

Selection requirements during verb generation: differential recruitment in older and younger adults

Jonas Persson, Ching-Yune C. Sylvester, James K. Nelson, Kathryn M. Welsh, John Jonides, and Patricia A. Reuter-Lorenz*

Department of Psychology, University of Michigan, Ann Arbor, MI 48109-1109, USA

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Age-related differences in cognitive performance are well documented. These differences are most pronounced during tasks with high demands on cognitive control, and it has been proposed that selective alteration of prefrontal activity is associated with cognitive changes in old age. Here, differences in the neural systems underlying selection requirements for older and younger adults were investigated using functional magnetic resonance imaging (fMRI). A verb generation task was used, and selection requirements were varied with regard to whether each noun could be associated with either few (scissors—cut) or many (ball—bounce, kick, throw...) competing alternatives. The two age groups showed statistically equivalent behavioral performance across the task conditions but marked differences in activation. Across both age groups, high selection demands activated several regions including bilateral frontal, left anterior frontal, left inferior temporal regions, and the dorsal anterior cingulate cortex (ACC). Between-group comparisons using region-of-interest analyses revealed less activation for senior adults in left inferior frontal gyrus (IFG), left inferior temporal gyrus, and the anterior cingulate and higher activation in right inferior frontal gyrus compared to young adults. These findings indicate age-related changes in multiple regions contributing to aspects of selection requirements during verb generation.

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Introduction

Age-related decline in various cognitive domains such as memory is well documented (Craik and Salthouse, 1999). In particular, senior adults often experience more difficulties than

younger adults on memory tasks with high demands on control processes (Craik, 1977; Moscovitch and Winocur, 1995). There is a growing consensus that the prefrontal cortex (PFC) undergoes anatomical and functional deterioration as a function of normal aging, and it has been proposed that dysfunction of frontal systems may underlie age-related cognitive decline (Raz et al., 1997; West, 1996). Here, we test this hypothesis using functional magnetic resonance imaging (fMRI), focusing on the role of prefrontal regions, and more specifically, the left inferior frontal gyrus (IFG).

Substantial research has shown that left IFG is activated when tasks are complex and the demands on cognitive resources are high. A common interpretation of this result is that this specific region is activated when novel or weakly associated representations are temporarily assembled to solve the task at hand and at the same time suppress other potential, but context-inappropriate, representations (Buckner, 2003; Duncan and Owen, 2000; Miller, 2000; Nolde et al., 1998; Thompson-Schill et al., 1997). Tasks in which responses are based on a straightforward match between a cue and a specific representation does not appear to engage these prefrontal regions. In a long-term memory framework, however, left IFG seems to play a role in the active selection of representations, possibly by means of interacting with posterior regions in temporal and parietal cortex that operate as storage sites. In one study (Thompson-Schill et al., 1997), subjects were asked to generate an appropriate verb in response to a visually presented noun. Two different generation tasks were used, one where the nouns had multiple alternative responses (high selection demands), and one task in which there was a clear dominant response to the noun (low selection demands). It was found that higher activity in left IFG was associated with the former task, in which there were several valid responses to a noun (i.e., higher demands on selection). These results suggest that, as a cognitive task gets more complex, the demand for top-down control of behavior increases and left inferior prefrontal regions are recruited.

As previously discussed, senior adults are selectively impaired in tasks with high demands on effortful processing and cognitive control (Hasher et al., 1991; Moscovitch and Winocur, 1995; Salthouse, 1996). Therefore, it is reasonable to believe that left IFG

* Corresponding author. Department of Psychology, University of Michigan, 525 East Hall, Ann Arbor, MI 48109-1109. Fax: +1 734 763 7480.

E-mail address: parl@umich.edu (P.A. Reuter-Lorenz).

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may show differential patterns of activation in senior adults compared to younger adults when demands on selection between competing alternatives are high. There is support for this interpretation from working memory studies. It has been shown, for example, that activity in left IFG is enhanced when young adults need to resolve conflict among competing representations in a verbal working memory task (Jonides et al., 2000). In this study, older adults were more sensitive to increases in conflict resolution than young adults (as reflected by their inferior performance), and they had less recruitment of left IFG under conditions of high conflict resolution. This finding suggests a selective underactivation of left IFG in old age. There is also evidence that focal brain damage involving IFG selectively disrupts performance on verb generation tasks that require high demands on cognitive control (Thompson-Schill et al., 1998).

In this study, we used the verb generation task of Thompson-Schill et al. (1997) to investigate the role of IFG in older and younger adults. We hypothesized that senior adults, who often have more difficulties on tasks with high demands on cognitive control, would show a selective underactivation in left IFG compared to young adults. Also, based on the previous evidence for age-related overrecruitment (Cabeza et al., 2002; Logan et al., 2002; Reuter-Lorenz, 2002), we expected to observe age-related differences in right homologous regions of left IFG. Several papers have reported that senior adults often recruit bilateral frontal regions on tasks in which young adults typically activate unilateral prefrontal regions. This is true for both working memory (Reuter-Lorenz et al., 2000) and episodic memory tasks (Cabeza et al., 1997; Logan et al., 2002; Madden et al., 1999). From this perspective, senior adults may specifically overactivate right IFG during tasks with high selection demands, possibly to compensate for age-related cognitive decline.

In addition to IFG activation, the anterior cingulate cortex (ACC) is often recruited under task conditions in which a response is not strictly constrained by the task context, as in verb generation tasks (Barch et al., 2000; Frith et al., 1991; Petersen et al., 1988; Thompson-Schill et al., 1997). ACC is also recruited in conditions with high demands for cognitive control (Milham et al., 2001, 2002) or in cases in which there is a high degree of competition between responses (Nelson et al., 2003). Thus, we hypothesized that the ACC would be more involved in the verb generation task with high selection demands (multiple potential responses) than with low selection demands (one or few potential responses). In addition, age-related differences in activation in the ACC may reflect the failure of senior adults to appropriately engage these cognitive control mechanisms.

Material and methods

Participants

The participants were 22 young adults (10 male; age range: 18–30 years) and 22 senior adults (12 male; age range: 60–80 years). Participants were recruited from local newspapers and posted advertisements, and completed a health screening. All participants were right-handed and had no existing neurological or psychiatric illness. None of the participants were taking medications or had a medical condition that could affect blood-oxygen levels (e.g., high blood pressure). All participants gave informed consent, and the study was approved by the University of Michigan institutional review board. All were native English speakers with normal vision

or vision corrected to near normal using MRI compatible glasses or contact lenses. Senior participants were excluded if they scored below 25 on the Mini-Mental State Examination (MMSE, Folstein et al., 1975). None of the participants that attended the prescanning session were excluded based on this criterion. Although one senior participant did score a 25 on the MMSE, the scores were overall high (mean = 28.6, SD = 1.3).

In a separate pilot study, 22 young adults (11 male; age range: 18–30 years) and 22 senior adults (11 male; age range: 60–80 years) were included. Participants were recruited and screened using similar criteria as the fMRI study.

All participants were paid US\$10–20 per hour for the experiment, and senior participants were additionally paid for their travel time to campus.

Behavioral methods

Potential participants first completed a comprehensive health screen over the telephone to ensure their suitability for the study. The study itself consisted of two separate sessions: neuropsychological pretesting (for senior adults only) and fMRI scanning with neuropsychological posttesting. The fMRI scanning took place at the MRI research facility, and the neuropsychological pretesting, completed exclusively for seniors, occurred in the laboratory testing space of the Psychology Department building on a separate day. In all statistical analyses (neuroimaging and behavioral), an effect was considered significant if it reached a threshold of $P < 0.05$, and a threshold of $P < 0.1$ was used for considering an effect a trend.

During the neuropsychological testing, senior participants were given the MMSE, the Wisconsin Card Sorting Test (WCST, Heaton, 1981), the California Verbal Learning Test (CVLT, Delis et al., 1987), the Dysexecutive Questionnaire (DEX, Burgess et al., 1996), Trails A and B (Reitan, 1958), Reading Span (Daneman and Carpenter, 1980), the Verbal Fluency Test (a.k.a. FAS/Animal Benton, 1968), the following tests included in the Wechsler Adult Intelligence Scale-III (WAIS, Wechsler, 1997): Digit-Symbol Coding, Block design, Forward/Backward Digit Span, Letter-Number Sequencing, and Vocabulary, and the following test included in the Wechsler Memory Scale (WMS-R, Wechsler, 1987): Logical Memory I, Visual Paired Associates, and Verbal Paired Associates (see also Table 1).

Table 1
Mean scores and standard deviation (SD) for the demographic and neuropsychological data

	Young	Senior
<i>Demographics</i>		
<i>n</i>	22	22
Age	21.9 (2.0)	68.8 (5.1)
Gender (M:F)	12:10	10:12
Education (years)	3.8 (1.2)	4.2 (2.9)
<i>Neuropsychological</i>		
Fluency		
Overall	72.7 (12.0)	60.7 (14.4)
Semantic	25.6 (4.1)	18.4 (5.1)
First-letter cue	16.2 (3.8)	14.3 (4.7)
Vocabulary	52.8 (5.7)	55.5 (7.4)
Letter-number sequencing	14.8 (2.6)	11.2 (2.2)
MMSE ^a	–	28.6 (1.3)

^a MMSE collected as a screening criterion for seniors (min = 25).

On the day the participants came in for the scanning session, they first participated in a short practice session. During practice, they were shown a blocked series of 24 nouns (12 “generate” and 12 “read”) on the computer screen at 4.5-s intervals. They were instructed on how to perform the verb generation task silently—by pressing a key after they came up with an appropriate verb to each noun, as well as the control condition where they merely silently read the words and pressed a key after they had “read” the word. Participants were asked to complete the practice aloud to make sure they understood the tasks and then completed it once silently to ensure they knew what to do in the scanner.

In the scanning session, the participants were asked to either generate a verb related to a visually presented noun or simply read the noun. For each of the nouns, the participants responded by pressing a button with their right hand after they had generated a verb in the “generate task” or after they had read the noun in the “read task.” The nouns were presented for 3400 ms each; button responses were recorded during presentation of the noun. Responses not falling within the 3400-ms response interval were considered nonresponses.

For the “generate task,” participants were not informed of the high selection condition (MANY) or the low selection condition (FEW). In the high selection condition (MANY), items were nouns with many appropriate associated responses (e.g., BALL—THROW, KICK, BOUNCE etc.) but without a clear dominant response. In the low selection condition (FEW), items were nouns with one clear dominant response or a few associated responses (e.g., SCISSORS—CUT). Participants completed two control tasks: (i) a READ condition where they were asked to silently read the presented nouns then respond by pressing a response button after they had read the word and (ii) a low-level baseline condition in which participants gazed at a central fixation cross (REST condition).

The study was divided into two runs, each with eight alternating sets of MANY, FEW, and READ blocks (24 blocks total) as well as four baseline blocks. Four nouns were presented in each approximately 16-s block (except for REST), with each word presented for 4 s. Before each task block began, an instruction was placed on the screen for 2 s (i.e., “GENERATE” or “READ”). The order of blocks was counterbalanced. Before noun presentation, a small letter “G” or “R” was displayed for 500 ms in the center of the screen to remind participants of the task at hand, then a blank screen was displayed for 100 ms. Following the presentation of each noun, within the same task block, a second blank screen was displayed for 100 ms. As part of a different study, participants were also scanned while performing several blocks of an item recognition task which were counterbalanced with the verb generation task. The total scanning time was approximately 50 min.

After the scanning session, all participants completed a letter fluency task (with the letters “F,” “A,” and “S”) and then the WAIS-III Vocabulary subtest. Participants were then debriefed as to the purpose of the study and provided with compensation for their time.

Pilot testing

A separate pilot study, preceding the fMRI experiment, was conducted to establish that latency differences between the two selection conditions (MANY/FEW) would be evident with a button press response for both younger and older adults. Data from this

study were also used to select only those noun stimuli that yielded the expected frequency of verb associate responses for their classification as MANY or FEW. Reaction times (RTs) for vocal and button responses were collected using Psyscope (<http://www.psychscope.psy.cmu.edu>), and the verbs generated were recorded on audio tape for subsequent scoring. Nonresponses, responses that were not verbs, and responses that were unrelated to the nouns were considered retrieval errors and were not included in vocal reaction time analyses. Pilot data established that (i) while older adults made more retrieval errors than younger adults on average [4.82 vs. 1.39, $F(1,42) = 19.88$, $P < 0.001$], selection condition produced no effect on error rate [$F(1,42) = 3.97$, $P = 0.053$] and did not interact with age [$F(1,42) = 0.033$, $P = 0.857$], (ii) older adults were generally slower than younger adults [1420 ms vs. 1137 ms, $F(1,42) = 11.6$, $P = 0.001$], and (iii) responses to the many condition were slower than the few condition for both age groups regardless of whether subjects responded verbally or manually [$F(1,42) = 123.7$, $P < 0.001$]. Vocal responses were generally faster than button responses [$F(1,42) = 7.75$, $P = 0.008$], and this was especially true for seniors [age by response mode interaction, $F(1,42) = 5.8$, $P = 0.021$]. Importantly, the effect of selection, which is of greatest interest for the scanning study, was evident in the significantly longer latencies for MANY versus FEW for each age group using the button response [senior: $t(21) = 3.7$, $P = 0.001$; young: $t(21) = 6.7$, $P < 0.001$]. Having established this result, we could refrain from requiring vocal responses in the scanner.

fMRI methods

Images were acquired using a 3-T whole-body MRI scanner (General Electric) equipped with a standard quadrature headcoil. Functional T2* blood oxygenation level-dependent (BOLD) images were acquired using a spiral sequence with 25 contiguous axial 5-mm slices [repetition time (TR) = 1500 ms, echo time (TE) = 25 ms, flip angle = 90°, and field of view (FOV) = 24 cm]. A T1-weighted gradient echo (GRE) anatomical image was also acquired by using the same FOV and slices as were used in the functional scans (TR = 275 ms, TE = 35 ms, and flip angle 90°). In addition, a 60-slice high-resolution set of anatomical images was acquired by using spoiled gradient-recalled acquisition in steady state (SPGR) imaging (TR = 35 ms, TE = 3 ms, flip angle = 35°, and FOV = 24 cm, 2.5-mm slice thickness). The T1 GRE images were acquired at the start of the scanning session, and the SPGR images were acquired at the end of the scanning session.

Experimental tasks were presented using E-Prime (Psychology Software Tools, Pittsburgh) and the IFIS 9.0 system (MRI Devices, Waukesha, WI), and responses were collected using two 5-button glove-like response pads. Head movement was minimized with foam padding, as well as a restraint that was strapped across participants' foreheads. Images were corrected for slice time differences using a local 17-point sinc interpolation program (Oppenheim et al., 1999). Head movement was adjusted by using the Automated Image Registration (AIR) software (Woods et al., 1998). Subsequent preprocessing and analyses were done using SPM99 (Wellcome Department of Cognitive Neurology, London, UK; <http://www.fil.ion.ucl.ac.uk/spm/>). SPGR images were corrected for signal inhomogeneity using a toolbox developed by G. Glover and K. Christoff (http://www.psych.stanford.edu/~kalina/SPM99/Tools/vol_homocor.html) and coregistered to the T1 images. The skull was removed from the SPGR images using the

Brain Extraction Tool from FSL (Smith, 2002) and normalized to a T1 template in the Montreal Neurological Institute (MNI) space. The same normalization procedure was used for the functional images. After spatial normalization, the functional images were smoothed using an 8-mm FWHM Gaussian filter. All images were high-pass filtered and scaled to a global mean intensity of 100.

All subsequent analyses of the functional images were performed using the general linear model implemented in SPM99. All conditions (MANY, FEW, and READ) were modeled as a fixed response (boxcar) waveform convolved with the hemodynamic response function (HRF). Statistical parametric maps (SPMs) were generated using t statistics to identify regions activated according to the model. Group data were then analyzed using a random-effects model. All reported overall activations passed a whole-brain false discovery rate (FDR) (Genovese et al., 2002) of $P < 0.05$ with an extent threshold of 20 contiguous voxels. For the ROI analyses, we selected peak coordinates that have been associated with verb generation/selection in previous neuroimaging studies and which were recruited in the MANY versus FEW contrast for all participants (Figs. 2 and 3). Effect sizes (% signal change) for the different conditions were extracted for each age group separately. The ROIs were created using Marsbar (<http://www.sourceforge.net/projects/marsbar>), and to extract percent signal change, we used the SPM ROI toolbox (<http://www.sourceforge.net/projects/spm-toolbox>).

Results

Behavioral data

Reaction time (RT) data were collected for the three behavioral tasks (READ, FEW, and MANY) during scanning. Two participants were excluded from the analysis due to technical problems. There were significant main effects of all conditions on median RT [$F(2, 84) = 212.87, P < 0.001$] and of the two selection conditions (FEW and MANY) [$F(1,42) = 112.208, P < 0.001$]. No main effects for age emerged from either the three conditions [$F(2,84) = 1.420, P = 0.240$] or selection conditions [$F(1,42) = 1.638, P = 0.208$] analyses. No age-by-task interactions were found for either the three conditions [$F(2,84) = 0.675, P = 0.445$] or selection condition [$F(1,42) = 1.962, P = 0.169$] analyses (Fig. 1). Regarding the neuropsychological test and demographic data, senior participants performed significantly worse on the fluency tests overall, [$t(37) = 2.802, P < 0.01$], the semantic fluency test [$t(38) = 4.87, P < 0.001$], and letter–number sequencing [$t(28) = 3.6, P < 0.01$]. Performance was equivalent for senior and young adults in WAIS-III Vocabulary [$t(36) = 0.176, P = 0.86$] and first-letter fluency [$t(38) = 1.38, P = 0.18$]. Education level was also equivalent [$t(38) = 0.658, P = 0.516$].

Neuroimaging data

First, to explore age-invariant activation effects related to selection, we contrasted the MANY condition with the FEW condition for all participants (both age groups combined). Activation related to selection was found in left and right prefrontal regions, ACC/medial prefrontal [Brodmann area (BA) 32/6], left inferotemporal gyrus (ITG; BA 21/37), and medial occipitotemporal regions (Fig. 2). The peak activations in the frontal regions were located in the inferior part of the prefrontal cortex (BA 45/46), with the left frontal region also extending dorsally (BA 9).

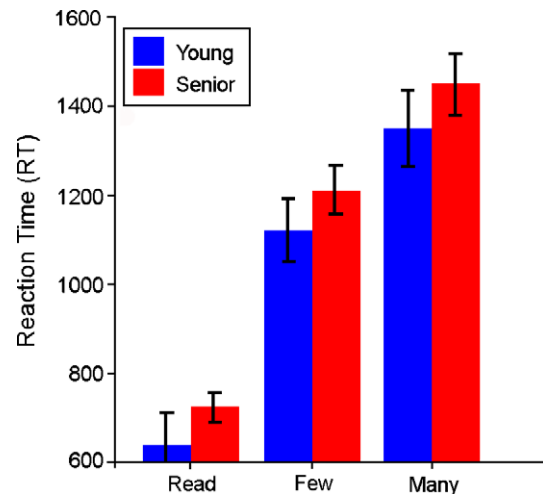


Fig. 1. Mean reaction time as a function of age group and task condition based on median reaction times for each participant. Error bars represent standard error of the mean.

Second, based on our hypotheses of activation related to high selection demands, we focused on four regions, the left and right IFG, the ACC, and left ITG, and used the results from the functional analyses to define the ROIs (Fig. 3). Using these ROIs, we found that activation in the left IFG was significantly higher for young adults than senior adults [$t(42) = 2.161, P < 0.05$] (Fig. 3A) in the MANY condition. There was no difference in activation between young and senior adults in the other conditions; FEW: [$t(42) = 1.623, P = 0.112$] and READ: [$t(42) = 1.464, P < 0.151$]. Activation in the right IFG was significantly higher for senior adults than for young adults in all conditions; MANY: [$t(42) = -3.194, P < 0.005$], FEW: [$t(42) = -3.094, P < 0.005$] and READ: [$t(42) = -2.263, P < 0.05$] (Fig. 3B). There was no significant difference in activation between young and senior adults in the left ITG in the FEW [$t(42) = -0.307, P = 0.760$] and READ conditions [$t(42) = 1.589, P = 0.119$]. The activation in left ITG for young adults was higher than for the senior adults in the MANY condition, but it barely reached statistical significance [$t(42) = 2.009, P = 0.051$] (Fig. 3C). In the ACC, activation was higher for young adults compared to senior adults in all task conditions; MANY [$t(42) = 2.919, P < 0.01$], FEW: [$t(42) = 2.388, P < 0.05$] and READ: [$t(42) = 2.263, P < 0.05$] (Fig. 3D).

Third, to confirm the results from the ROI analyses and to investigate if additional brain regions were selectively activated for young and senior adults, we contrasted the MANY and FEW conditions separately for each age group. As suggested by the ROI analyses, there were pronounced age-related differences in activation in lateral and medial frontal regions and in left ITG. In addition, younger adults showed stronger activation in dorsal frontal regions, and older participants activated the bilateral basal ganglia (Fig. 4) whereas young participants did not. Finally, to assess brain activation-behavior relationships, we correlated activation (% signal change in the MANY condition) in the four a priori-defined ROIs with RT data in the MANY condition for young and old participants separately. In one of the ROIs, the left IFG, we found a positive correlation between the fMRI signal and RT for young adults. That is, slower young adults showed increased cortical activity in this region than faster young adults [$r = 0.451, P < 0.05$]. For old adults, on the other hand, a reverse

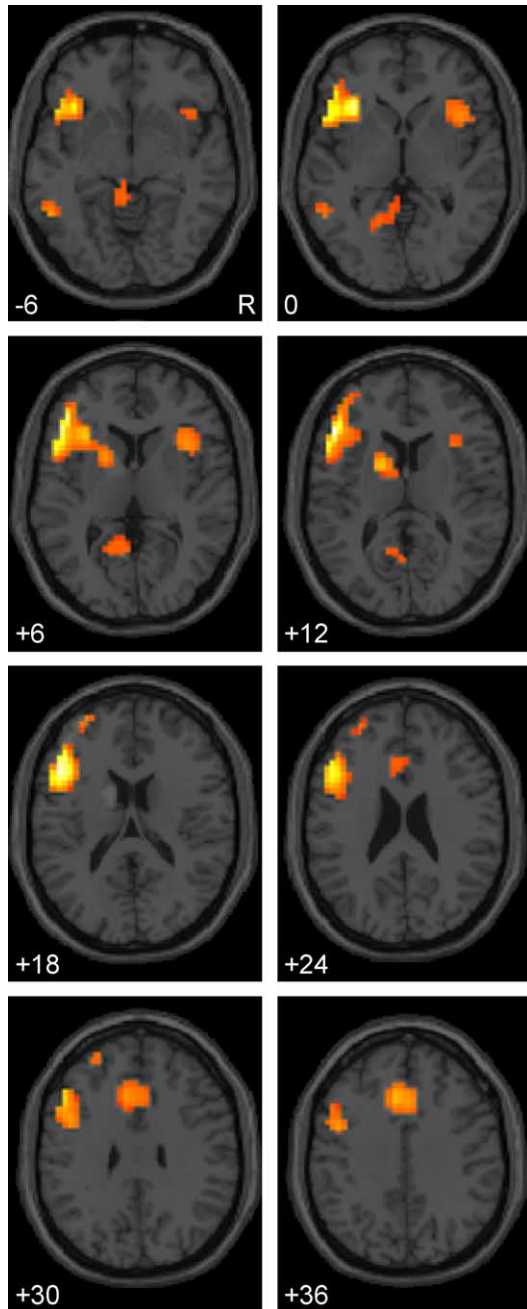
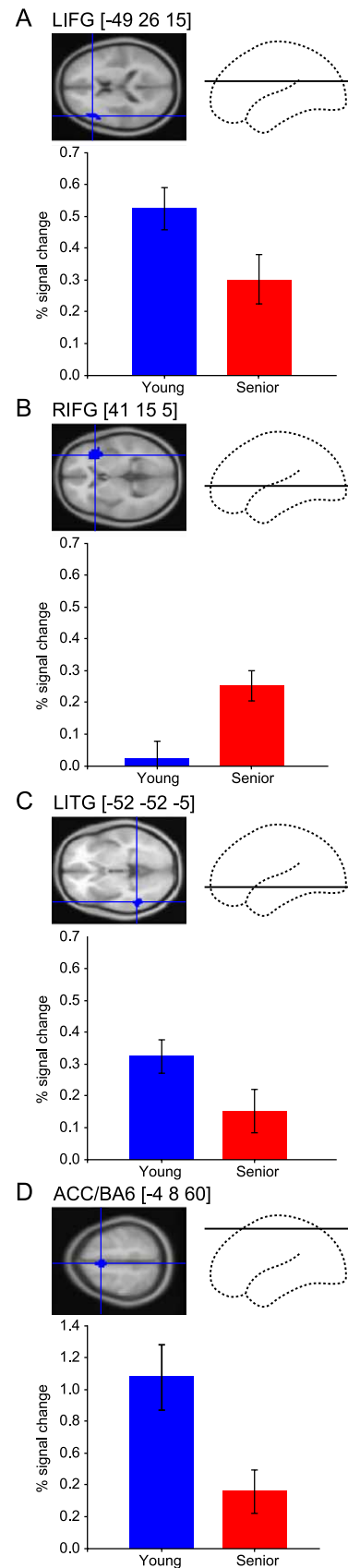


Fig. 2. Transverse sections of an anatomical template brain on which are superimposed loci where activation was significantly greater during MANY trials compared to FEW trials for all participants (FDR corrected threshold at $P < 0.05$).

pattern of correlation was observed. This correlation, however, did not reach statistical significance [$r = -0.411$, $P = 0.080$]. No other behavior-activation correlation or interregional correlation reached significance.

Fig. 3. Transverse sections depict the location of the areas (in yellow) used for the ROI analyses. Bar graphs represent the average percent signal change for young (blue) and senior (red) participants in the high selection condition (MANY). Error bars represent standard error of the mean. IFG indicates inferior frontal gyrus; ACC, anterior cingulate cortex; ITG, inferior temporal cortex.



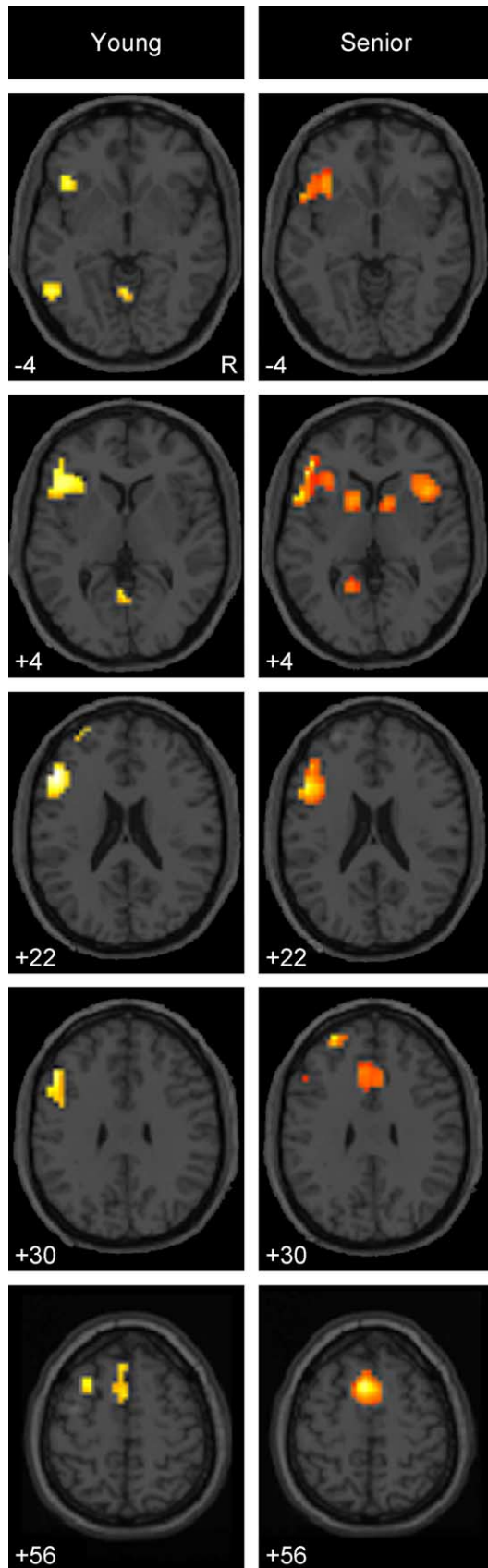


Fig. 4. Transverse sections of an anatomical template brain on which are superimposed loci where activation was significantly greater during MANY trials compared to FEW trials for each age group separately.

Discussion

It is evident from these results that several regions in the brain show differential recruitment for young and senior adults when the requirements for selection of semantic information are high. These regions include left and right IFG, left ITG, and the ACC. Additional activation was found in left anterior PFC for both young and senior adults and in the basal ganglia for senior adults.

The result that senior adults showed less recruitment of left IFG than young adults during a cognitive selection task is supported by several previous studies (Cabeza et al., 1997; for a review, see Grady and Craik, 2000). This underactivation is particularly evident during conflict resolution or tasks in which strategies must be initiated, suggesting that complex cognitive operations are more vulnerable to aging. Analyses of participant RTs in the MANY condition and fMRI signal in left IFG indicated a different pattern of correlations for younger and senior adults. Slower senior adults showed decreased brain activity compared to their faster counterparts, while slower young adults showed increased brain activity compared to faster young adults. These results indicate that decreased processing speed during high selection verb generation is associated with increases in left IFG activation in young participants but to decreases in left IFG activation in old participants. Decreased speed may be related to less effective memory-scanning processes (Sternberg, 1966). Previous results from working memory and aging studies have also shown positive correlations between RT and cortical activity in young adults and negative correlations between RT and cortical activity in senior adults in dorsolateral PFC (DLPFC, Reuter-Lorenz et al., 2001; Rypma and D'Esposito, 2000). It has been suggested that there are age-related differences in the neural mechanisms of processing efficiency in DLPFC and that this effect may specifically pertain to conditions with high memory load (Rypma and D'Esposito, 2000, 2001). Our findings are interesting in light of these results in that they suggest that age-related neural correlates of processing efficiency may not be confined only to the DLPFC but may involve other frontal regions as well, possibly in a task-dependent manner.

Consistent with the predictions of several models of cognitive control, activation in the ACC was increased when the requirements for selection were high. This pattern of activation was observed for both young and senior adults and is in line with previous imaging studies of memory and linguistic functioning associated with attentional demands and response selection (Kapur et al., 1996; Petersen et al., 1988; Posner and Petersen, 1990). We also found significant age-related differences, with senior adults showing less activation in ACC than young adults. This finding was not, however, restricted to conditions with high selective demands but was evident in the verb generation condition with low selective demands and the reading condition as well. It has been hypothesized that age-related alterations of ACC activity may reflect a decrease in the effectiveness of cognitive control in older participants (Milham et al., 2002). If true, activation in ACC might reach a maximum level during trials of low selection demands (FEW) and may be limited in additional recruitment during high selection trials (MANY). This hypothesis was not supported by our results, which rather suggest a general, task-independent decline in ACC function.

Theories of age-related cognitive decline differentiate between resources that are absent (i.e., no longer available) and those that

are available but not recruited effectively or spontaneously. Central to the idea of absent resources is that aging is associated with irreversible loss of executive resources resulting in cognitive decline, possibly due to atrophy or changes at the cellular level. Ineffective recruitment or underrecruitment, on the other hand, is associated with age-related deficits that are observed under some cognitive conditions but not others. Our results suggest, although speculatively, that age-related differences in left IFG may be related to underrecruitment because they are only seen during the condition in which the selection requirement is high. In the ACC, however, differences in activation between young and old participants may be related to a more general absence of resources because the difference is found during all task conditions. This proposal is supported by results showing negative correlations between age and regional cerebral blood flow in specific medial prefrontal areas, including the ACC (Schultz et al., 1999), and differences in structural anatomy in anterior cingulate in senior adults using voxel-based morphometry (Tisserand et al., 2001).

Although activation in left temporal regions has consistently been found during semantic tasks, the activation of left ITG during high selection (MANY) compared to low selection (FEW) requirements was somewhat surprising. One possible explanation is that left ITG activation is related to semantic retrieval demands during verb generation and that participants are generating more semantic information (verbs) during the MANY condition. This idea is supported by a study in which retrieval and selection demands during verb generation were manipulated independently (Thompson-Schill et al., 1999). The study found that activation in left temporal cortex was modulated by repetition of semantic information, whereas the left IFG was sensitive to the effects of competition. The age-related difference in left ITG activation during high selection demands is a new finding, although similar results have been reported in the context of tasks involving semantic memory such as visual word identification (Madden et al., 1996) and during attention to infrequent visual stimuli using an oddball paradigm (Madden et al., 2004). Also, decreased activation in inferior temporal regions has been found during semantic tasks (word fluency and object naming) in individuals with high risk for developing Alzheimer disease compared to normal adults of the same age (Smith et al., 1999).

The hypothesis that senior adults would exhibit additional activation in right IFG beyond that of young participants was also supported. Senior adults showed extensive right IFG recruitment compared to young adults during high selection demands. This finding, seen in the light of the absence of age-related performance differences, suggests that senior adults may compensate for declining performance by the use of additional right homologous brain regions. The idea of compensation is supported by several neuroimaging studies in which right prefrontal recruitment in senior adults is associated with faster response times (Reuter-Lorenz et al., 2000, 2001) and higher memory performance (Cabeza et al., 2002). Also, neuropsychological studies have shown that recovery of cognitive and motor functions after unilateral brain lesions may involve recruitment of homologous regions in the unaffected contralateral hemisphere (e.g., Buckner et al., 1996; Honda et al., 1997; Thulborn et al., 1999).

The finding of increased activation in basal ganglia for senior adults compared to young adults was somewhat unexpected, as this region has mainly been associated with diverse forms of motor behavior. It has also been proposed, however, that the basal ganglia

may underlie cognitive functions such as attentional control; increased activation in basal ganglia has been found in working memory studies with high working memory load (Barch et al., 1997; Rypma et al., 1999). There are also extensive reciprocal neural projections from the basal ganglia via the thalamus to the anterior cingulate and prefrontal regions. In light of the age-related differences in activation observed in prefrontal and anterior cingulate regions during this task, basal ganglia activation in senior adults may reflect increased attentional demands and/or cognitive control during high selection requirements. Together with other age-related alternations in the frontostriatal circuitry, increased basal ganglia activation may be a compensatory response to increased task-related demands associated with normal aging.

Taken together, these findings indicate age-related changes in multiple regions contributing to aspects of selection requirements during verb generation. These findings were observed although the groups did not differ in terms of performance. Regions supporting high selection requirements such as left IFG and the ACC, and posterior temporal regions possibly involved in more material-specific aspects of verb generation show reduced recruitment in healthy seniors. By comparison, specific regions such as the right IFG and the basal ganglia are up-regulated during the condition with high selection requirements, possibly to compensate for cognitive changes associated with old age. In relation to healthy aging, brain systems underlying cognitive control demonstrate critical adaptive changes in response to increasing cognitive demands.

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