

# Individual Differences in Older Adult Frontal Lobe Function Relate to Memory and Neural Activity for Self-Relevant and Emotional Content

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## Abstract

**Objectives:** Older adults show memory benefits for self-relevant and emotional content, but there are individual differences in this effect. It has been debated whether processing of self-relevant and emotional information relies on similar processes to one another. We examined whether variation in frontal lobe (FL) function among older adults related similarly to the processing of self-relevant information as it did to emotional information, or whether these relations diverged.

**Methods:** While undergoing fMRI, participants (ages 60–88) viewed positive, negative, and neutral objects, and imagined placing those objects in either their home or a stranger's home. Participants completed a surprise memory test outside of the MRI. In a separate session, a cognitive battery was collected and composite scores measuring FL and medial temporal lobe function were computed and related to the behavioral memory performance and the neural engagement during fMRI.

**Results:** Behaviorally, FL function related to memory for self-relevant, but not emotional content. Older adults with higher FL function demonstrated reduced self-bias in memory performance. During the processing of self-relevant stimuli, independent of emotion, levels of activity in the middle frontal gyrus showed positive associations with FL function. This relationship was not driven by compensatory activity or disruptions to nonself-relevant neutral content.

**Discussion:** These findings point to divergence in the cognitive functions relating to memory enhancements for self- and emotional-relevance. The results further suggest self-relevance as a mnemonic device for older adults, especially in those with lower FL function.

**Keywords:** Cognitive neuroscience, Memory, Social cognition

It is well established that healthy cognitive aging is associated with declines in memory, but not all information is treated equally. Self-relevance can increase the likelihood of successful memory encoding (Rogers et al., 1977) as can emotion (Kensinger, 2004). Memory benefits from self-relevance and emotion extend to older adults as a group (reviewed by Kensinger & Gutches, 2017); however, it is unclear how individual differences in older adult general cognitive function relate to the benefits conveyed by socioemotional content. In particular, it is unclear whether the benefits conveyed by self-relevance and emotion may rely on overlapping processes and abilities or whether the benefits are supported by largely dissociable abilities (see Gutches & Kensinger, 2018 for discussion). Understanding how individual differences in cognitive profile relate to these effects is important for determining the efficacy of targeted socioemotional strategy deployment in older adults. In the current study, we test how individual

differences in cognitive function relate to participant memory performance and neural activity during self-relevant or emotional content processing. This approach will provide two insights: It will provide novel information about the types of cognitive abilities that underlie memory enhancements for self-relevant or emotional information, and clarify the basis of differences in memory-enhancement patterns among older adults.

Variability in cognitive function could affect the utility of self-relevant or emotional content at the time of encoding, resulting in individual differences in memory, and neural mechanisms used when processing this content. One useful way to characterize older adult cognitive function, pioneered by Glisky et al. (1995) is to distinguish performance on tasks thought to rely on frontal lobe (FL) processes (e.g., working memory, selective attention, and so on) from tasks thought to rely on medial temporal lobe (MTL) processes

(e.g., longer-term retention of information; Butler et al., 2004; Davidson et al., 2006; Kersten et al., 2018; McFarland & Glisky, 2009; Peterson et al., 2017). Presently, it is unclear whether this approach to characterizing older adult cognitive functioning, and FL processes in particular, can provide further insight into the memory benefits afforded by self-relevant or emotional information at the time of encoding.

Although the FL function examined in previous work is characterized by cognitive abilities that are typically associated with lateral prefrontal cortices (Barbey et al., 2013; Braver et al., 2001), enhanced memory for self-relevant content is associated with *medial* prefrontal cortex activity in healthy older adults (Gutchess, Kensinger, & Schacter, 2007). This is also true in individuals diagnosed with Alzheimer's disease, but the memory effect is more strongly associated with gray matter density in the *lateral* prefrontal cortex (Genon et al., 2014). Enhanced memory for both emotional and self-relevant content has been demonstrated in individuals with neurological damage affecting memory and executive function (Grilli & Glisky, 2010; Grilli & McFarland, 2011). These findings suggest that these socioemotional memory benefits do not necessarily show a relationship to or benefit from better FL functioning in older age more generally (Glisky & Marquine, 2009). Instead, the benefit may be due to the relative automaticity by which self-relevant content is processed and subsequently encoded (Humphreys & Sui, 2016; Sui & Humphreys, 2017).

Alternatively, the relationship between FL function and memory for self-relevant content may have been masked in prior experimental paradigms that utilized, but did not control for emotional content. For example, Glisky & Marquine (2009) presented participants with positive and negative personality traits under self-relevant or semantic encoding conditions and demonstrated memory enhancements for self-relevant content regardless of FL or MTL function. Without the presentation of "neutral" personality traits, it is unclear whether self-relevant or semantic encoding conditions independent of emotion relate to cognitive function generally, and FL function specifically. Similarly, Hou et al. (2019) demonstrated that memory for words was also enhanced under self-relevant encoding conditions for older adults, even for those individuals with low FL or MTL function. Although words were matched on concreteness and imageability, the emotionality was not controlled. Emotion could confound the relationship between cognitive function and memory for self-relevant content, rendering conclusions about whether FL function contributes to the processing of self-relevant information more difficult. By including neutral and emotional stimuli in the present study, we could tease apart whether the processes needed for FL function tasks are the same as those that boost the encoding of self-relevant content.

Even if self-relevant encoding relies on prefrontal processes, those may differ from the processes utilized for neuropsychological assessments of FL function. Neuropsychological measures of FL function are thought to reflect executive functioning (Glisky et al., 1995), a complex set of processes most often associated with *lateral* prefrontal cortices. By contrast, self-relevant content is processed and encoded disproportionately by the *medial* prefrontal cortex (Kelley et al., 2002; Macrae et al., 2004). Although both lateral and medial prefrontal cortices show some of the earliest age-related gray matter atrophy (Raz et al., 1997), the relative functional preservation of the medial prefrontal

cortex is thought to contribute to the preservation of cognitive processes associated with the self (Gutchess, Kensinger, & Schacter, 2007; Leshikar & Duarte, 2014). Individuals with lower executive functioning may be able to successfully utilize self-relevant information at the time of encoding, due to their reliance on medial rather than lateral prefrontal regions. To our knowledge, no study has examined older adult FL function (or MTL function), as measured by neuropsychological testing, in relation to the neural mechanisms associated with the processing of self-relevant content. The medial prefrontal cortex (PFC) is associated with successful memory for emotional content (Euston et al., 2012), so it is important to examine the relationship between FL function and the neural mechanisms associated with processing self-relevant content independent of emotion. In other words, although individual differences in older adult cognitive abilities affect many types of memory, it is currently unclear whether these differences would extend to memory for emotional and self-relevant information given the overall benefit and different neural substrates associated with processing these stimuli.

The present design fully crosses the self-relevance of material with its emotional valence, providing a clear way to disambiguate these two factors. Participants viewed positive, negative, and neutral objects and imagined the objects in self-relevant and nonself-relevant encoding conditions. The current study is a secondary data analysis. We previously reported group analyses of these data (Daley, Bowen, Fields, Parisi, et al., 2020), revealing that both older and younger adults show memory enhancements for self-relevant and emotional content, over nonself-relevant and neutral content. Consistent with similarities in memory performance, both groups showed similar engagement of posterior regions during the processing of emotional content. However, older adults additionally demonstrated more distributed cortical activity during the processing of self-relevant content. These results speak to age similarities in behavioral performance alongside differences in neural activity during our task. In the present study, we examined how *variability* in FL function among older adults relates to both behavioral and neural patterns during encoding of self-relevant and emotional content.

## Behavioral Hypotheses

Competing hypotheses arise regarding the relationship between FL function and the effect of self-relevance on memory. Because memory for self-relevant stimuli relies on relatively preserved medial PFC regions, but memory for other-relevant stimuli relies on lateral PFC regions, those with lower FL function may show greater deficits in memory for other-relevant stimuli than for self-relevant stimuli. This would predict a negative relationship between the self-relevance effect in memory and FL function. On the other hand, our task required participants to switch between imagining information in self-relevant and nonself-relevant contexts; if such switching requires successful engagement of executive functioning abilities, the self-relevance manipulation would be most effective for participants with greater FL functioning. This would predict a positive relationship between FL function and the effect of self-relevance in this task. Finally, it is possible that the relative automaticity of self-relevance processing might allow older adults to exhibit better memory for self-relevant content regardless of FL function, which

predicts no relationship between FL function and the effect of self-relevance on memory.

We did not have a hypothesis about the relation between FL function and emotion. This was an open question addressed in the current study.

Finally, given that self-relevant processing and memory are linked to prefrontal regions, we did not have behavioral hypotheses related to individual differences in MTL function.

## Neural Hypotheses

We were interested in the relationship between older adult FL function and neural activity supporting the processing of self-relevant content and emotional content, independent of memory performance. There are two competing hypotheses regarding FL function and brain activity during the processing of self-relevant content independent of emotion. First, if the present task requires participants to engage executive functioning resources to switch between self-relevant and nonself-relevant contexts, FL function may show positive associations with activity in lateral and medial prefrontal regions. That is, lateral prefrontal activity may assist context switching, whereas medial prefrontal activity may automatically assist imagining self-relevant contexts in those with higher FL function. This would be consistent with work demonstrating that although self-relevance processing is most frequently associated with medial PFC regions, the lateral PFC is sometimes associated with self-relevance processing (for review, see Northoff & Bermpohl, 2004). Alternatively, FL function could show negative associations, such that those with poorer FL function would show greater associations with PFC activity during self-relevant content processing. A negative association may indicate over-recruitment of task-related prefrontal activity to achieve the same performance level as those with higher FL function (Reuter-Lorenz & Cappell, 2008).

Individual differences in FL function may be associated with neural activity during the processing of emotional content. The frontal lobes are involved in emotion processing, as indicated above, so there are three competing hypotheses related to FL function and brain activity during the processing of emotional content independent of self-relevance. First, FL function may show positive associations with activity in the lateral and medial PFC due to successful use of these regions during emotional content processing. Second, these prefrontal regions may show overlap with, or be completely distinct from, regions identified by the analyses examining the processing of self-relevant content. Finally, consistent with our behavioral predictions, it remains possible that FL function could show no association with neural activity in frontal regions for emotional content.

## Method

### Participants

The behavioral analyses for the current study include 44 older adult participants (31 female; ages 60–88). Participants were predominantly White ( $n = 42$ ), but there was one African American participant and one Asian participant. The participant sample also completed 17.48 years of education on average ( $SE = 0.33$ ).

The fMRI analyses include 41 older adults because two participants (both female) were excluded due to excessive

movement in the scanner and one participant (male) was excluded due to an anatomical abnormality. Further details on exclusion criteria are listed in the Supplementary Materials. As indicated in the introduction, these data were part of a larger project examining age-group differences in the neural activity associated with the encoding of socioemotional content. Young adult data were not included in main analyses due to low variability in FL and MTL performance, although we present group data from the 50 younger adults (28 female; ages 18–39) with useable fMRI data as comparisons in some sections.

### Procedures

While undergoing fMRI, participants viewed images of positive, negative, and neutral objects (e.g., a cake, a snake, and a rake, respectively) and imagined either placing the objects in their home or a stranger's home, cued as "self" or "other" above each image. Next, participants indicated via button press that they imagined placing the object in the correct home. Participants viewed 252 objects (equal numbers per valence and self/other) during encoding. After approximately 30 min, they completed a surprise, self-paced recognition task outside the scanner. During recognition, 252 objects from encoding and 168 new objects (56 per valence) were presented in random order, and participants made old/new judgments. For "old" responses, participants then made a remember/know/guess judgment (Rajaram, 1993).

In a separate session, participants completed a battery of neuropsychological tests. All older adult participants completed neuropsychological tests within 2 years of the fMRI task ( $M_{\text{days}} = 77.68$ ,  $SD_{\text{days}} = 125.83$ ,  $n = 44$ ). Full results are reported in Daley, Bowen, Fields, Parisi, et al. (2020); here, we report the subset used to calculate composite FL scores and MTL scores (Glisky & Marquine, 2009; Glisky et al., 1995). The FL tests included: Digit Span Backward, Mental Arithmetic, Mental Control, and the F-A-S subtest of the Neurosensory Center Comprehensive Examination for Aphasia (Spreen & Benton, 1977). The MTL tests included: the Long-Delay Cued-Recall subtest of the California Verbal Learning Test-II (Delis et al., 1987), Verbal Paired Associates I and Visual Paired Associates II from the Wechsler Adult Intelligence Scale-IV (Wechsler, 2008), and Logical Memory I subscale of the Wechsler Memory Scale-III (Wechsler, 1997). The Modified Wisconsin Card Sorting Task (Hart et al., 1988) has been used previously (Glisky et al., 1995) to compute composite FL and MTL lobe scores, but due to concerns with data quality (high rates of ceiling effects) it was not administered for the present study.

## Analyses

### Behavioral data

Based on previous work (Glisky & Kong, 2008; Glisky & Marquine, 2009; Glisky et al., 1995), we ran a confirmatory factor analysis (CFA) on our sample's neuropsychological test scores to determine the goodness of fit of a two-factor model for FL and MTL scores. Raw scores for each cognitive task were used in the CFA (R package "lavaan" v.0.6-7; Rosseel, 2012). Following confirmation of the two-factor structure (see Results), FL and MTL composite scores were computed for each subject as follows: First, raw scores were converted to  $z$ -scores (based on the sample means and standard deviation) for each cognitive test; next,  $z$ -scores for each subject were averaged according to those

cognitive tests involved in each factor (e.g., FL =  $[z(\text{Digit Span Backwards}) + z(\text{Mental Arithmetic}) + z(\text{Mental Control}) + z(\text{F-A-S})]/4$ ). These composite scores were then used as continuous regressors in a repeated measures ANCOVA of the behavioral memory data and in each group-level fMRI model. Finally, to determine how FL and MTL function relate to memory for self-relevant and emotional content, we ran a 3 (valence: positive, negative, neutral)  $\times$  2 (self-relevance: self, other) repeated measures ANCOVA with both FL and MTL composite scores as continuous regressors and  $d'$  for “remembered” items as the dependent variable. As indicated in Daley et al. (2020), “know” and “guess” responses were not included in the behavioral or fMRI analyses due to low response rates.

### fMRI Data

#### Image acquisition and preprocessing parameters

All fMRI preprocessing and analyses were conducted using SPM12 (Wellcome Department of Cognitive Neurology, London, UK) via MATLAB version 2016a (The Mathworks Inc.) using standard preprocessing methods (motion correction, normalization, and smoothing). FMRI image acquisition and preprocessing parameters are previously reported (Daley et al., 2020).

### fMRI analyses

A general linear model was created to determine neural activity during stimulus processing independent of memory performance. Each participant's data were entered into a fixed effects model with six regressors of interest, corresponding to the stimulus conditions (*Positive-Self*, *Negative-Self*, *Neutral-Self*, *Positive-Other*, *Negative-Other*, *Neutral-Other*), a linear drift regressor and six motion regressors. Each trial was modeled as an event (duration = 2.5 s). Modeling was identical to first-level data reported in Daley, Bowen, Fields, Gutchess, et al. (2020).

Two second-level (group random effects) models were created to determine how FL and MTL function correlated with brain activity during stimulus processing. For the FL model, participant data were entered into a group-level one-way ANCOVA with one factor consisting of six levels (*Positive-Self*, *Negative-Self*, *Neutral-Self*, *Positive-Other*, *Negative-Other*, and *Neutral-Other*). The FL composite for each participant was added as a continuous regressor of interest for each level of the factor. These steps were repeated with the MTL composite as a continuous regressor.

To examine associations between FL function and the neural mechanisms supporting the processing of self-relevant and nonself-relevant content, the effect of the FL regressor on neural activity associated with processing *Neutral-Self* versus *Neutral-Other* content was examined in an  $F$ -contrast. Two other main effects  $F$ -contrasts tested associations between FL function and the neural activity supporting the processing of emotional or neutral content (examining the *Other* condition only): (1) *Positive* versus *Neutral*; (2) *Negative* versus *Neutral*. As FL function may relate to self-relevance and emotion interactions the following interaction  $F$ -contrasts were also created: (1) *Positive/Neutral*  $\times$  *Self/Other*; (2) *Negative/Neutral*  $\times$  *Self/Other*; and (3) *Positive/Negative*  $\times$  *Self/Other*.

These steps were repeated for the MTL model. MTL model results are reported in Supplementary Tables S1 and S2, given

that our hypotheses were related to FL function, and the regions identified by the MTL model showed no overlap with the FL model.

### Data reporting and visualization

In prior work (Daley, Bowen, Fields, Parisi, et al., 2020), we discussed clusters that survived an  $F$  test threshold of  $p = .005$  and a voxel extent of  $k = 40$  contiguous voxels determined by Monte Carlo simulations to correct for multiple comparisons at  $p < .05$  (Slotnick, 2017; Slotnick et al., 2003). Here we probed  $F$  tests that showed significant main effects or interactions by examining clusters that survived a  $t$  test with a  $k = 40$  cluster extent, inclusively masked with the  $F$  test at  $p = .005$ . Only clusters that survive  $k = 40$  will be discussed, but we report regions that survived a  $k = 10$  cluster extent to avoid Type II errors for future meta-analyses examining these relationships. When reporting directional patterns of activity within revealed clusters of a given interaction contrast, we did not require an exact match on the peak coordinate.

Montreal Neurological Institute (MNI) and Talairach coordinates are reported in Supplementary Table S3. Conversion from MNI to Talairach space was completed with the icbm\_spm2tal transform from GingerALE 3.0.2 (<http://www.brain-map.org/ale/>), and manually checked with the Talairach atlas (Talairach & Tournoux, 1988). Significant contrasts were visualized using MRICroGL (<https://www.nitrc.org/projects/mricrogl/>).

## Results

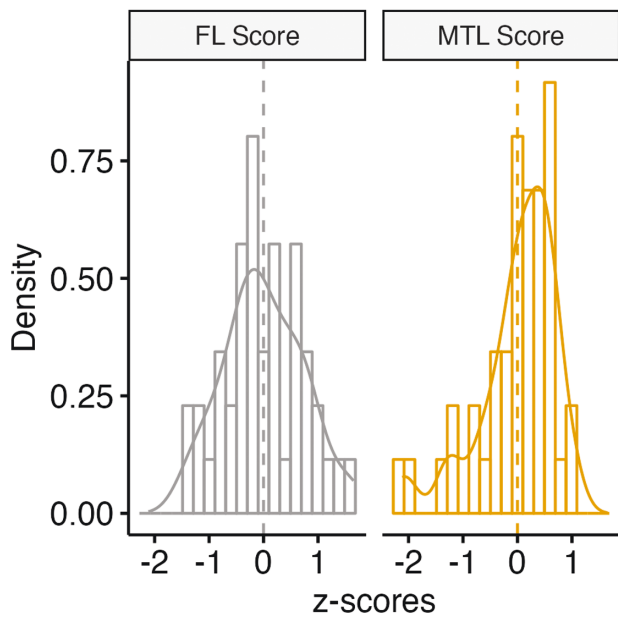
### Confirmatory Factor Analysis

Consistent with previous work (Glisky & Kong, 2008; Glisky et al., 1995) the CFA on the neuropsychological data (Table 1) indicated the two-factor structure fit the data well,  $X^2(19) = 17.56$ ,  $p = .552$ , CFI = 1.00, TLI = 1.03, RMSEA = .00 (90% CI [.00, 0.12]), SRMR = 0.074. The standardized factor loadings are reported in Supplementary Table S4. The density plot and histogram of  $z$ -scored FL and MTL composites are reported in Figure 1 (raw scores are presented in Table 1).

**Table 1.** Cognitive Testing Raw Scores

Test ( $n = 44$ )	<i>M</i>	<i>SD</i>
Frontal lobe function		
Digit backwards	8.36	2.66
Mental arithmetic	16.07	2.70
Mental control	25.09	5.22
F-A-S	45.84	10.61
Medial temporal lobe function		
California verbal learning test (long-delay cued-recall)	13.57	2.20
Logical memory I	29.16	6.02
Verbal paired associates I	24.23	7.06
Visual paired associates II	5.70	0.73

Notes: F-A-S = xxx; *M* = mean; *SD* = standard deviation.



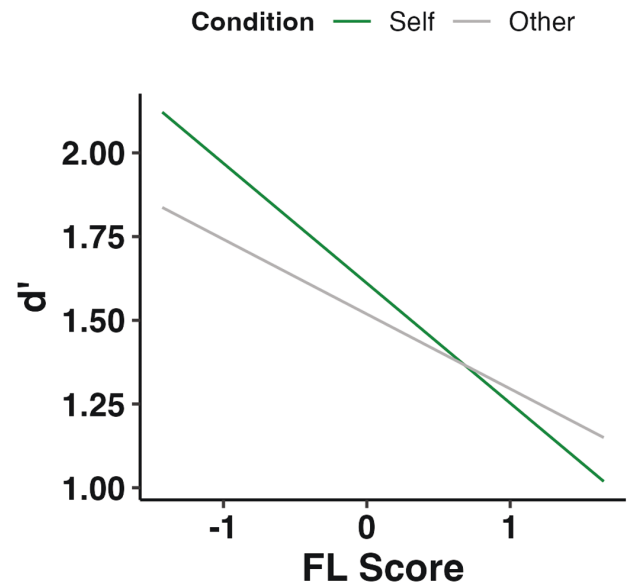
**Figure 1.** Cognitive testing composites. Distribution of cognitive testing composite frontal lobe (FL) and medial temporal lobe (MTL) scores for older adult participants ( $n = 44$ ). The dashed lines indicate the average score for each subscale.

### Memory Performance

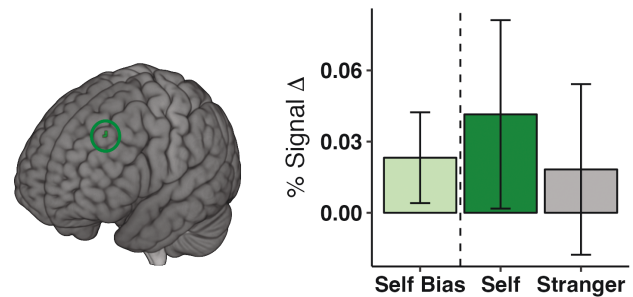
The 3 (valence: positive, negative, neutral)  $\times$  2 (self-relevance: self, other) repeated measures ANCOVA on  $d'$  that included FL and MTL composites as covariates of interest indicated a significant FL composite by self-relevance interaction,  $F(1, 41) = 6.47, p = .015, \eta_p^2 = 0.14$ . This suggests that discrimination of self-relevant objects varied at different levels of FL function. Specifically, higher levels of FL function were associated with lower self-referential enhancements in memory, or a lower “self-bias” in memory discrimination (Figure 2). Neither the FL composite by valence interaction,  $F(1.87, 76.87) = 1.16, p = .318, \eta_p^2 = 0.03$ , nor the FL composite by valence by self-relevance three-way interaction were significant,  $F(1.99, 81.70) = 1.51, p = .227, \eta_p^2 = 0.04$ . Also, the MTL composite showed no significant relationships with valence, self-relevance, or their interaction (all  $ps > .200$ ).

### FL Function is Associated With Middle Frontal Gyrus Activity During Self-Relevant Processing

The main effect  $F$ -contrast examining the relationship between individual differences in FL function and processing of self-relevant and nonself-relevant content, independent of emotion, revealed one significant cluster ( $k = 41$ ) in the left middle frontal gyrus (MNI:  $-36, 36, 46$ , BA 8/9; Figure 3; Supplementary Table S3). A follow-up directional  $t$  test revealed a significant positive association between FL scores and the processing of *Neutral-Self* > *Neutral-Other* content. This region was probed further to determine whether activity was: (1) compensatory for older adults compared to younger adults; and (2) disrupting memory discrimination for *Neutral-Other* content in older adults. To do so, we extracted parameter estimates for all six conditions for each subject, and calculated percent signal change for *Self* and *Other* content averaging across all valence conditions and dividing by



**Figure 2.** Frontal lobe (FL) function interacts with self-relevance in memory discrimination. FL score in older adults is negatively associated with behavioral self-bias (i.e., Self-Other) on memory discrimination. The regression lines reflect post hoc comparisons from the Self/Other  $\times$  FL function interaction in the behavioral ANCOVA.



**Figure 3.** Self-bias processing in middle frontal gyrus. The middle frontal gyrus cluster ( $k = 41$ , MNI =  $-36, 36, 46$ ) circled in the brain image to the left showed a positive association with frontal lobe (FL) function during the processing of *Neutral-Self* > *Neutral-Other* stimuli. Percent signal change in this region for self and other conditions, independent of FL function, was computed for older adult participants. The self-bias score was computed by subtracting percent signal change in the other condition from percent signal change in the self-condition. MNI = Montreal Neurological Institute.

baseline activity for each subject. A neural self-bias score was calculated by subtracting *other* activity from *self-relevant* activity. To test for age differences, we computed scores in a sample of younger adults ( $n = 50$ ) who completed the same paradigm (Daley, Bowen, Fields, Gutches, et al., 2020). An independent sample  $t$  test indicated that older ( $M = 0.02, SD = 0.12$ ) and younger adults ( $M = -0.02, SD = 0.15$ ) had no significant difference between their neural self-bias scores,  $t(88.99) = 1.60, p = .114, d = 0.33$ . This suggests that activity in this region was not compensatory in older adults. In older adults, the neural self-bias score also showed no significant correlation with  $d'$  scores for *Neutral-Other* content ( $r = -0.24, p = .139$ ), suggesting that activity in this region also did not disrupt memory discrimination for nonself-relevant neutral content in older adults. The neural self-bias

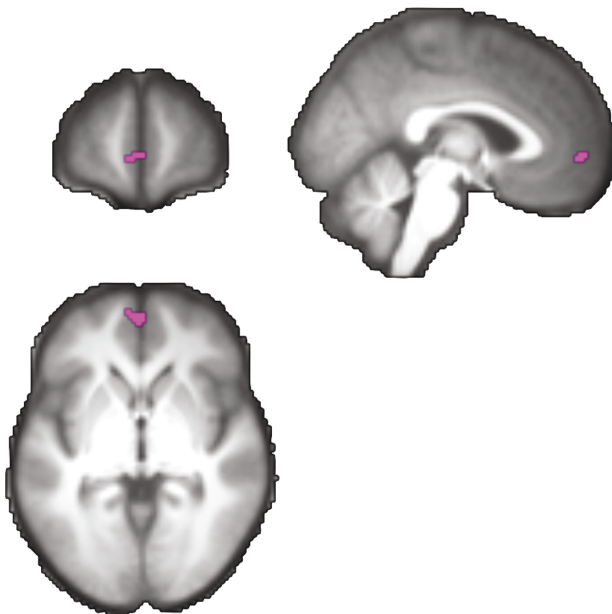
score did, however, demonstrate a significant negative correlation with  $d'$  scores for *Neutral-Self* content ( $r = -0.31$ ,  $p = .049$ ).

### FL Function is Not Associated With Levels of Neural Activity During Emotion Processing

The main effect  $F$ -contrast examining the relationship between individual differences in FL functioning and the processing of *Positive* versus *Neutral* content revealed no significant clusters. There was, however, a significant cluster identified by the main effect  $F$ -contrast *Negative* versus *Neutral* content located in the dorsomedial PFC ( $k = 51$ , BA9, MNI:  $-4$ ,  $60$ ,  $36$ ) and extending into superior frontal gyrus (MNI:  $-18$ ,  $60$ ,  $30$ ; [Supplementary Table S3](#)). Follow-up directional  $t$  tests did reveal a significant positive association between FL scores and the processing of *Neutral-Other* > *Negative-Other* content in this cluster. These findings suggest FL function does not correlate with the processing of emotional content, independent of self-relevance.

### FL Function is Associated With Ventromedial Prefrontal Cortex Activity During Self-Relevance and Emotion Interactions

The interaction  $F$ -contrast examining the relationship between individual differences in FL functioning and the *Self/Other*  $\times$  *Positive/Negative* interaction revealed a significant cluster ( $k = 41$ ) in the ventromedial PFC (MNI:  $-2$ ,  $56$ ,  $-2$ , BA 10; [Figure 4](#); [Supplementary Table S3](#)). Follow-up directional  $t$  tests revealed that FL functioning showed positive correlations with activity in this cluster for *Positive-Self* > *Positive-Other* and *Negative-Other* > *Negative-Self*. This finding demonstrates correlations in this cluster for *Self* > *Other* for positive content, but *Other* > *Self* for negative content.



**Figure 4.** Frontal lobe (FL) function is associated with self-relevance and emotion interactions in the ventromedial prefrontal cortex (PFC). FL function was associated with activity in the ventromedial PFC ( $k = 41$ ; MNI:  $-2$ ,  $56$ ,  $-2$ ) during the processing of *Positive-Self* > *Positive-Other* stimuli and *Negative-Other* > *Negative-Self* stimuli. MNI = Montreal Neurological Institute.

Individual differences in FL function also positively correlated with increased activity in the lateral inferior frontal gyrus (MNI:  $-30$ ,  $44$ ,  $-20$ , BA 47; [Supplementary Table S3](#)) and the superior temporal gyrus (MNI:  $68$ ,  $0$ ,  $2$ , BA 22; [Supplementary Table S3](#)) during self-relevance by emotion interactions. The lateral inferior frontal cluster was identified by the *Positive/Neutral*  $\times$  *Self/Other*  $F$ -contrast. Follow-up  $t$  tests revealed that FL function showed positive associations with activity in this region for *Positive-Self* > *Positive-Other* and *Neutral-Other* > *Neutral-Self*. Outside the frontal lobe, only a superior temporal gyrus cluster was identified by the *Negative/Neutral*  $\times$  *Self/Other*  $F$ -contrast. Follow-up  $t$  tests revealed that FL function showed positive associations with activity in this region for *Negative-Self* > *Negative-Other* and *Neutral-Other* > *Neutral-Self*.

## Discussion

In the current study, we examined whether variability in FL function among older adults relates similarly to processing and encoding of self-relevant content as it does to emotional content. Behaviorally, older adults' FL function showed associations with memory for content in self-relevant contexts, but the pattern indicated a negative relationship, such that older adults with higher FL function showed less self-bias in memory discrimination. In contrast, FL function showed no association with memory for emotional content. Neurally, FL function was positively associated with activity in the middle frontal gyrus during self-relevance processing independent of emotion, but was not associated with neural activity during emotion processing independent of self-relevance. FL function was associated with activity in the ventromedial PFC and lateral inferior frontal gyrus during self-relevance and emotion interactions (i.e., positive self-relevant and negative nonself-relevant content, respectively). Overall, the findings point to divergence in the role of cognitive profile, particularly FL function, in relation to memory enhancement for self-relevant and emotional content.

There were two competing hypotheses regarding FL function and memory discriminability. In line with our main prediction, discrimination of self-relevant objects varied at different levels of FL function. As shown in [Figure 2](#), however, higher levels of FL function were associated with *lower* self-referential enhancements. As a result, self-relevance may provide important mnemonic benefits for older adults with lower FL function. This is consistent with previous work demonstrating that self-relevance is a useful mnemonic for older adults ([Glisky & Marquine, 2009](#); [Hou et al., 2019](#)) and that self-relevant content may be processed and encoded in a more automatic fashion ([Humphreys & Sui, 2016](#); [Sui & Humphreys, 2017](#)). Our findings advance this work by demonstrating that older adults with lower FL function see greater memory benefits from employing this mnemonic strategy.

Many studies utilize paradigms that require participants to assign personality traits to the self or another person ([Glisky & Marquine, 2009](#); [Gutchess, Kensinger, Yoon, et al., 2007](#); [Yang et al., 2012](#)), and as highlighted in our previous work ([Daley, Bowen, Fields, Parisi, et al., 2020](#)), a strength of the current paradigm is the ability to separate self-relevance and emotion effects on memory. The novel manipulation of requiring participants to switch between imagining objects in their home or a stranger's home might account for the

interaction between FL function and self-relevance that did not emerge in prior research (Glisky & Marquine, 2009). This task likely required recruitment of top-down control processes, and the nonself-relevant condition (i.e., imagining objects in the stranger's home) may have required higher executive functioning abilities. For example, more executive functioning resources may be required to imagine placing an object in a novel room inside a stranger's home, compared to placing that same object in a familiar room inside one's own home. That is, familiarity with one's own home, may allow for individuals to more automatically bring an imagined room to mind as compared to the effortful creation of an imagined novel room in a stranger's home. The reduced self-bias in those with higher FL function, may reflect greater ability to efficiently engage the appropriate executive functions to process nonself-relevant content given the task instructions. As a result, the mnemonic benefit from the self-relevance condition may not be as substantial as it is for individuals with lower FL function.

The positive association between FL function and activity in the middle frontal gyrus (BA 8/9) during self-relevant processing, independent of emotion, has two potential explanations based on previous literature. First, this finding could indicate compensatory activity. Healthy older adults sometimes show over-recruitment of prefrontal regions during memory tasks to obtain similar memory performance to younger adults (Davis et al., 2008). Given that older adults performed similarly to younger adults in our previous analyses using this paradigm (Daley, Bowen, Fields, Parisi, et al., 2020), we compared the neural self-bias scores in our older adult sample to our sample of younger adults. We found no significant group differences, suggesting the positive association between FL function and self-relevant processing likely does not reflect compensatory activity by older adults in our sample. Second, this finding could indicate that activity in this region disrupted memory for nonself-relevant neutral content. This explanation seems unlikely, given that FL scores did not correlate with  $d'$  for *Neutral-Other* content, but did negatively correlate with *Neutral-Self* content.

Follow-up analyses ruled out these interpretations but as noted in the introduction, neuropsychological measures contributing to FL function are thought to reflect executive functioning (Glisky et al., 1995). Although executive function is most often associated with lateral PFC and much of the prior work examining the processing of self-relevant stimuli involves cortical midline structures (Qin et al., 2013), several studies demonstrate lateral prefrontal activity during the processing of self-relevant stimuli, and the middle frontal gyrus specifically (Gutchess, Kensinger, & Schacter, 2007; Northoff & Bermpohl, 2004; Sajonz et al., 2010). Our findings suggest that a stronger neural self-bias in this lateral PFC region during the initial processing of stimuli, may actually be detrimental for subsequent discrimination of self-relevant content in older adults. Future work using different stimuli and paradigms will provide additional information about whether this relationship between FL function and activity in the middle frontal gyrus (BA 8/9) during self-relevant processing is specific to our task.

Medial PFC regions did not appear to be associated with FL function during the processing of self-relevance independent of emotion but were associated with FL function during self-relevance and emotion interactions. Specifically, the ventromedial PFC (BA10), showed associations with FL

function during the processing of *Positive-Self > Positive-Other* and *Negative-Other > Negative-Self*. The ventromedial PFC is a region of convergence for both self-relevant and emotional content processing (Gutchess & Kensinger, 2018) and is involved in emotion regulation processes (Etkin et al., 2015). As such, the association between FL function and this region during the processing of positive self-relevant content, as well as negative nonself-relevant content, is potentially consistent with its role in maintaining a positive self-concept. Further evidence of this potential interpretation is provided by our finding that FL function showed associations with the lateral inferior frontal gyrus, another region involved in emotion regulation processes, during the processing of *Positive-Self > Positive-Other* and *Neutral-Other > Neutral-Self*.

The primary limitation of this study is that it is a secondary data analysis. Replication with larger samples that are more variable in cognitive ability is needed to test the boundaries of the self-referential enhancement in memory. Indeed, the present sample includes older adults with a relatively limited range of healthy FL and MTL functions. Individuals with more extreme cognitive decline within the range of normal cognitive functioning, or even in the realm of amnesic mild cognitive impairment or early stages of dementia, will be required to determine whether the present findings generalize and have practical implications beyond cognitively healthy older adults. Relatedly, it is unclear whether the null results reported in this study reflect true relationships or the lack of appropriate power to detect significant effects. This is especially important in the context of behavior-MTL function associations. Future replication with sufficient power to detect small to medium effect sizes may also address this limitation.

To conclude, even in the present sample of older adults within the normal range of FL function, the processing of social content and its interaction with emotional content are associated with FL function, but in different ways. Our findings point to the importance of self-relevance as a mnemonic strategy, but self-referential biases may be particularly useful for those with poorer FL function, and FL function may not support memory for emotional content. Although individual differences in older adult cognitive abilities affect many cognitive processes, it was previously unclear whether this would extend to memory for socioemotional content, which relies on different neural systems. Even with the limited range of cognitive abilities in the present sample, we demonstrated that individual differences in FL function are associated with differential neural activity, primarily in PFC regions during processing of socioemotional content.

## Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences* online.

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## Conflict of Interest

None.

## Data Availability

Data materials and analytic code transparency statement. Summary data and analytic code for behavioral analyses can be found on the Open Science Framework at: <https://osf.io/2xr78/>. Upon publication of the manuscript, group-level fMRI data will also be posted to OSF. The research conducted in this study was not preregistered.

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## Author Contributions

R. T. Daley: investigation, analysis, writing—original draft and revision; H. J. Bowen: investigation, analysis, writing—original draft and revision; E. C. Fields: investigation, analysis, writing—original draft and revision; K. R. Parisi: investigation, writing—original draft; A. Gutches: conceptualization, methodology, writing—original draft and revision, funding acquisition; and E. A. Kensinger: conceptualization, methodology, investigation, writing—original draft and revision, funding acquisition.

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