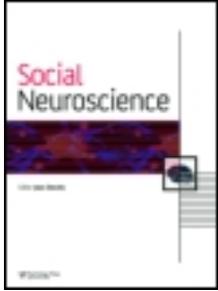


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Age-related changes to the neural correlates of social evaluation

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Recent work suggests the existence of a specialized neural system underlying social processing that may be relatively spared with age, unlike pervasive aging-related decline occurring in many cognitive domains. We investigated how neural mechanisms underlying social evaluation are engaged with age, and how age-related changes to socioemotional goals affect recruitment of regions within this network. In a functional MRI study, 15 young and 15 older adults formed behavior-based impressions of individuals. They also responded to a prompt that was interpersonally meaningful, social but interpersonally irrelevant, or non-social. Both age groups engaged regions implicated in mentalizing and impression formation when making social relative to non-social evaluations, including dorsal and ventral medial prefrontal cortices, precuneus, and temporoparietal junction. Older adults had increased activation over young in right temporal pole when making social relative to non-social evaluations, suggesting reliance on past experiences when evaluating others. Young adults had greater activation than old in posterior cingulate gyrus when making interpersonally irrelevant, compared to interpersonally meaningful, evaluations, potentially reflecting enhanced valuation of this information. The findings demonstrate the age-related preservation of the neural correlates underlying social evaluation, and suggest that functioning in these regions might be mediated by age-related changes in socioemotional goals.

Keywords: Impression formation; Aging; fMRI; Dorsomedial prefrontal cortex; Posterior cingulate gyrus.

Evaluating and forming impressions of others is an inescapable and essential part of life. Given this necessity, people possess the ability to form remarkably convergent impressions of others in as little as 100 ms (Willis & Todorov, 2006). Although it is well established behaviorally that people implicitly evaluate others and form impressions (Uleman, Saribay, & Gonzalez, 2008), research has just begun to address the neural mechanisms underlying impression formation.

Engagement of dorsomedial prefrontal cortex (dmPFC) has been widely reported to play a role in impression formation (Baron, Gobbini, Engel, & Todorov, 2010; Gilron & Gutchess, 2012; J. Mitchell,

Cloutier, Banaji, & Macrae, 2006; J. Mitchell, Macrae, & Banaji, 2005; Schiller, Freeman, Mitchell, Uleman, & Phelps, 2009) and other tasks in the social neuroscience literature, such as self-referencing (Kelley et al., 2002), self-representation (Lou et al., 2004), monitoring the actions of others (Ramnani & Miall, 2004), and representing others' psychological states (Frith & Frith, 2006). The functional neuroanatomy associated with evaluating person information, including dmPFC, has been shown to be distinct from the brain regions recruited when thinking about objects (J. Mitchell, Heatherton, & Macrae, 2002). Accordingly, dmPFC is preferentially engaged when

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forming and encoding impressions over remembering a sequence of behavioral sentences, which engages the hippocampus (J. Mitchell, Macrae, & Banaji, 2004). Whether dmPFC, implicated in social evaluation, impression formation, and mentalizing (J. Mitchell et al., 2004, 2005), undergoes age-related functional declines is largely unknown. Recent studies have proposed that, in aging, dmPFC activity does not show patterns of decline similar to other regions of prefrontal cortex (Gutchess, Kensinger, & Schacter, 2010) and possibly shows increased activity under some conditions (Williams et al., 2006).

In addition to the role of dmPFC in impression formation, forming impressions of others recruits a mentalizing network that including ventromedial prefrontal cortex (vmPFC), precuneus (PrC), posterior cingulate cortex (PCC), temporoparietal junction (TPJ), and temporal pole (TP) (Ma, Vandekerckhove, VanOverwalle, Seurinck, & Fias, 2011). The amygdala has also been implicated in impression formation, and specifically, the formation of spontaneous appearance-based impressions (Baron et al., 2010). Similar to dmPFC, the amygdala has been implicated in a host of socioemotional processes, including the ability to interpret salient social information (Anderson & Phelps, 2001), the acquisition and expression of fear responses (Whalen, 1998), and the coding of facial properties (Engel, Haxby, & Todorov, 2007). Lesion work (Todorov & Olson, 2008) has demonstrated that recruitment of the amygdala and temporal pole, but not the hippocampus, is critical in encoding and retrieving person information, and provided some evidence that this ability is age-invariant. Although the Todorov and Olson (2008) study does not directly demonstrate that the ability to make social evaluations is age-invariant, the idea that implied impressions were successfully encoded and retrieved by older adults and those with hippocampal damage suggests that the initial processing of social material is also potentially intact. Other behavioral work (Cassidy & Gutchess, in press), using a larger sample of older adults, suggested that the ability to form and remember impressions is spared with age, particularly when impressions are formed under interpersonally meaningful task conditions. Although no fMRI study has directly investigated the neural correlates of social evaluation in aging, these behavioral findings support the idea that brain regions involved in these processes may be functionally spared with age.

Behavioral work evidences the relative sparing of the processes underlying impression formation and social evaluation with age. In some cases, older adults have been shown to use behavioral information more effectively than young when evaluating others. For instance, older adults place more

emphasis than young on trait-diagnostic information when making judgments of others (Hess & Auman, 2001). Consistent with this finding, increasing age has also been associated with increased sensitivity to the addition of behavioral cues that might moderate the diagnostic value of an initial given behavior (Hess, Osowski, & Leclerc, 2005). This may reflect increased processing of social information among older adults relative to young, resulting in social inferences that better reflect others' behaviors. Recent research suggests that older adults' ability to remember impressions of others is dependent upon the context in which they learn about others' behaviors, such that increasing social relevance reduces age differences in remembering impressions, and enhances older adults' ability to successfully retrieve contextual person information (Cassidy & Gutchess, in press). This may be conceptually similar to behavioral work showing that the addition of emotional content to stimuli increases source memory, in contrast with perceptual task orientations (May, Rahhal, Berry, & Leighton, 2005; Rahhal, May, & Hasher, 2002). The relative success of older adults in processing and remembering social material potentially supports the hypothesis that, functionally, the neural regions underlying social evaluation may be preserved with age. These findings also suggest that the degree of these brain regions' engagement might depend on the socioemotional relevance of the task at hand. However, it remains unclear whether equivalent performance between age groups may stem from similar or different patterns of neural activity, such as compensation in healthy older adults (Cabeza, Anderson, Locantore, & McIntosh, 2002).

Potential qualitative difference in how young and older adults focus on incoming information could also affect the recruitment of brain regions when socially evaluating others. Socioemotional selectivity theory (SST) posits that when time is open-ended, people prioritize knowledge-related goals, and as time grows more limited with age, people prioritize goals having socioemotional meaning (Carstensen, Isaacowitz, & Charles, 1999). These goals may be especially salient among older adults in terms of improving performance, as meaningful goals have been shown to increase cognitive engagement in older adults to a greater extent than young (Hess, Follett, & McGehee, 1998). Given meaningful information and goals, older adults might selectively engage a neural mechanism for social evaluation, whereas young adults, given their focus on novelty and information acquisition (Carstensen & Mikels, 2005; Fung & Carstensen, 2003), might be less affected. For instance, Fung and Carstensen (2003) showed that older adults remember more advertisements with emotionally meaningful

versus knowledge-related messages, whereas young adults were unaffected by this distinction. The inclusion of socially meaningful orientations may similarly enhance processing of and memory for information similar to emotion-rich contexts, and the recruitment of brain regions may potentially be affected by this distinction. Indeed, the role and engagement of dmPFC may shift over the life span in response to the personal meaningfulness and self-relevant orientation of information (K. Mitchell et al., 2009).

The present work investigated how the brain regions underlying social evaluation are recruited with age. We expected that common brain regions implicated in impression formation (Ma et al., 2011), including dmPFC, vmPFC, PrC, PCC, TPJ, and TP, would be recruited among young and older adults in response to socially evaluating others versus evaluating a non-social question about the presented material. We did not expect these regions to be engaged when evaluating a non-social question about the presented material, consistent with work evidencing that dmPFC and related regions preferentially activate during social relative to non-social tasks (J. Mitchell et al., 2004). Given behavioral work suggesting that older adults place more weight on diagnostic behavioral information than young (Hess & Auman, 2001; Hess et al., 2005), we anticipated that older adults might engage these regions *more* than young when evaluating person information in a social relative to a non-social way. However, some work has demonstrated equivalent recruitment of mPFC among young and older adults during a self-reference task (Gutchess, Kensinger, & Schacter, 2007), and the age-related preservation of mentalizing circuits (Castelli et al., 2010). Therefore, young and older adults may show similar activation patterns when evaluating person information in a social relative to a non-social way. However, demonstrating that older adults show increased neural activity over young during social evaluation or that neural recruitment is age-equivalent during these processes would be novel in light of previous aging-related neuroimaging work. Much of this work uses non-social stimuli, and evidences that age-related functional decline may be compensated for by the recruitment of additional brain regions, leading to equivalent behavioral performance across age groups (Cabeza et al., 2002).

This work also addressed how brain regions involved in social evaluation may be selectively recruited among young and older adults given how individuals orient to person information. Older adults display increased cognitive engagement when task goals increase in meaningfulness (Hess et al., 1998; Hess, Germain, Swaim, & Osowski, 2009). Given

that increasing social relevance improves older adults' memories of impressions (Cassidy & Gutchess, in press; Hess, Rosenberg, & Waters, 2001), we hypothesized that older adults may display increased engagement of dmPFC and connected regions when making interpersonally meaningful social evaluations of others relative to social, but interpersonally irrelevant evaluations. We did not expect young adults to display the same bias, given their overall focus on acquiring information.

While dmPFC has been implicated in the processing of incoming person information, PCC, another region implicated in mentalizing, plays a distinct role, as it may be potentially involved in the *valuation* of incoming social material (Schiller et al., 2009). Given that young adults have goals related to knowledge acquisition, while older adults tend to focus on socioemotional material (Carstensen et al., 1999), we identified PCC as a potential region reflecting this difference. PCC has been implicated in the assignment of reward value under risky conditions (Kable & Glimcher, 2007), and, importantly, in the assignment of value to social information that guides first impressions (Schiller et al., 2009). We expected that older adults would have enhanced recruitment of this region when making social and interpersonally meaningful relative to social but interpersonally irrelevant evaluations. We hypothesized that young adults, prioritizing novelty and information acquisition, would show the opposite pattern of activity. Young adults might recruit PCC to evaluate and acquire knowledge based on social but more ambiguous person information, whereas older adults might recruit PCC for evaluating more socioemotional material.

To summarize our predictions, we expected that if the neural correlates of social evaluation were relatively spared with age, young and older adults would similarly activate these regions when socially evaluating others. However, we believed that if older adults tend to place more emphasis on diagnostic behavioral material than young, they would activate these regions more when socially evaluating others compared to making non-social judgments. Further, we anticipated that older adults' focus on social and emotionally meaningful incoming information would result in increased activity in these brain regions when making interpersonally meaningful relative to interpersonally irrelevant evaluations, whereas young adults would not display this bias. We also expected that young adults would show increased recruitment of PCC when making evaluations leading to information acquisition, whereas older adults would be more likely to engage PCC when making interpersonally meaningful evaluations, given young adults' emphasis

on gaining knowledge, and the increased focus on socioemotional information with advancing age.

METHOD

Participants

Fifteen older (61 to 85 years old, 6 men; $M = 72.80$, $SD = 6.91$) and 15 younger (20 to 29 years old, 8 men; $M = 21.13$, $SD = 3.00$) adults recruited from Brandeis University and the surrounding community participated. The Brandeis University and Partners Healthcare institutional review boards approved this study, and participants provided written, informed consent. Older adults had MMSE scores of >26 (Folstein, Folstein, & McHugh, 1975) ($M = 29.07$, $SD = 1.33$), and were characterized on cognitive measures to ensure comparability to others in the literature. Age groups were equated on years of education and vocabulary (Shipley, 1986). Young adults exhibited faster processing speed ($M = 83.60$, $SD = 14.07$) than older adults ($M = 53.87$, $SD = 9.06$), $t(28) = 6.88$, $p < .001$, using a digit-comparison measure (Hedden et al., 2002), and had higher letter-number sequencing scores (Wechsler, 1997) ($M = 12.60$, $SD = 2.80$) than older adults ($M = 10.40$, $SD = 2.77$), $t(28) = 2.16$, $p < .05$, indicating impaired executive function in older adults relative to young.

Stimuli

Ninety-six images of Caucasian faces (evenly distributed across young/old and male/female) with neutral expressions, and rated for attractiveness, distinctiveness, and trustworthiness (Gillon & Gutchess, 2012), were drawn from the PAL database (Minear & Park, 2004). Each face was paired with a unique sentence, providing information about a behavior that implies a particular trait, drawn from a data set

(Uleman, 1988) normed for trait convergence, arousal, and valence extremity by young and older adults (Cassidy & Gutchess, in press). Forty-eight sentences inferred positive traits and 48 inferred negative traits.

Procedure

Participants were told they would be forming impressions and making judgments of others. Participants practiced the task, receiving feedback on their responses, before completing the full task in the scanner. Stimuli were presented via E-Prime software (Psychology Software Tools, Pittsburgh, PA, USA).

Participants incidentally encoded 96 trait-inferring face-behavior pairs one at a time. Participants were instructed to form impressions based on the face-behavior pairs, and then to answer the prompt displayed on top of the display. To assess how task orientation affects the recruitment of brain regions associated with social evaluation, one-third of the trials directed participants to the social-meaningful evaluation (“Do I want this person to play a role in my life?”), one-third to the social-irrelevant evaluation (“Does this person have a pet?”), and one-third to the non-social evaluation (“Does the sentence contain any three-syllable words?”) (Figure 1). Participants responded “yes” or “no” to the prompts via button box. Sentences of positive and negative valence, along with the four age-gender groups, were evenly distributed among the three evaluations. Attractiveness, distinctiveness, and trustworthiness ratings of faces did not differ by evaluation condition. For the event-related design, trials were interspersed with periods of baseline (indicated by a fixation point at the center of the screen) to introduce jitter (Dale & Buckner, 1997). Intervals of fixation were obtained with the Optseq program (<http://surfer.nmr.mgh.harvard.edu/opt-seq>) and ranged from 2000 to 20,000 ms. Trials were presented for 6000 ms each.



Figure 1. Example stimuli from the three conditions. Participants were asked to form a behavior-based impression and then evaluate the person based on the prompt, which appeared directly above the face. Condition labels were not presented to participants.

Participants viewed each face–behavior pair twice through the experiment, once during the first two 8-min runs, and again during the last two 8-min runs, for a total of 32 min of functional scans. Face–behavior pairs were counterbalanced among the evaluation conditions (equated across age-gender groups and behavioral valence), totaling three versions of the paradigm. This eliminated any stimulus-specific effects on the neural engagement for each condition. Participants then completed the additional cognitive measures outside the scanner.

Image acquisition

Data were collected via a Siemens Trio 1.5T whole-body scanner, using an echo-planar imaging (EPI) sequence (TR = 2000 ms, TE = 40 ms, FOV = 200 mm, flip angle = 90°) to acquire 26 AC/PC oriented slices 3.2 mm thick with a 10% skip. Voxel-wise data were collected in 3.1 mm by 3.1 mm by 3.2 mm volumes. Stimuli were back-projected onto a screen behind the scanner, and viewed by a mirror attached to the head-coil. High-resolution anatomical images were acquired with a multiplanar rapidly acquired gradient echo (MP-RAGE) sequence.

Image analysis

Individual brains were inflated by FreeSurfer (<http://surfer.nmr.mgh.harvard.edu>), and statistical analyses of the functional data were performed with FS-FAST. Native functional volumes for each participant were slice-timed, motion corrected, spatially smoothed with a 6-mm Gaussian kernel, and normalized individually across sessions. For intersubject averaging, each participant's functional and anatomical data were spatially normalized to a common spherical surface (Fischl, Sereno, & Dale, 1999), using the general linear model with random effects.

fMRI data analyses included an event-related design comparing the neural responses across age groups. First, we compared activity associated with social versus non-social evaluation of person information by using the following subtraction: (social-meaningful plus social-irrelevant) minus non-social. That is, the trials in which participants made social and interpersonally meaningful, as well as social but interpersonally irrelevant, evaluations were contrasted to the non-social judgments. To compare how focusing on information acquisition versus socioemotional material affects the recruitment of the neural mechanism underlying impression formation and social

evaluation, we created a second contrast, using the subtraction of social-meaningful minus social-irrelevant. That is, the trials in which participants made social and interpersonally meaningful evaluations were contrasted to the trials in which social but interpersonally irrelevant judgments were made. Contrasts for young and older adults were compared in random-effects group analyses, and two-sample *t*-tests had an uncorrected threshold of $p < .001$. Significant clusters of activated voxels were identified on the basis of a Monte Carlo simulation (corrected $p < .05$). Conjunction analyses, to assess regions of common activity for both young and old age groups, were also tested in the aforementioned contrasts at a corrected $p < .05$. Locations of peak activation on the cortical surface were identified by the FreeSurfer cortical parcellation (Desikan et al., 2006; Fischl et al., 2004) and confirmed via the Talairach atlas (Talairach & Tournoux, 1988). To characterize activation maps, group-averaged data indicating percent signal change were extracted from regions of interest (ROIs) based on corrected significant clusters previously implicated in studies of social cognition.

RESULTS

Behavioral data

To verify that both age groups displayed attentional vigilance in the scanner, we analyzed response rate (proportion of recorded button presses in answering the behavioral prompts), using a 2×3 mixed ANOVA with Age Group (young, old) as a between-groups factor and Evaluation (non-social, social-irrelevant, social-meaningful) as a within-group factor. There was a significant main effect of Evaluation, $F(2, 56) = 29.92$, $p < .001$, $\eta_p^2 = .52$. While participants responded to similar percentages of prompts in the social-meaningful ($M = 0.97$, $SD = 0.03$) and social-irrelevant ($M = 0.96$, $SD = 0.04$) evaluations, $F(1, 28) = 1.10$, *ns*, they responded to fewer prompts in the non-social evaluation ($M = 0.91$, $SD = 0.07$) when compared to the social-meaningful, $F(1, 28) = 35.29$, $p < .001$, $\eta_p^2 = .56$, and social-irrelevant, $F(1, 28) = 29.83$, $p < .001$, $\eta_p^2 = .52$, evaluations. There was no main effect of Age Group, $F(1, 28) = 1.48$, *ns*, nor an interaction between Age Group and Evaluation, $F < 1$, *ns*. We also calculated the percentage of correct responses to the non-social evaluation (“Does the sentence contain any three-syllable words?”) and compared accuracy between the age groups to further assess task vigilance. Young

adults had better accuracy during the non-social evaluation ($M = 0.90$, $SD = 0.04$) than older adults ($M = 0.78$, $SD = 0.12$), $t(28) = 3.81$, $p < .01$.

Similarities with age in social evaluation

In the conjunction analysis (Figure 2) of young and older adults, socially evaluating others (social-meaningful plus social-irrelevant) versus non-socially evaluating material produced increased neural recruitment in left dmPFC, right vmPFC, bilateral precuneus, left TPJ, and left TP, all regions contributing to mentalizing (Table 1A). It also recruited bilateral fusiform gyrus, a region implicated in visual face processing. Evaluation in the non-social versus the social orientations produced common activations among young and older adults in left inferior frontal gyrus, right middle frontal gyrus, right insula, left middle temporal gyrus, and left inferior temporal gyrus (Table 1B). There were no regions of common activation for young and older adults for the social-meaningful versus social-irrelevant contrast.

Age-related differences in social evaluation

The next analysis explored age-related changes in social evaluation by contrasting young and older adults' neural activation to the social (social-

meaningful plus social-irrelevant) versus non-social evaluations. In order to characterize patterns of activation across the age groups, we analyzed percent signal change within statistically significant regions. In this contrast, older adults visually showed increased activity over young in the right TP (rTP), a region believed to store social concepts (Zahn et al., 2007) (Table 2A, Figure 3A). We then compared activation during each evaluation type between the age groups in this region (Figure 3A). While young and older adults elicited greater activation to the social-meaningful and social-irrelevant orientations versus the non-social condition, there were age differences in response to the non-social condition, $F(1, 28) = 19.07$, $p < .001$, $\eta_p^2 = .41$. Young adults recruited rTP to a greater extent than old when making non-social evaluations, $t(28) = 2.42$, $p < .05$. Older adults also displayed heightened activity in bilateral cuneus, a low-level visual processing region, when making social versus non-social evaluations. No brain regions showed greater activation for young compared to older adults in response to this contrast.

We then compared age differences in neural response to evaluating information by contrasting the social-meaningful with the social-irrelevant evaluation. Older adults visually showed increased activity in bilateral PCC and left PrC, regions associated with the mentalizing network (Table 2B, Figure 3B). These age differences varied by type of evaluation. Older adults visually showed increased activity in left, $F(1, 28) = 34.88$, $p < .001$, $\eta_p^2 = .56$, and right, $F(1, 28) = 27.52$, $p < .001$, $\eta_p^2 = .50$, PCC

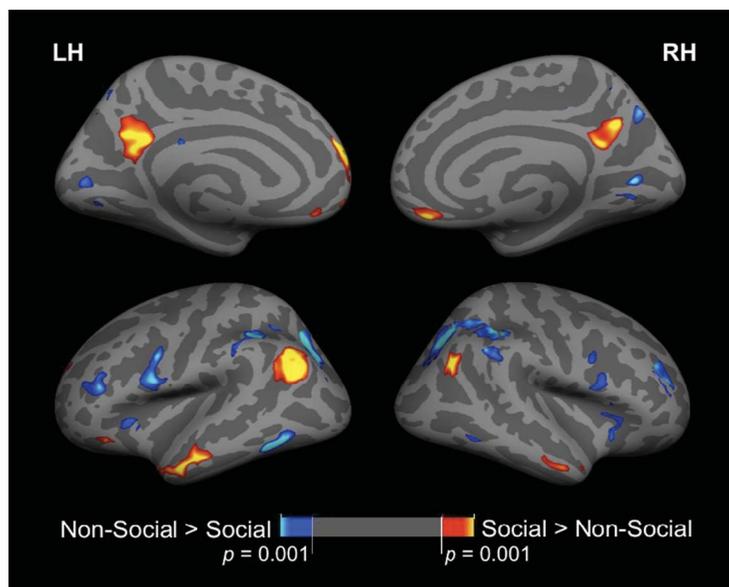


Figure 2. A conjunction analysis, shown at an uncorrected threshold of $p = .001$, determined regions of common activation between young and older adults when forming impressions in socially meaningful and socially irrelevant compared to non-social conditions (Table 1).

TABLE 1
Age similarities in response to social (social-meaningful plus social-irrelevant) versus non-social evaluations, thresholded at $p < .05$ (corrected)

| Region | Brodman area | Activation peak (x, y, z) | | | Area (mm ²) | Significance |
|---|--------------|---------------------------|-----|-----|-------------------------|--------------|
| <i>A. Social > non-social</i> | | | | | | |
| L. dorsomedial prefrontal | 10 | -8 | 61 | 12 | 385.82 | .0002 |
| R. ventromedial prefrontal | 11 | 8 | 39 | -16 | 181.59 | .02 |
| L. precuneus | 31 | -6 | -58 | 26 | 614.72 | .0001 |
| R. precuneus | 7 | 6 | -55 | 33 | 380.98 | .0001 |
| L. angular gyrus (temporoparietal junction) | 39 | -38 | -55 | 25 | 486.32 | .0001 |
| L. temporal pole/fusiform gyrus | 20/38 | -56 | -5 | -24 | 869.28 | .0001 |
| R. fusiform gyrus | 20 | 59 | -6 | -22 | 172.43 | .03 |
| <i>B. Non-social > social</i> | | | | | | |
| L. inferior frontal | 44 | -48 | 3 | 15 | 471.07 | .0001 |
| L. inferior frontal | 46 | -37 | 32 | 14 | 321.58 | .0009 |
| R. middle frontal | 10 | 33 | 35 | 21 | 392.74 | .0001 |
| R. insula | 13 | 30 | 18 | -5 | 149.10 | .04 |
| R. insula | 13 | 46 | 10 | 15 | 201.13 | .01 |
| L. middle temporal | 39 | -31 | -68 | 26 | 223.90 | .009 |
| L. inferior temporal | 20 | -52 | -54 | -11 | 336.03 | .0007 |

TABLE 2
Age differences in response to social evaluation, thresholded at $p < .05$

| Region | Brodman area | Activation peak (x, y, z) | | | Area (mm ²) | Significance |
|---|--------------|---------------------------|-----|-----|-------------------------|--------------|
| <i>A. Older > younger (social > non-social)</i> | | | | | | |
| R. temporal pole/middle temporal | 21/38 | 46 | 6 | -27 | 1419.50 | .003 |
| L. cuneus | 17 | -12 | -89 | 10 | 6146.36 | .0001 |
| R. cuneus | 17 | 13 | -82 | 5 | 6768.71 | .0001 |
| <i>B. Older > younger (social-meaningful > social-irrelevant)</i> | | | | | | |
| L. posterior cingulate | 23 | -5 | -31 | 29 | 888.85 | .056* |
| R. posterior cingulate | 23 | 3 | -27 | 25 | 2279.41 | .0002 |
| L. precuneus | 7 | -17 | -63 | 31 | 2067.74 | .0001 |
| L. inferior frontal | 47 | -27 | 29 | -11 | 994.81 | .03 |
| L. middle occipital | 19 | -46 | -72 | 10 | 1009.55 | .03 |

Notes: *Marginally significant at corrected threshold of $p < .05$, but an a priori ROI.

for this contrast compared to young. This was driven primarily by young adults' greater activation for the social-irrelevant over the social-meaningful evaluations in both the left, $t(14) = 7.20$, $p < .001$, and right, $t(14) = 7.20$, $p < .001$, hemispheres. Older adults displayed a non-significant visual trend in the predicted direction in left PCC, with increased activation in the social-meaningful relative to the social-irrelevant evaluation. In the left PrC, older adults tended to show increased activity over young, $F(1, 28) = 23.49$, $p < .001$, $\eta_p^2 = .47$. However, this was driven by more deactivation to the social-meaningful relative to the social-irrelevant evaluations among young adults, $t(14) = 5.40$, $p < .001$. Older adults also tended to

show increased activity over young in the left inferior frontal gyrus (IFG) when making social-meaningful relative to social-irrelevant evaluations, $F(1, 28) = 36.29$, $p < .001$, $\eta_p^2 = 0.56$ (Figure 3B). Interestingly, older adults displayed increased activity in social-meaningful relative to social-irrelevant evaluations, $t(14) = 2.28$, $p < .05$, whereas young adults tended to have enhanced activity for social-irrelevant over social-meaningful evaluations, $t(14) = 5.91$, $p < .001$. Older adults also displayed increased activation over young in the middle occipital gyrus. No brain regions showed significantly greater activation for young over older adults in response to this contrast.

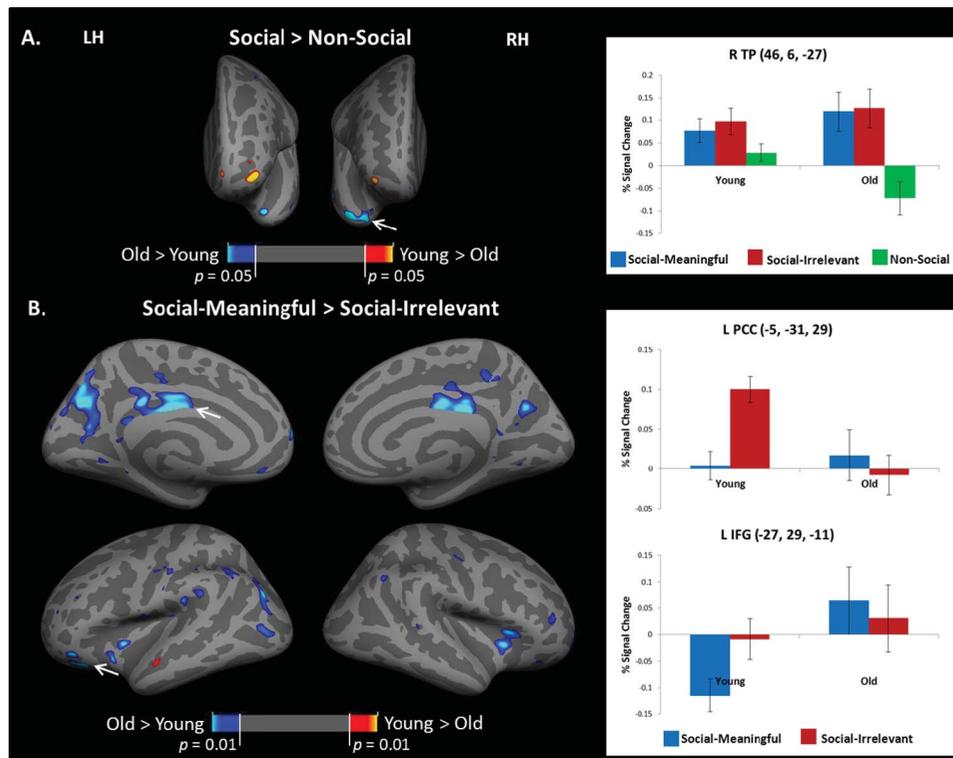


Figure 3. Age differences in response to forming impressions in socially meaningful, socially irrelevant, and non-social evaluation conditions were compared (Table 2). ROI bar graphs characterize activation maps, reflecting peak activation in each brain region categorized by age group and evaluation. Older adults showed enhanced activation relative to young in rTP in response to the two social versus non-social evaluations (A). Although older adults showed enhanced engagement relative to young adults in response to the social-meaningful versus social-irrelevant evaluations in L. PCC, this effect was largely driven by young adults' engagement in the social-irrelevant evaluation (B). In L. IFG, older adults showed significantly more engagement in the social-meaningful evaluation compared to younger adults (B).

DISCUSSION

This study investigated how age affects the recruitment of the neural correlates of impression formation and social evaluation, and how the engagement of regions within this network might vary based on age-related changes in socioemotional goals. Much research has identified decreases in prefrontal function in aging (Nyberg et al., 2010; West, 1996), with supplementary neural regions compensating for this deficit (Park & Reuter-Lorenz, 2009). However, the majority of the previous work did not use social tasks, and it is unclear whether the functional impairments extend to regions underlying social cognition, and, specifically, the engagement of medial prefrontal cortex and connected regions. Importantly, the current data extend literature involving self-referencing (Gutchess et al., 2007) and theory of mind (Castelli et al., 2010), indicating that a broad mentalizing network, including medial prefrontal regions, is involved in impression formation (Ma et al., 2011) and, functionally, is relatively spared in healthy aging. The current work demonstrates that brain regions

implicated in impression formation and mentalizing, including dmPFC, vmPFC, and TPJ—anatomically corresponding to angular gyrus in Table 1A, but functionally defined in social neuroscience literature as TPJ (Saxe & Kanwisher, 2003)—are similarly recruited among young and older adults when forming impressions and socially evaluating others.

Moreover, the current work demonstrates how the social nature of the material itself may not be enough to engage this social processing system. Previous memory research has demonstrated that successfully encoding impressions correlates with increased activity in dmPFC, whereas hippocampal engagement corresponds to trying to memorize a sequence of statements, orienting to the material in a non-social way (J. Mitchell et al., 2004). We found that making social evaluations (interpersonally meaningful and interpersonally irrelevant) relative to orienting to person information in a non-social manner increased activation in a broad network of regions implicated in social cognition, including left dmPFC, right vmPFC, bilateral PrC, left TPJ, left TP, and bilateral fusiform gyrus. Although mPFC is implicated in responding to

self-referential thought (Kelley et al., 2002), we did not find differential medial prefrontal activity when contrasting the social-meaningful with the social-irrelevant conditions across conditions or across age groups. This suggests that, regardless of age, participants recruited a number of regions involved in the processing of person information to evaluate others, differing from self-reference tasks primarily mediated by mPFC engagement.

Although dmPFC and other regions in the current work were similarly recruited with age, suggesting the functional preservation of a social evaluation network, this research also supports the idea that age-related changes in socioemotional goals and social expertise may moderate the engagement of neural regions. Behavioral work indicates that older adults can perform at the level of young when given a purposeful goal (Hess et al., 1998; Hess & Tate, 1991). Other research evidences that older adults show expertise in social situations compared to a younger cohort (Hess & Auman, 2001; Hess et al., 2005). Surprisingly, the rTP exhibited heightened activity in older relative to young adults when contrasting the social and non-social conditions. The rTP, a region implicated in mentalizing (Ma et al., 2011) and social cognition (Olson, Plotzker, & Ezzyat, 2007), has been identified as a region involved in storing information regarding social behaviors (Zahn et al., 2007). Although not predicted a priori, enhanced activation in rTP among older adults relative to young seems consistent with the growing literature on this region (Beadle, Yoon, & Gutches, *in press*), potentially indicating that older adults rely on stored social experiences to evaluate others, based on their greater accumulated life experiences relative to young. This speculatively provides potential neural evidence supporting behavioral findings of enhanced social mastery in older adults relative to young. Older adults showed deactivation in rTP while making non-social evaluations, while young adults engaged this region during these decisions, although to a lesser extent than when making the two social evaluations. This may demonstrate that young adults can more successfully access social resources in the presence of a distracting and irrelevant task. Notably, when comparing activity related to the social-meaningful and social-irrelevant evaluations (see Figure 3A), older adults did not show differential activity within rTP. This suggests that older adults recruit rTP to evaluate different kinds of social questions, and do not solely focus on interpersonally meaningful incoming information.

When comparing the social-meaningful and social-irrelevant evaluations, activity between young and older adults differed in bilateral PCC. This may

reflect age-related changes in the prioritization of incoming information. Socioemotional selectivity theory posits that while young adults focus on novelty and information acquisition, older adults concentrate on information with heightened socioemotional meaning (Carstensen et al., 1999; Fung & Carstensen, 2003). Interestingly, a recent fMRI study of impression formation noted that while dmPFC is recruited to process person information, PCC engagement may reflect the valuation of this incoming person information, such that PCC activity during impression formation corresponds with the subsequent strength of evaluations (Schiller et al., 2009). In the current study, older adults had increased PCC activity over young in the social-meaningful versus social-irrelevant contrast. This difference was largely driven by young adults' increased activity during the social-irrelevant evaluations. This potentially reflects young adults' focus on knowledge-related goals, in that given an ambiguous question (e.g., pet ownership), young adults may have taken the time to consider the possibilities when evaluating others, whereas older adults may have chosen to reserve cognitive effort for a more personally engaging task.

Other work, however, suggests that PCC activity may be related to appearance-based over character-related judgments (Moran, Lee, & Gabrieli, 2011), and highlights PCC's role in attentional processes (Pessoa & Padmala, 2005). In this light, the increased activity in PCC for young over older adults for the social-irrelevant condition might not be related to value assignment per se, but actually represents attention required to extrapolate knowledge from ambiguous information. Regardless, an attention-based framing may still support young adults' overall emphasis on information acquisition over older adults, given that older adults might be less likely to concentrate and exert cognitive effort on judgments lacking social meaning.

Unexpectedly, older adults showed increased activity for the social-meaningful evaluations in left IFG, when compared to young adults. Although not as widely cited in impression formation literature, IFG has been implicated in processing intentions of observed actions (de Lange, Spronk, Willems, Toni, & Bekkering, 2008), and as indicating the degree of self-relevance (Kelley et al., 2002). Older adults showed greater activation in this region for making socially meaningful over social, but interpersonally irrelevant, judgments while young adults did not. Heightened activity in this region in older over young adults for the social-meaningful evaluations may illustrate that these evaluations held greater semantic meaning for older adults, given that left IFG has been implicated in semantic processing (Fiez, 1997), and in retention

of semantic meaning (Hamilton, Martin, & Burton, 2010). We speculate that this may reflect older adults' prioritization of processing information with emotionally and socially meaningful content (Carstensen et al., 1999; Fung & Carstensen, 2003; Hess et al., 1998). Consistent activation in this region for older adults during the two social evaluations could also indicate the labeling of incoming social information as salient, influencing recruitment of the neural mechanism underlying social evaluation, given a recent study suggesting that attenuation in left IFG activity represents the filtering out of irrelevant information in order to highlight the salience of human but not non-biological action (Chong, Williams, Cunnington, & Mattingley, 2008).

Given that our sample consisted of well-educated and active older adults, these results may not generalize to the entire older adult population. Because the older adults who volunteered for this study had relatively active lifestyles, this may have buffered the cognitive decline that may have been more apparent in a more sedentary cohort. The "use it or lose it" approach to cognitive decline (Hultsch, Hertzog, Small, & Dixon, 1999) would suggest that the regions involved in social evaluation remained well preserved with age, although recruitment of some of these regions may be modulated due to an increased focus on socioemotional information relative to young, because forming impressions and evaluating others is such an important part of an active lifestyle. Furthermore, even though our sample of older adults engage these processes much like young adults, it is difficult to know the extent to which forming impressions of others in the scanning environment captures everyday interactions with others in a natural environment.

Although the age groups display similar recruitment of regions involved in social evaluation, suggesting that our older adults may be immune from age-related decline, it is important to note that they performed worse than young adults on tasks of processing speed and executive function. This suggests that our sample of older adults is similar to those in fMRI studies showing age-related decrements in functionality (Gazzaley, Cooney, Rissman, & D'Esposito, 2005; Hedden & Gabrieli, 2004). To address whether the preserved activation of brain regions underlying social evaluation resulted from our active and well-educated sample of older adults, a potential follow-up study could include a task where older adults would be expected to show decreased performance or neural activation.

Additionally, differences in pet ownership experience between the age groups could have contributed to differential activation to the social-irrelevant

evaluation, which was framed as a question of pet ownership. However, an assessment of pet ownership characteristics between the age groups¹ revealed that more older participants currently owned pets than young participants, and that older adults reported more years living with and percentage of time per day with pets than young adults, although all young participants had lived with pets in the past. Additionally, young and older adults did not differ in the degree of personal connection to their pets. Thus, differential neural activity to the socially irrelevant evaluation involving pet ownership cannot be solely due to age differences in the self-relevance of the question itself. Rather, the ambiguity of determining pet ownership question may have caused increased activation among young relative to old in the social-irrelevant condition if young adults took time to consider the possibilities of pet ownership in an unconscious effort to acquire knowledge, whereas older adults did not.

Notably, although both young and older adults exhibited neural recruitment of dmPFC during social evaluation, we cannot establish whether both groups similarly generated impressions without corresponding behavioral data from the present study. However, previous behavioral findings support the idea that the generated impressions may indeed be similar and that if anything, older adults may show more consistent use of behavioral information than young. For instance, older adults assess diagnostic behavioral material to a greater extent than young in some circumstances (Hess & Auman, 2001; Hess et al., 2005). Furthermore, recent work has also found that older adults infer target traits more accurately than young (Cassidy & Gutchess, in press).

It is important to note that the potential age-related preservation of the neural correlates of social evaluation may not extend to all aspects of social cognition. Although our study extends research on self-referencing (Gutchess et al., 2007) and theory of mind (Castelli et al., 2010), supporting age-invariance in brain function during these social tasks, functional impairments may not become apparent until these social processes are studied under different task conditions. Future work must not only test the reliability

¹ Six young and 8 older participants identified themselves as current pet owners. All young and 11 older participants identified themselves as having owned pets in the past. Older adults reported having lived more years with a pet ($M = 33.27$, $SD = 21.08$) than young ($M = 8.73$, $SD = 7.49$), $t(24) = 4.19$, $p < .001$, and as spending a greater percentage of the day (when not sleeping) with their pets ($M = 32.10$, $SD = 25.25$) than young ($M = 14.46$, $SD = 11.69$), $t(22) = 2.31$, $p < .05$. Young and older adults reported similar degrees of connectedness to their pets, as indicated on a 1 (none) to 7 (very much) scale.

of this finding in different contexts (e.g., cognitive load), to assess the extent of preserved functionality within these brain regions, but also test the extent to which older adults can remember these impressions. While findings showing that the recruitment of neural regions underlying impression formation is relatively stable with age are important, this information cannot be used to anticipate the future behaviors of others unless the impressions are successfully encoded into memory. Although some work (Todorov & Olson, 2008) suggests that the ability to remember impressions is age-invariant, other research has demonstrated that older adults receive disproportionate benefits in memory when evaluating relationship-based questions after forming impressions (Cassidy & Gutchess, in press). This suggests that the regions underlying the successful retrieval of impressions might depend on how individuals orient to information at encoding. The hypothesis that memory for impressions is preserved with age, however, needs to be tested by fMRI in a subsequent memory paradigm to extend the current work and clarify how the engagement of the neural correlates of social evaluation may change with healthy aging.

These findings add to a burgeoning literature on the social neuroscience of aging, and provide the first evidence that, with advancing age, the neural underpinnings of social evaluation may remain functionally intact. These findings show that functionality in brain regions underlying social cognition may be preserved with age, in contrast to influential work showing age-related functional decline and compensatory mechanisms (Cabeza et al., 2002; Hedden & Gabrieli, 2004). Importantly, we also show that age-related changes to socioemotional goals may modulate the recruitment of regions within this social processing network. Future work can clarify how aging impacts how the impressions underlying these social judgments are transferred into memory, and how aging may affect the neural substrates of other social decisions.

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