or mPFC) via the FreeSurfer Anatomical ROI Map (ROI 1014/2014). A threshold of .99999 and voxel count of 0 was used to extract brain activation averages for the left (1014) and right (2014) sides of the medial orbitofrontal region. The left and right activation averages were then averaged to calculate the average activation across the left and right sides of the medial orbitofrontal region (or mPFC).

Bayesian Analyses. Our OA distribution for mPFC activation was compared to the prior YA distribution for mPFC activation to determine if similarities or differences in activation were present.. YA priors were defined by the mean and standard deviation of the aforementioned second level SPM analysis activation average betas that were extracted for the specific medial

orbitofrontal region (or mPFC) via the FreeSurfer Anatomical ROI Map (ROI 1014/2014). We chose to use Bayesian analyses instead of frequentist analyses (ANOVA, t-tests, etc.) for the following reasons. Credible intervals that are estimated by Bayesian analyses do not depend on large sample approximations (as confidence intervals often do in frequentist analyses). Bayesian analyses are also able to generate credible intervals for any derived parameter, such as difference values, which were used in the current study. Finally, since we were interested in testing specific hypotheses, another strength of conducting Bayesian analyses for this study is that it can provide support in favor of the null hypothesis, in comparison to only providing support against the null hypothesis as in frequentist approaches.

Data modelling was performed using the 'rstanarm' package (Stan Development Team, 2016) of the R software (R Core Team, 2019). This package contains functions that fit linear models using the Markov chain Monte Carlo (MCMC) Bayesian estimation method implemented in the STAN programming language (Stan Development Team, 2016). To assess the evidence of effects, Bayes Factor ratios based on Jefferys (1961) were calculated using the 'rstanarm' package within R software. All models were fitted using 10 independent Markov chains, each with 5,000 iterations of which the first 1,000 were warmup. This led to a total of 40,000 post-warmup posterior samples used for inference.

Additional ROI Analyses. To extract ROI activation averages from possible compensatory regions, we conducted paired t-tests using SPM to examine the fit of each metamemory judgment condition for accuracy (Accurate, Maybe, and Inaccurate) for OAs compared to the HRF, which resulted in three beta-values per participant that represent brain activation averages for four additional frontal regions of interest (ROIs). These ROIs were investigated using the FreeSurfer Anatomical ROI Map and included the Caudal Middle Frontal

Region (1003/2003), the Rostral Middle Frontal Region (1027/2027), the Superior Frontal Region (1028/2028), and the Frontal Pole (1032/2032) for each metamemory condition for all participants (YAs and OAs). A threshold of .99999 and voxel count of 0 was used to extract brain activation averages for the left and right sides of the aforementioned ROIs. The left and right activation averages were then averaged to calculate the average activation across the left and right sides of these four specific regions. Paired t-tests were then conducted in SPSS to compare activation averages for three different metamemory contrasts (Likely > Maybe, Likely > Unlikely, and Maybe > Unlikely) for both YAs and OAs regarding the four additional regions of interest listed previously. These multiple t-test comparisons were conducted using Bonferroni adjusted alpha levels of .01667 per test (.05/3).

RESULTS

Bayesian Analyses

Magnitude (Likely > Maybe). Results indicated moderate evidence in favor of our alternative hypothesis, that YA and OA JOL magnitude would differ, for the Likely > Maybe contrast, *BF* = 7.58. Specifically, YAs showed similar levels of mPFC activation for the likely > maybe contrast, while OAs were trending towards higher mPFC activation for likely compared to maybe judgments. The prior and posterior distributions of the model parameters for magnitude regarding the Likely > Maybe contrast can be found in *Figure 1*.

Magnitude (Likely > Unlikely). Results revealed that anecdotal evidence was found regarding our alternative hypothesis that YA and OA JOL magnitude would differ for the Likely > Unlikely contrast, *BF* = 1.22. This indicated no support for either our alternative hypothesis or the null hypothesis. Both YAs and OAs displayed greater mPFC activation for the likely > unlikely contrast, with YAs seeming to display a larger difference in activation between likely and unlikely judgments. This indicated that YAs and OAs had similar mPFC magnitude differences in terms of likely and unlikely judgments. Prior and posterior distributions of the model parameters for magnitude in terms of the Likely > Unlikely contrast can be found in *Figure 2*.

Magnitude (Maybe > Unlikely). Moderate evidence was found in support of the null hypothesis, which predicted that there were no differences in JOL magnitude between OAs and YAs, for the Maybe > Unlikely contrast, *BF* = 1/5.8. This indicated that both YAs and OAs were shown to have similar levels of mPFC activation for the Maybe > Unlikely contrast. Specifically,

OAs produced the same mPFC activation levels for both maybe and unlikely judgments in terms of magnitude. This was also the case for YAs. Prior and posterior distributions of the model parameters for magnitude regarding the Maybe > Unlikely contrast can be found in *Figure 3*.

Accuracy (Accurate > Maybe). Results revealed that there was anecdotal evidence found in favor of the alternative hypothesis, that OA and YA JOL Accuracy differed, for the Likely > Maybe contrast, *BF* = 1.64, indicating no support for either our alternative hypothesis or the null hypothesis. Specifically, YAs displayed similar levels of mPFC activation in terms of their accurate and maybe judgements. However, OAs displayed greater activation regarding accurate judgements when compared to maybe judgements. Prior and posterior distributions of the model parameters for accuracy in terms of the Likely > Maybe contrast can be found in *Figure 4*.

Accuracy (Accurate > Inaccurate). Moderate evidence was found in support of the null hypothesis, which stated that there were no differences in YA and OA JOL Accuracy for the Accurate > Inaccurate contrast, *BF* = 1/4.06. Specifically, mPFC activation for accurate and inaccurate judgements were found to be similar for both YAs and OAs. Prior and posterior distributions of the model parameters for accuracy in terms of the Accurate > Inaccurate contrast can be found in *Figure 5*.

Accuracy (Maybe > Inaccurate). Moderate evidence was found in support of the null hypothesis, which stated that there were no differences in YA and OA JOL Accuracy for the Maybe > Inaccurate contrast, *BF* = 1/7.22. Specifically, mPFC activation for maybe and inaccurate judgements were found to be similar for both YAs and OAs. Prior and posterior distributions of the model parameters for accuracy in terms of the Maybe > Inaccurate contrast can be found in *Figure 6*.

Additional ROI Analyses

Caudal Middle Frontal Activation (ROI 1003/2003). Independent samples t-tests were conducted between YA and OA Caudal Middle Frontal activation averages for Accurate, Maybe, and Inaccurate metamemory judgments. Results indicated that there was no difference in activation averages amongst YAs and OAs for accurate judgments $t(50) = -1.485$, $p = .144$. Additionally, results revealed that there was no difference in activation averages amongst YAs and OAs regarding Maybe judgments $t(50) = .508$, $p = .614$. Finally, results indicated that there was no difference in activation averages amongst YAs and OAs regarding Inaccurate judgments $t(44) = -1.755$, $p = .086$. A comparison of these Caudal Middle Frontal activation averages in terms of YA and OA metamemory accuracy judgments can be seen in *Figure 7*.

Rostral Middle Frontal Activation (ROI 1027/2027). Independent samples t-tests were conducted between YA and OA Rostral Middle Frontal activation averages for Accurate, Maybe, and Inaccurate metamemory judgments. Results indicated that there was no difference in activation averages amongst YAs and OAs for accurate judgments $t(50) = -1.784$, $p = .08$. Additionally, results revealed that there was no difference in activation averages amongst YAs and OAs regarding Maybe judgments $t(50) = .858$, $p = .395$. Finally, results indicated that there was no difference in activation averages amongst YAs and OAs regarding Inaccurate judgments $t(44) = -.937$, $p = .354$. A comparison of these Rostral Middle Frontal activation averages in terms of YA and OA metamemory accuracy judgments can be seen in *Figure 8*.

Superior Frontal Activation (ROI 1028/2028). Independent samples t-tests were conducted between YA and OA Superior Frontal activation averages for Accurate, Maybe, and Inaccurate metamemory judgments. Results indicated that there was no difference in activation averages amongst YAs and OAs for Accurate judgments $t(50) = -1.608$, $p = .114$. Additionally,

results revealed that there was no difference in activation averages amongst YAs and OAs regarding Maybe judgments $t(50) = .648$, $p = .52$. Finally, results indicated that there was no difference in activation averages amongst YAs and OAs regarding Inaccurate judgments $t(44) = -.912$, $p = .367$. A comparison of these Superior Frontal activation averages in terms of YA and OA metamemory accuracy judgments can be seen in *Figure 9*.

Frontal Pole Activation (ROI 1032/2032). Independent samples t-tests were conducted between YA and OA Frontal Pole activation averages for Accurate, Maybe, and Inaccurate metamemory judgments. Results indicated that there was no difference in activation averages amongst YAs and OAs for Accurate judgments $t(50) = -1.323$, $p = .192$. Additionally, results revealed that there was no difference in activation averages amongst YAs and OAs regarding Maybe judgments $t(50) = .842$, $p = .404$. Finally, results indicated that there was no difference in activation averages amongst YAs and OAs regarding Inaccurate judgments $t(44) = -.326$, $p = .746$. A comparison of these Frontal Pole activation averages in terms of YA and OA metamemory accuracy judgments can be seen in *Figure 10*.

DISCUSSION

In terms of Hypothesis 1, our prediction that YA and OA distributions would be different was partially supported. Only moderate evidence in favor of the alternative hypothesis, that YA and OA magnitude activation would differ in the mPFC, was shown for the Likely > Maybe contrast. This could be due to there being a difference in terms of when YAs an OAs feel an answer is more correct, hence there could be differences in feelings of rightness (Higgins, 2000) amongst YAs and OAs when making these metamemory judgments. In contrast, seeing only moderate evidence for differences in YA and OA distributions in terms of brain activation when making metamemory judgments could be due to metacognitive processes in OAs simply being similar to that of YAs. This supports the notion that metacognitive ability may be spared in OAs (Connor et al., 1997, Hertzog & Hultsch, 2000; Hertzog, Kiddler, Powell-Moman, & Dunlosky, 2002; Hertzog, Sinclair, & Dunlosky 2010; Hines, Touron, & Hertzog, 2009; Robinson, Hertzog, & Dunlosky, 2006). Specifically, OA metacognitive ability regarding JOLs could possibly be similar to that of YAs because the neural correlates involved in metacognition remain intact throughout the aging process.

In terms of Hypothesis 2, our prediction that higher activation would be seen in additional frontal areas besides the mPFC in OAs was partially supported in terms of visible activation differences, but not supported in terms of significant differences in activation averages in YAs vs. OAs for metamemory accuracy judgments. However, there were two instances where activation differences in YAs and OAs approached significance. These included Rostral Middle Frontal activation for Accurate metamemory judgments, and Caudal Middle Frontal activation

for Inaccurate metamemory judgements. That is, although statistical YA and OA brain activation comparisons in these additional frontal regions were not significant, we do see noticeable increased activation averages in OAs in both the Caudal Middle Frontal and Rostral Middle Frontal regions. This supports the notion that additional regions besides the mPFC could possibly be recruited by OAs when making metamemory judgments, which could either be indicative of compensatory mechanisms or decreased efficiency. More specifically, the Rostral Middle Frontal region being associated with higher activation in OAs for Accurate metamemory judgments could possibly represent compensatory mechanisms being utilized (Festini, Zahodne, & Reuter-Lorenz, 2018). In contrast, the Caudal Middle Frontal region being associated with higher activation in OAs for Inaccurate metamemory judgments could possibly be indicative of decreased efficiency rather than compensation (Morcom & Henson, 2018).

Compensatory models such the Compensation-Related utilization of Neural Circuits Hypothesis Reuter-Lorenz & Cappell, 2008), the Posterior Anterior Shift in Aging (Davis et al., 2008), and The Scaffolding Theory of Aging and Cognition (Park & Reuter-Lorenz, 2009; Reuter-Lorenz, & Park, 2014) presume that OAs modify cognitive processing deficiencies via compensation, which entails "over activation" of additional regions or networks in OAs while performing memory-based tasks. More specifically, increased activation in prefrontal areas is thought to be due to different neural circuits being utilized to achieve a certain goal in terms of cognition. However, there is speculation as to whether this "over activation" of additional networks or regions may instead be indicative of inefficient neural firing within the brain instead of compensatory mechanisms (Morcom & Henson (2018)). In the current study, no behavioral age differences were found, consistent with the sparing of metamemory in older age. However, OAs showed increased brain activity when compared to YAs for the accurate > inaccurate and

maybe > inaccurate contrasts in the middle frontal gyrus. This supports the notion that additional regions besides the mPFC are recruited by OAs when making encoding-based metamemory judgments. This could be indicative of compensatory mechanisms, but additionally might represent less specific and/or efficient brain activation as opposed to proposed compensation mechanisms that are known for counteracting cognitive decline.

Limitations and Future Directions

One limitation of the current study is that our OA sample only consisted of individuals ranging from 60-74 years of age. The usual range for older adults is 60-85 years of age, so had we been able to utilize an older OA sample, we might have been able to detect a significant difference between YAs and OAs in terms of activation averages for metamemory accuracy judgements regarding the additional frontal ROIs that were utilized. Another limitation is that we only compared YAs and OAs in the current study. The inclusion of Middle Aged (MA) adults could help shed light on whether the investigated ROI activations in MAs may be different when compared to both YAs and OAs. Lastly, the additional frontal ROIs that were utilized in this study were chosen via FreeSurfer and doing so sacrificed spatial specification. Specifically, we were unable to detect the specific regions being activated withing the chosen ROIs. Possibly conducting a follow-up whole brain analysis to detect more specific regions could be useful in determining what may be happening when participants engage in metacognitive processes.

Conclusions

Individuals are faced with metamemory tasks daily. While it seems that the behavioral processes involved in making metamemory judgments may be spared in older adults, it also appears that there is more to be investigated in terms of what may be happening during neural processes. While OAs are presumed to have “less wiring,” which has been thought to initiate

"more firing," it is still a mystery as to whether this firing is always helpful. That is, instead of aiding in OA compensation mechanisms, this increase in firing could be inefficient in terms of memory success. Further research regarding whether increased activation or "firing" in frontal regions of the brain in OAs could help aid in the understanding of how the older adult brain functions when making metamemory judgments.

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APPENDIX

Figure 1

Prior (YA) and posterior (OA) distributions of the parameters describing JOL magnitude of the Likely > Maybe contrast.

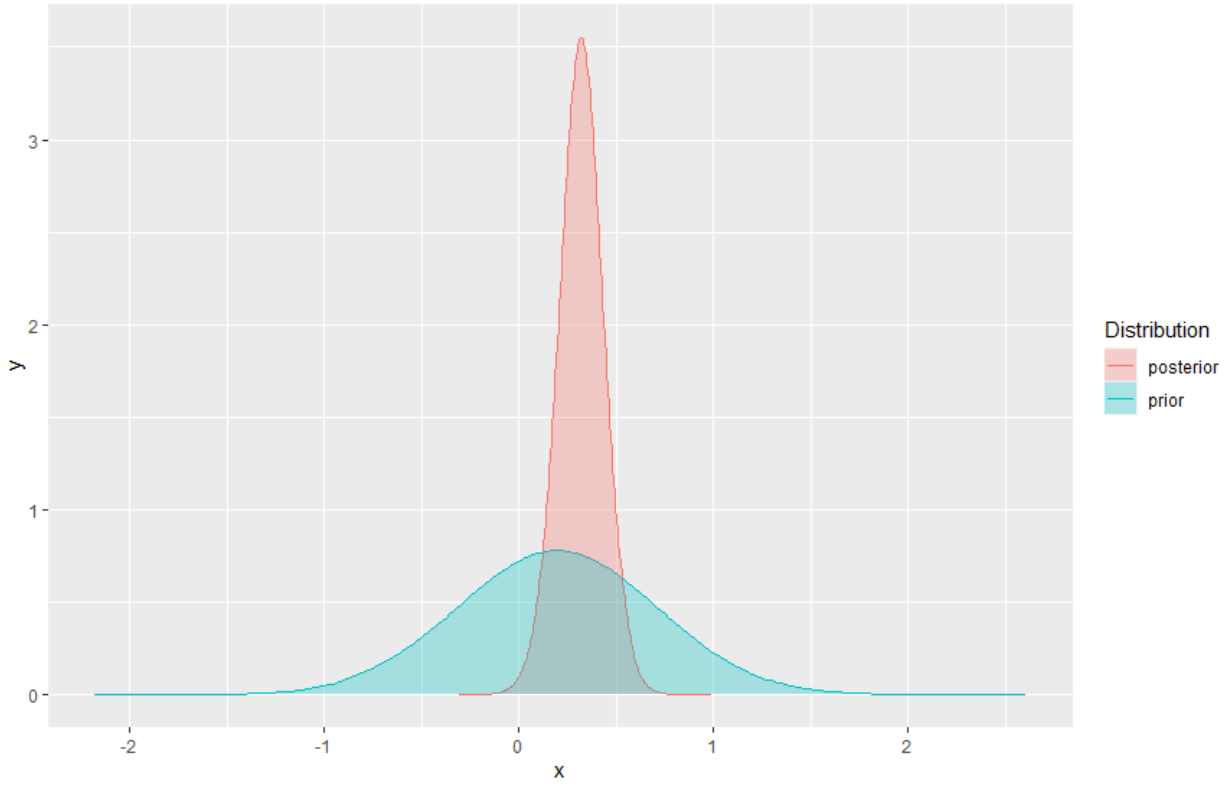

Figure 2

Prior (YA) and posterior (OA) distributions of the parameters describing JOL magnitude of the Likely > Unlikely contrast.

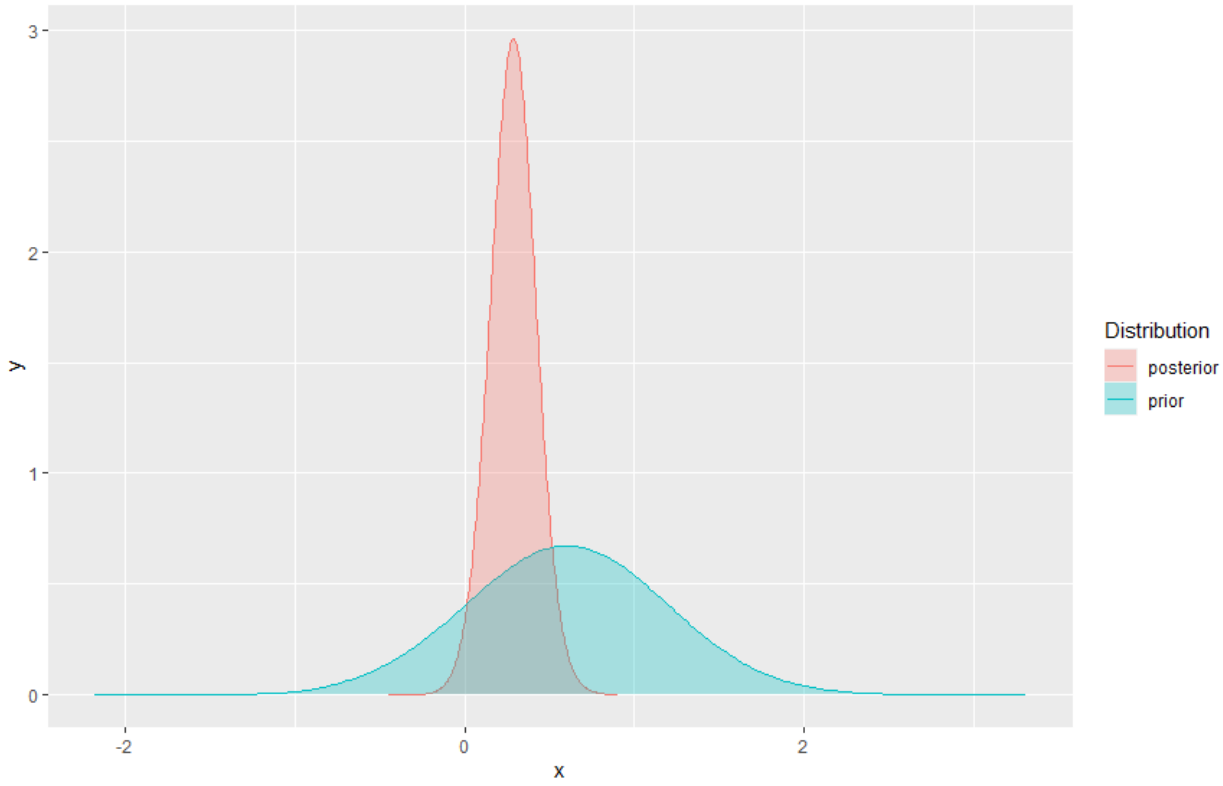

Figure 3

Prior (YA) and posterior (OA) distributions of the parameters describing JOL magnitude of the Maybe > Unlikely contrast.

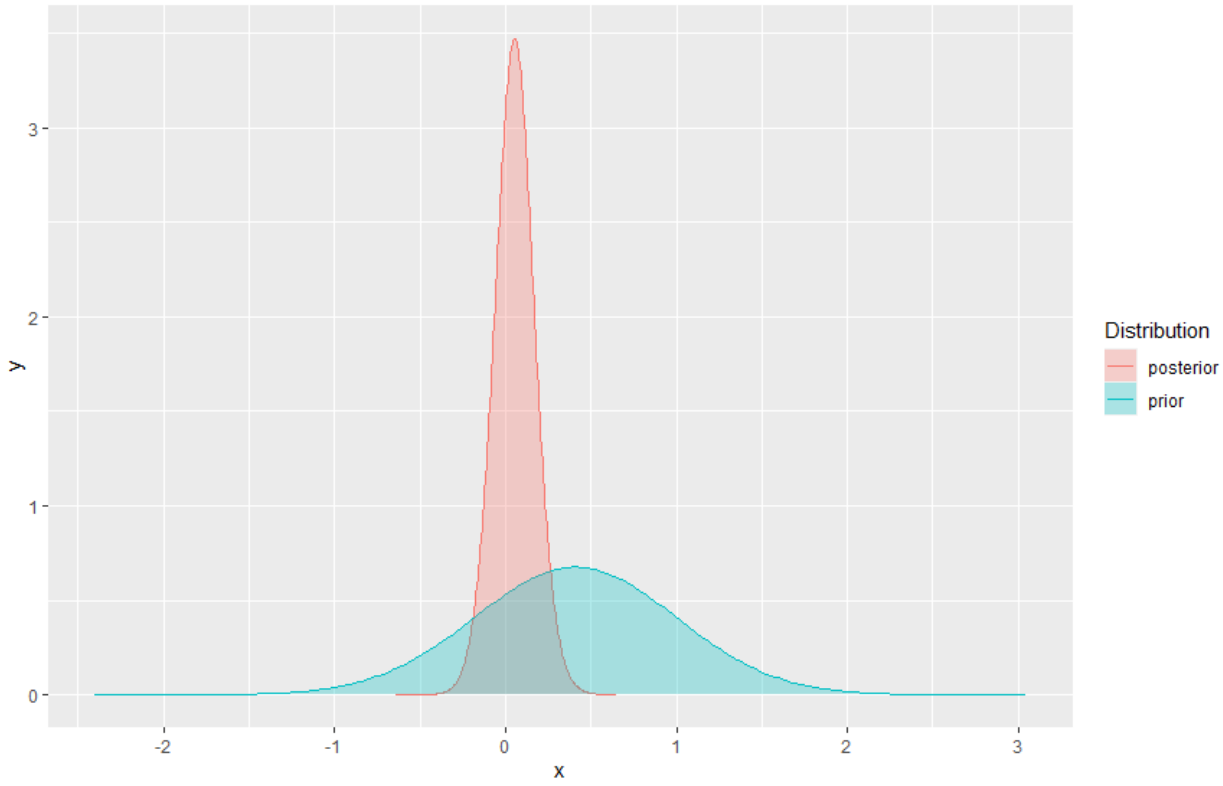

Figure 4

Prior (YA) and posterior (OA) distributions of the parameters describing JOL accuracy of the Accurate > Maybe contrast.

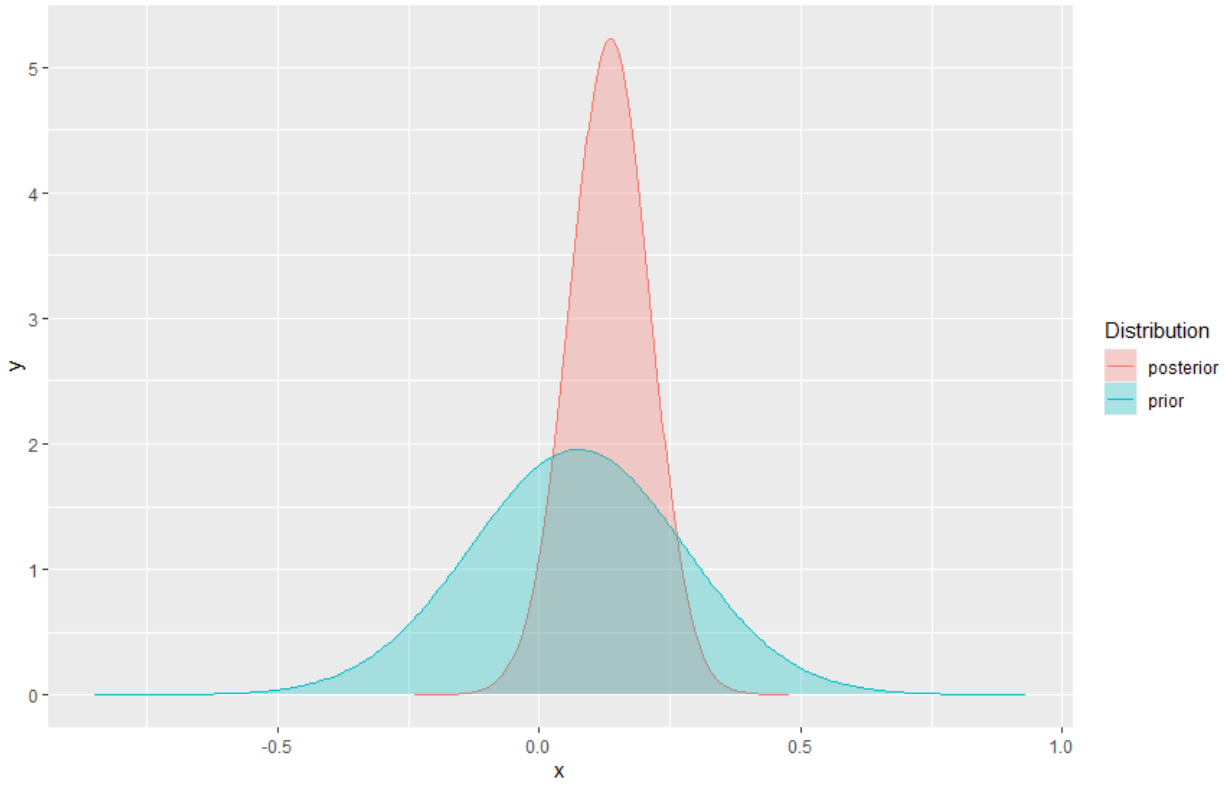

Figure 5

Prior (YA) and posterior (OA) distributions of the parameters describing JOL accuracy of the Accurate > Inaccurate contrast.

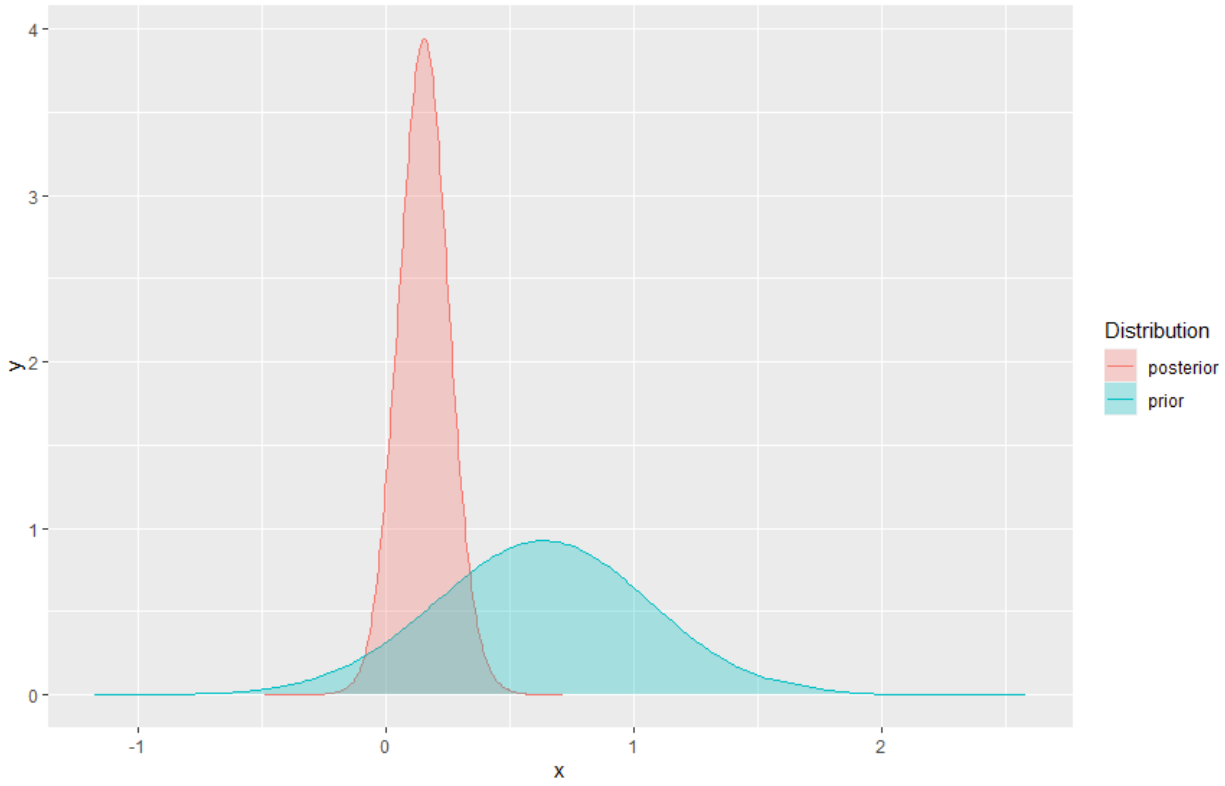

Figure 6

Prior (YA) and posterior (OA) distributions of the parameters describing JOL accuracy of the Maybe > Inaccurate contrast.

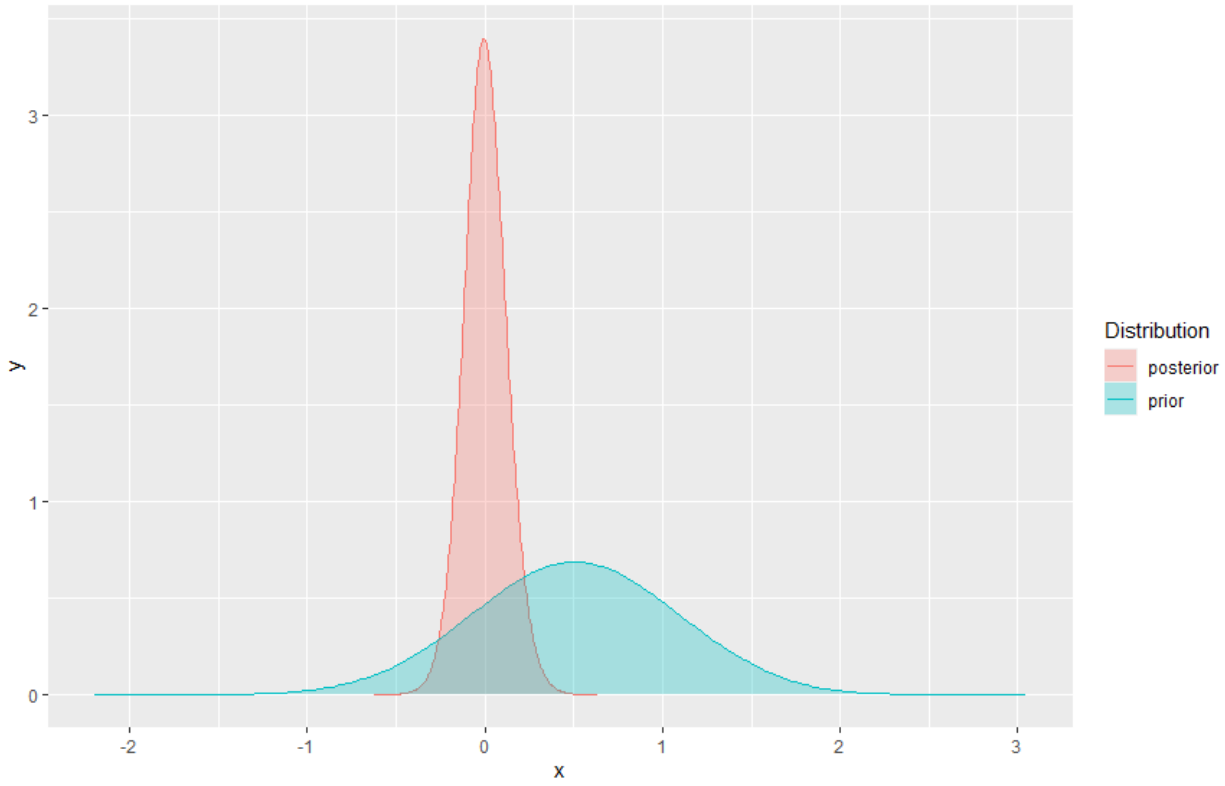

Figure 7

YA/OA Caudal Middle Frontal Activation Average Comparison for Metamemory Accuracy Judgments.

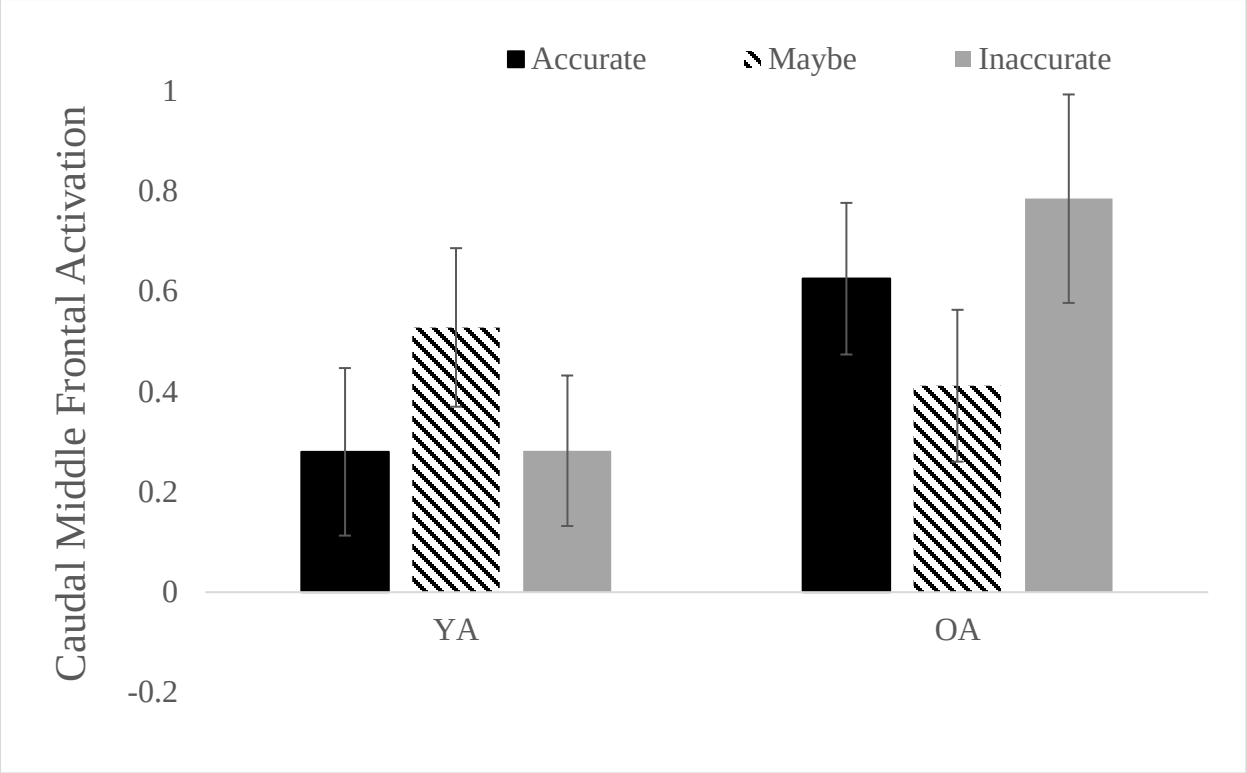

Figure 8

YA/OA Rostral Middle Frontal Activation Average Comparison for Metamemory Accuracy Judgments.

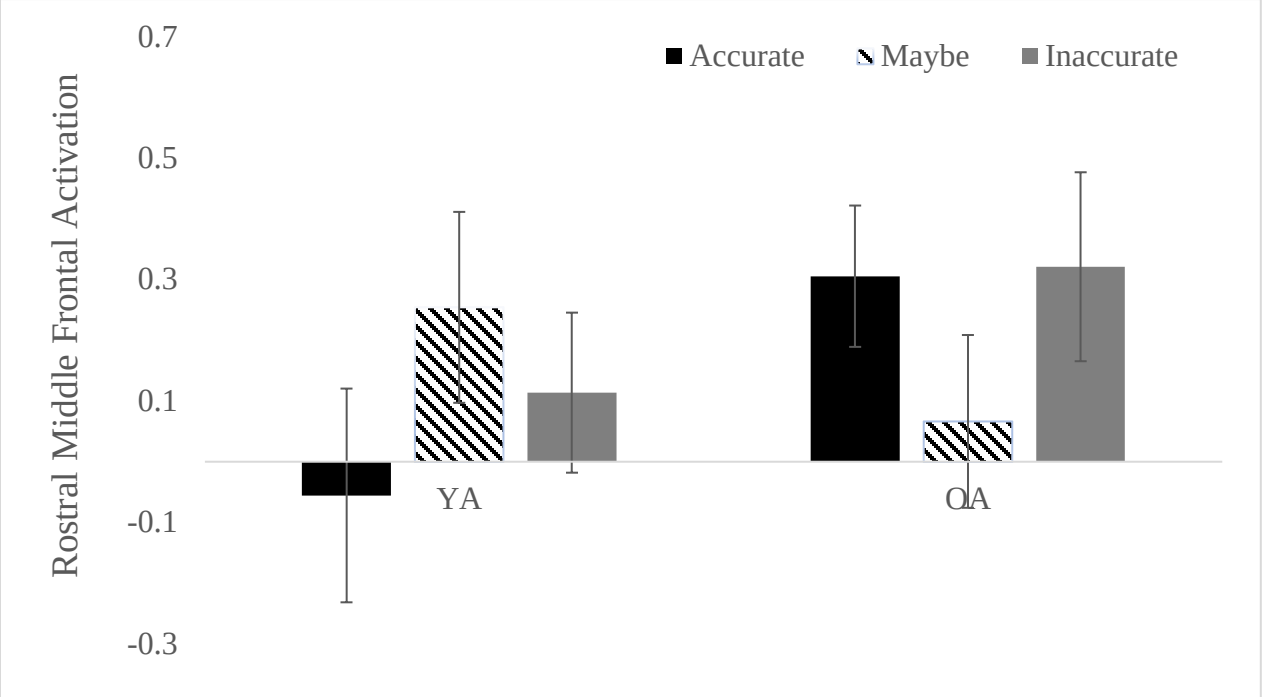

Figure 9

YA/OA Superior Frontal Activation Average Comparison for Metamemory Accuracy Judgments.

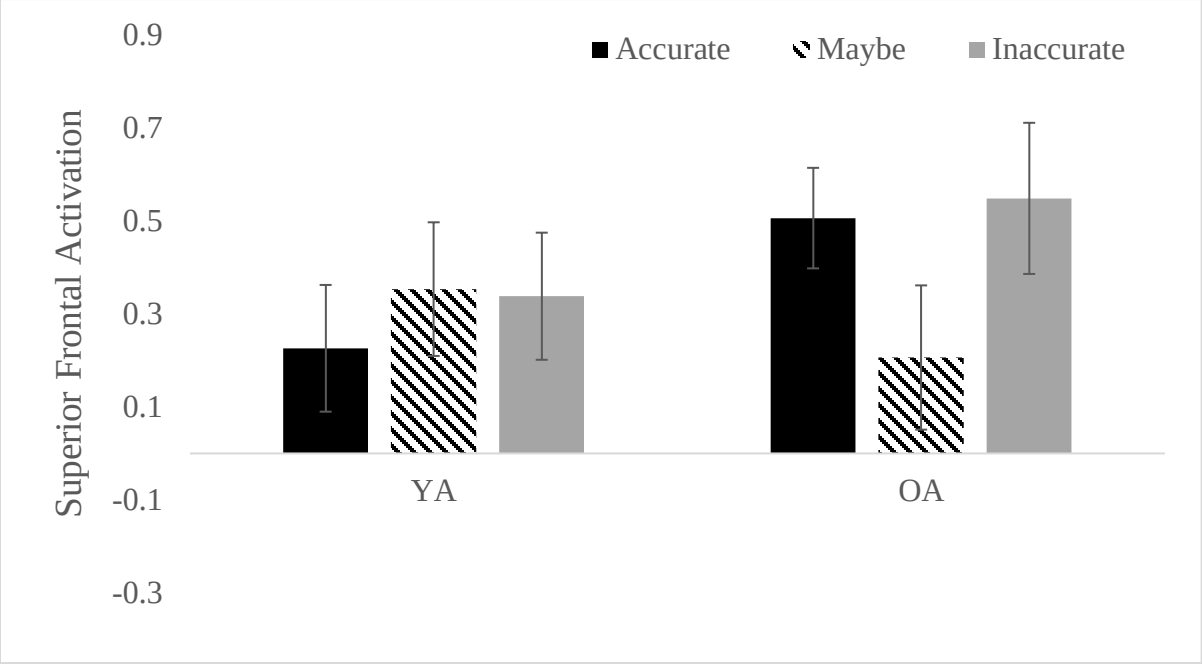

Figure 10

YA/OA Frontal Pole Activation Average Comparison for Metamemory Accuracy Judgments.