



Received: 20 October 2015  
Accepted: 21 April 2016  
First Published: 04 May 2016

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## CLINICAL PSYCHOLOGY & NEUROPSYCHOLOGY | RESEARCH ARTICLE

# Executive functioning and lateralized semantic priming in older adults

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**Abstract:** Normal aging is associated with a number of cognitive deficits, including changes in executive functioning. Research suggests that hemispheric asymmetry during certain tasks becomes less pronounced in the elderly, reflected in greater bilateral patterns of cortical activation among older adults. Forty-two younger adults and thirty-five older adults were administered a battery of neuropsychological tests sensitive to frontal functioning. In addition, they completed a lexical decision task to assess lateralized implicit priming at two stimulus onset asynchronies (50 and 750 ms). Results of accuracy and reaction time data support Cabeza's model of reduced asymmetry in older adults completing a semantic priming task. Analysis of the contribution of executive functioning revealed its importance in semantic memory processing.

**Subjects:** Cognitive Neuroscience; Cognitive Neuroscience of Language; Gerontology/Aging; Psychological Science

**Keywords:** aging; cognition; semantic priming; executive function

### 1. Introduction

Older adults frequently show a variety of changes in thinking, including increased distractibility, self-reported memory problems, and an inability to inhibit task-irrelevant thoughts. There is also evidence of reduced hemispheric asymmetry in cognitive processing in older adults. Summarizing this literature, Cabeza (2002) developed his Hemispheric Asymmetry Reduction in Older Adults (HAROLD) model, which proposed that older adults show less lateralization during certain cognitive tasks because they recruit resources from both hemispheres in order to compensate for age-related decrements of functioning. In support of this model, Stebbins et al. (2002) utilized fMRI to demonstrate that both younger and older adults experienced significant activation of the frontal-lobes during a semantic decision task compared to a control task requiring non-semantic decisions. Younger

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### PUBLIC INTEREST STATEMENT

Older adults frequently show a variety of changes in thinking, including increased distractibility, self-reported memory problems, and an inability to inhibit task-irrelevant thoughts. In younger adults these thinking tasks are accomplished differently by the two halves of the brain. One model of aging and thinking suggests that in the aging brain the individual recruits resources from both halves of the brain in order to compensate for age-related decrements of functioning. This study supports this theory by demonstrating greater involvement of both hemispheres of the brain during language processing.

participants demonstrated twice as much activation in the left prefrontal cortex than in the right. In contrast, older participants exhibited reduced left prefrontal activation resulting in the absence of a hemispheric processing asymmetry. Other studies utilizing structural neuroimaging and evoked potential techniques also report less activation in the left frontal lobe in older adults performing semantic judgments or recognizing faces (Grady et al., 1995; Trott, Friedman, Ritter, Fabiani, & Snodgrass, 1987).

Semantic priming is based on a premise outlined by Quillian (1967) that “memory search is an activation spreading from two or more concept nodes in a semantic network until an intersection is found.” The presentation of a prime word results in faster processing of a second target word when the two words are semantically related (Meyer & Schvaneveldt, 1971). Semantic priming also provides a means of elucidating hemispheric interaction and the contributions of each hemisphere to semantic processing. Beeman (1993) and Chiarello (1991) suggested that the hemispheres process incoming lexical information in different ways. In general, both researchers argue that when semantic information is encountered by the left hemisphere (LH), a narrow categorical meaning of a word is activated from the array of possible word meaning candidates. In contrast, the right hemisphere (RH) activates multiple possible meanings and maintains them for an indefinite amount of time, in this way the RH codes semantic information coarsely while the LH engages in fine-grained semantic analysis. Presenting the stimulus words to a single visual field (VF) restricts the initial stimulation to one hemisphere. When the RH is primed, participants not only display priming to highly associated target words but also to less associated target words; in contrast, the LH primes predominantly to highly related words. If Cabeza’s reduced hemispheric asymmetry model is also supported for semantic priming, one would hypothesize that older adult’s performance would differ in important ways from younger adults.

Early research reported increased priming of remote associations in the older adult (Howard, 1983). Albert, Heller, and Millberg (1988) reported that as individuals age, there is an increase in semantic naming errors characterized by incorrect, though semantically related, words offered for a target item (e.g. “dice” for “dominoes”). This increased activation of remote associations was also related to deficits in frontal lobe functioning thought to reflect altered inhibitory function (Levine, Stuss, & Milberg, 1997). Hasher and Zacks (1988) proposed that a reduction in the “efficiency” of inhibitory mechanisms that participate in the modulation of working memory may underlie this phenomenon. For example, when reading an ambiguously worded passage, older adults maintained a wider array of possible interpretations as compared to younger adults (Hamm & Hasher, 1992). This finding was thought to reflect a failure of the processes involved in narrowing down possible interpretations. As a result, older adults show an inefficiently broad range of activated ideas in sentence and discourse processing tasks, produce more intrusions by material directed “to be forgotten” and evidence a longer arousal of activated associations (Hartman & Hasher, 1991; Howard, 1983; Howard, Heisey, & Shaw, 1986; Howard, McAndrews, & Lasaga, 1981). A number of studies also confirm that older adults have access to, or are distracted by, a broader range of associations than are younger adults (Cameli & Phillips, 2000; Hamm & Hasher, 1992).

Lateralizing both primes and targets permits a comparison of ipsilateral priming (prime and target to the same side) with contralateral priming (prime to one hemisphere and target to the other) and provides a more complete picture of interhemispheric interactions. We employed the priming procedure and stimuli used by Hutchinson, Whitman, Abeare, and Raiter (2003). Following Burgess and Simpson (1988), they presented primes to one VF and targets to the other, contralateral priming occurred at both long and short stimulus onset asynchronies (SOA). At 50 ms, LH primes primed high but not low associates bilaterally (narrow activation) whereas RH primes produced broad priming of both high and low associates in both target locations. At 750 ms, contralateral priming patterns converged, demonstrating only high associate priming in both hemispheres. The current study sought to integrate these findings by comparing young and older adults using a semantic priming paradigm and an executive functioning battery.

## 2. Method

### 2.1. Participants

All participants were right-handed, native English speakers with normal or corrected to normal vision. Exclusion criteria included left handedness (Edinburgh Handedness Inventory (Oldfield, 1971), lower than 8th grade reading level (using the reading subtest (Blue Edition) of the Wide Range Achievement Test-III (Jastak & Wilkinson, 1993), and absence of a history of stroke, head injury, drug and alcohol abuse, pharmacologically treated depression within the last 10 years, and treatment resistant hypertension or diabetes. Acute and chronic health problems were assessed using the *Physical Health Symptoms Checklist* (Toro et al., 1997). Participants were screened with the Folstein Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) to exclude those of questionable cognitive status. Only participants with a score of 27 or greater were included (Tombaugh, McDowell, Kristjansson, & Hubley, 1996).

In the current study, the younger participants ( $n = 42$ , males = 10, mean age  $21.21 \pm 4.6$  years) were recruited from the Wayne State University undergraduate subject pool. The older adult participants ( $n = 41$ , males = 13, mean age =  $75.61 \pm 5.8$  years) were recruited through participation in other Wayne State University laboratories and community contacts. All older adult participants were community dwelling individuals. The older adults (WRAT-III mean  $SS = 108.8$ ) in the current study were found to have a significantly higher reading level than the younger adults (mean  $SS = 103.14$ ),  $t(81) = -2.768$ ,  $p = 0.007$ .

Power computations for relevant Group  $\times$  Condition Interactions (e.g. Hemisphere  $\times$  Prime Type) were performed using the procedures outlined in Murphy and Myors (1998) and were based on the rationale provided by Cohen (1988). We used the convention that small, medium, and large effect sizes correspond to 0.01, 0.10, and 0.25, respectively. We assumed that theoretically meaningful interactions would be based on a pilot study associated with medium effect sizes. Therefore, the  $N$  chosen for the following studies ( $n = 40$  per group) was based on a medium effect size estimated from the repeated measures four-way interactions in the study described below.

### 2.2. Measures

#### 2.2.1. Lexical decision task

The experiment consisted of 552 trials divided into four blocks of 138 trials. Each trial consisted of an English word prime followed by a target string that was either an English word or a pronounceable nonsense word. Nonsense words were created by altering a single phonemic segment of an English word. Half of the trials had non-word targets while the other half had word targets. In the word target condition, each prime was combined with one of three target types—high associate (e.g. CLEAN-DIRTY), low associate (e.g. CLEAN-TIDY), and unrelated (e.g. CLEAN-FAMILY)—and counter-balanced across VF locations (Left VF-Left VF, Left VF-Right VF, Right VF-Left VF, Right VF-Right VF).

Association strength of the word lists was determined using Nelson, McEvoy, and Schreiber's (1994) word association norms. High associate targets included only primary associates to the prime in which at least 30% of participants reported that associate immediately upon free association. Target words with a 1–5% response rate to the prime words were used in the low associate prime condition, while unrelated targets have no empirical relationship to the prime. Word frequency was controlled across association strength levels as all prime and target words used had a minimum frequency of 20 per million. The inner edge of each prime and target was presented one degree to the left or right of the center, and all trials were presented in random order.

#### 2.2.2. Executive functioning tasks

Participants completed a battery of executive functioning tasks, including the Wisconsin Card Sort Test (Grant & Berg, 1948; Heaton, 1981), Trail Making Test for Adults (Reitan, 1958), Controlled Oral Word Association Test (Spreeen & Benton, 1969), Design Fluency (Milner, 1979), and the Stroop Test

(Stroop, 1935). Each of these tasks has been found to be sensitive to frontal lobe pathology (i.e. Rhodes, 2004).

### 2.2.3. Procedure

The experiment was run on a 166 MHz Pentium 2 personal computer which used SuperLab Pro to generate the experiment and record both reaction time (RT) and accuracy. All stimuli were printed in lowercase 20-point courier font black lettering against a white background. Participants were seated approximately 30 cm (12 inches) from the computer screen. A chin rest was used to ensure proper positioning of the head. Each subject was given 32 practice trials consisting of primes and targets that were not used during test trials. Immediately following the practice trials, participants began the test trials.

Using visual half-field priming with a lexical decision task, Hutchinson et al. (2003) investigated ipsilateral and contralateral prime-target conditions; contralateral priming was evident at the 50 ms SOA indicating that even at this brief interval, interhemispheric communication had occurred. Due to reduction in RT in normal aging (Rozas, Juncos-Rabadán, & González, 2008), a longer SOA (750 ms) was included.

Trials consisted of a focusing mark (\*) in the center of the screen for 1,000 ms, followed by the prime, which was randomly projected to either the left or right visual field (RVF) for 50 ms or 750 ms. The target was then projected to the left or RVF for 185 ms. Both prime and target stimuli were presented horizontally, approximately 1.8 degrees of visual angle to the left or right of the fixation point. In one-half of the trials for all SOA conditions, the prime and target were projected to the same VF (left visual field (LVF) or RVF; in the other half, prime and target were projected to different VFs (prime to LVF, target to RVF; prime to RVF, target to LVF). Following the presentation of the target, participants performed a lexical decision task for the target word by pressing the appropriate button (i.e. "WORD" or "NONWORD") on a button box. The order of trials was randomized for each subject.

Participants also completed the consent paperwork, MMSE, WRAT-III, Edinburgh Handedness Inventory and the executive functioning battery. The task administered first (lexical decision or executive functioning battery) was counterbalanced across participants. Participants were tested in single sessions lasting approximately two hours.

### 3. Analysis

Means for RT and accuracy were computed for each participant based on correct lexical decisions in the word conditions, with outliers (scores two standard deviations above or below the mean) removed. z-Scores were calculated for the RT for each condition (i.e. High related, Left VF-Left VF presentation, 50 SOA, etc.). Univariate outliers (those with z-scores greater than 3.29,  $p < 0.001$ ) were identified for each condition separately (Tabachnick & Fidell, 1996). Multivariate outliers were identified by conducting a Mahalanobis Distance test and identifying participants with a score greater than 51.179,  $p < 0.001$ . Six participants were identified as outliers both by univariate and multivariate tests and were removed from further analysis as it appeared they did not have the requisite baseline ability to complete the task as instructed. See Table 1 for comparison between outliers and remaining participants.

These analyses were followed by a principal components analysis (PCA) without rotation of the eight neuropsychological variables to determine if the scores on the executive functioning battery all loaded on a single component (factor). These variables included T scores for Trail Making Test Parts A and B, Verbal Fluency, Design Fluency free and fixed conditions, Stroop interference, perseverative errors on the Wisconsin Card Sorting Test, and raw number of categories completed on the WCST. Only variables with loadings of 0.32 and above were interpreted (Tabachnick & Fidell, 2001). The scores on the executive functioning battery were converted to Z scores and a new variable was computed from the sum of these z-scores. This new "frontal lobe index" served as a covariate in the

**Table 1. Demographic information for sample**

	Young	Old (non-outliers)	Old (outliers)
Number	42	35	6
Males	10	11	2
Mean age	21.21 (4.6)	75.3 (5.8)	77.5 (6.3)
MMSE	28.93 (1.4)	28.7 (1.4)	27.7 (2.3)
EHI**	23.9 (4.8)	19.5 (3.1)	20.2 (2.4)
Family left?	12	21	3
WRAT**	103.1 (10.5)	108.1 (7.8)	113 (8.13)

Notes: MMSE = Mini-Mental Status Exam, EHI = Edinburgh Handedness Inventory, Family left = History of left handedness in immediate family, WRAT = Wide Range Achievement Test-reading standard score.

\*\*Level of significant at  $p < 0.05$ .

remaining analyses. Given the significantly higher reading level of the older adult group, WRAT standard scores were also included as a covariate.

The PCA was performed on all of the neuropsychological measures for all individuals and was conducted as a precursor to the mixed-factorial analyses. We created a novel metric which was comprised of 8 separate executive functioning tests. To justify the use of the new metric, which we termed “frontal lobe index”, we performed a PCA which allowed us to demonstrate a meaningful level of construct validity. PCA results were used to support our application of the new metric as a covariate for the remaining analyses.

Utilizing General Linear Models in SPSS, a series of mixed-factorial ANCOVAs were performed on the RT and accuracy data to determine the effect of executive functioning upon these dependent variables. Within-subject independent variables included SOA (50 and 750 ms), side of presentation of the prime and targets (LVF–LVF, RVF–RVF, LVF–RVF, and RVF–LVF), and association strength of the prime (high, low, or no association to the target). The between subjects factor was age group (old vs. young). An a priori decision was made to describe  $p < 0.05$  and/or  $>2\%$  of variance explained as a statistically significant effect (Murphy & Myers, 1998).

#### 4. Results

Univariate ANCOVAs on the frontal lobe measures, controlling for reading level, revealed differences between the old and young group for several indices (see Table 2). Participants in the young adult group scored significantly higher on Trails A, Stroop interference, and number of categories completed on the WCST. Unexpectedly, the older adult group scored significantly higher on verbal fluency ( $M = 52.4$ ,  $SD = 11.46$ ) than the younger group ( $M = 42.85$ ,  $SD = 15.5$ ). Correlation analyses revealed a series of significant correlations between several variables on the frontal lobe battery. Whereas the correlational analyses focused on associations between measures, the PCA was performed to identify underlying processes across the neuropsychological variables. PCA without rotation was conducted on all eight neuropsychological variables to determine if combining them into a single linear composite was justifiable. This analysis yielded a three-component solution accounting for 66.3% of the variance. Given the objective of this analysis, only the first unrotated solution of the PCA was inspected. All the neuropsychological variables loaded onto the first component which accounted for 34.8% of the variance (see Table 3) legitimizing the use of the linear composite as a covariate in the remaining analyses. The ANCOVA conducted on the frontal lobe measures was done to provide more descriptive information on how the sample performed. This was done in the tradition of clinical neuropsychology research in which mean performance values are of interest to the reader. These analyses were conducted separately, prior to the mixed-factorial ANCOVAs, and are not performed on nested data.

**Table 2. Mean scores and standard deviations of executive functioning measures and Wrat-III for sample**

Measure	Young	Old
Trails A T-score	54.74 (13.35)	49.17 (9.53)*
Trails B T-score	54.14 (12.06)	51.97 (11.43)
Verbal fluency T-score	42.85 (15.5)	52.4 (11.46)**
Figural fluency free T-score	48.99 (8.07)	53.51 (13.86)
Figural fluency fixed T-score	51.11 (14.87)	47.7 (15.32)
Stroop interference T-score	54.48 (7.17)	45.82 (8.31)**
WCST perseverative errors T-score	56.9 (14)	58.97 (16.36)
WCST categories completed raw score	5.40 (1.48)	4.40 (2.04)**
Linear composite z-score	0.65 (4)	0.207 (4.71)
WRAT-III standard score	103.1 (10.5)	108.1 (7.8)**

\*Level of significant at  $p < 0.05$ .

\*\*Level of significant at  $p < 0.01$ .

**Table 3. Component loadings of the neuropsychological test variables**

Test variable	Component 1
Trails A T-score	0.64
Trails B T-score	0.58
Verbal fluency T-score	0.48
Figural fluency free T-score	0.54
Figural fluency fixed T-score	0.71
Stroop interference T-score	0.35
WCST perseverative errors T-score	0.61
WCST categories completed raw score	0.72
Eigenvalue	2.78

#### 4.1. Reaction time

A  $2 \times 4 \times 3 \times 2$  mixed-factorial ANCOVA was performed to evaluate significant differences between the younger and older groups across the three within subject variables (SOA, association strength, and side of presentation). Though the main effect for group was not significant, several significant interactions were identified.

A side  $\times$  group interaction was present ( $F(3, 66) = 3.747, p < 0.05$ , 14% of variance explained). Post hoc testing revealed that young and older participants had different RT profiles depending on side of presentation. For the young adults, the LVF-LVF and LVF-RVF presentations were significantly slower than the RVF-RVF presentations. Thus, younger adults had faster RT when both prime and target were presented to the LH (RVF-RVF) as compared to trials when the targets were presented to the RH. In contrast, older adults were significantly slower in all ipsilateral conditions (LVF-LVF, RVF-RVF) as compared with contralateral conditions (LVF-RVF, RVF-LVF). This suggests that older adults have faster RTs when the target and prime are presented to different hemispheres regardless of order. Upon the introduction of the “frontal lobe index” covariate, the interaction remained significant ( $F(3, 65) = 4.121, p = 0.01$ , 17% of the variance explained) and the pattern of RT among groups was similar.

Across all variables, including RT, Issues with skew and kurtosis were addressed with preliminary data screening procedures. Outliers were identified according to both univariate and multivariate

analyses. After removing outliers, issues with skew and kurtosis were much improved and we proceeded as planned with ANCOVA analysis (Figures 1 and 2).

#### 4.1.1. Accuracy

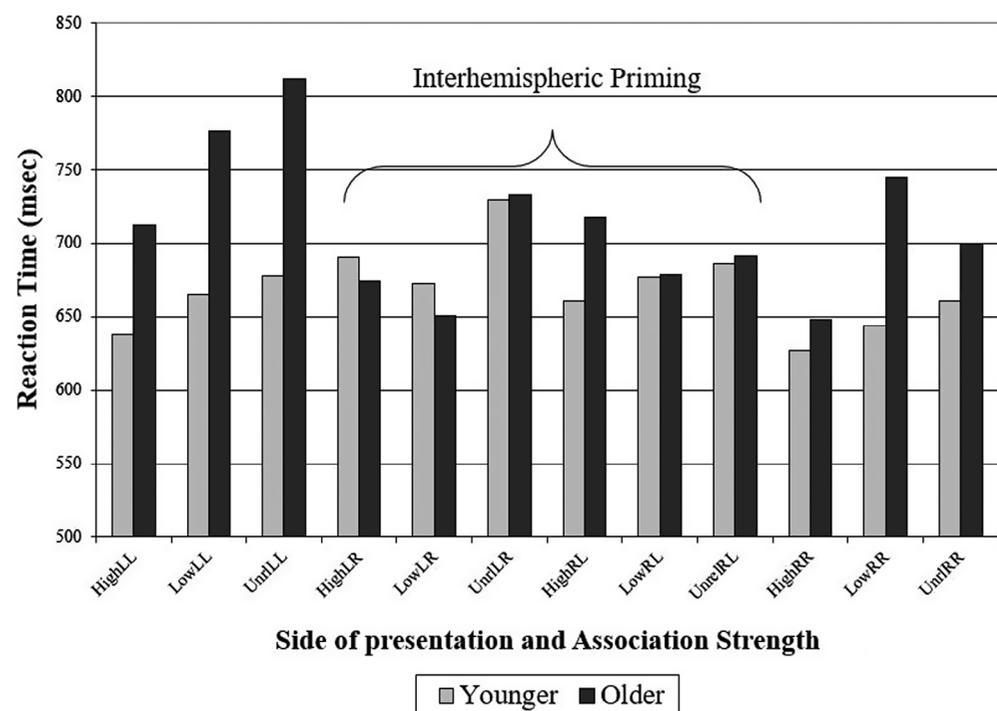
A  $2 \times 4 \times 3 \times 2$  mixed factorial ANCOVA was performed on the accuracy data to evaluate differences between the younger and older adult groups (Figures 3 and 4). The main effect for group was statistically significant ( $F(2, 66) = 8.979, p < 0.01$ , 11.5% of variance explained) with older adults performing less accurately ( $M = 73\%$  correct) than younger adults ( $M = 80\%$  correct). Results were similar even after accounting for the effects of executive functioning.

A side  $\times$  group interaction was present ( $F(3, 66) = 3.514, p < 0.05$ , 14% of variance explained) which remained stable after controlling for executive functioning. Post hoc analyses indicated that younger adults were less accurate in the LVF-LVF condition versus the RVF-LVF condition. The older adults were significantly less accurate in the LVF-LVF condition compared with all other VF conditions. They were more accurate, however, in the LVF-RVF condition versus all other conditions. The RVF-RVF and RVF-LVF conditions did not differ significantly from each other.

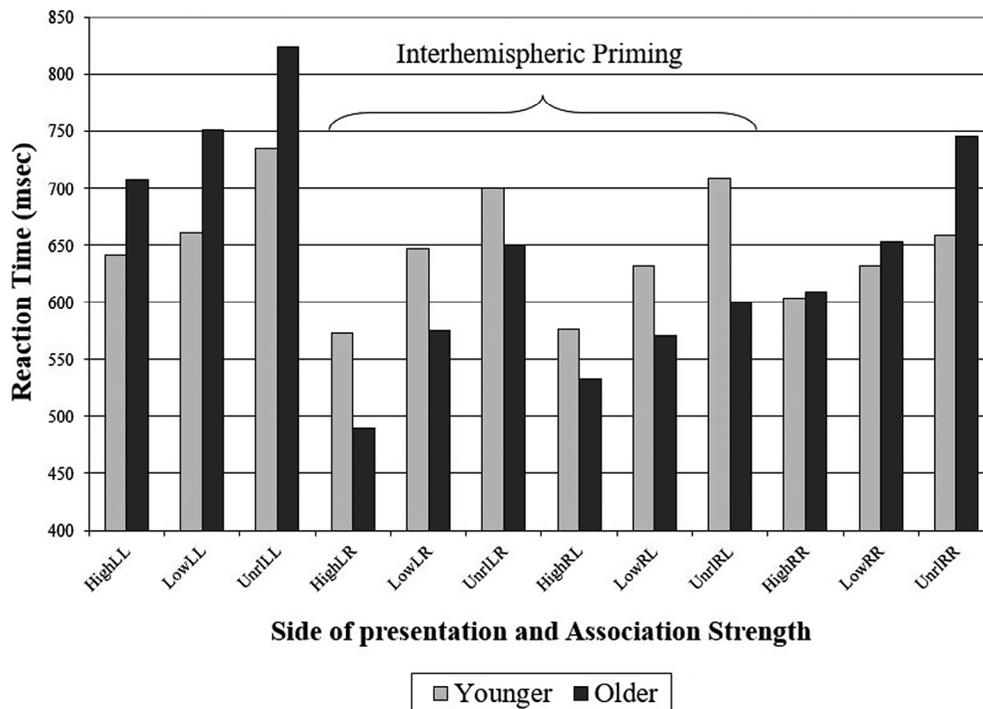
The four-way interaction of group  $\times$  side  $\times$  association strength  $\times$  SOA was significant ( $F(6, 62) = 2.232, p < 0.05$ , 17% of variance explained). Follow-up analyses revealed that at the 50 ms SOA, the older adults had reduced accuracy for low associates in both ipsilateral conditions and in the RVF-LVF condition compared with the LVF-RVF conditions. The aforementioned results were similar even after controlling for executive functioning performance (Table 4).

Upon the introduction of the “frontal lobe index”, a significant side  $\times$  SOA  $\times$  group interaction was present ( $F(3, 65) = 5.80, p < 0.01$ , 28% of variance explained). At the 50 ms SOA, older adults were less accurate in the LVF-LVF condition compared to all other VF presentations. Also, the RVF-LVF condition resulted in poorer accuracy than the LVF-RVF condition. At the 750 ms SOA, both younger and older adults were significantly less accurate in the LVF-LVF condition compared to all other VF conditions. The older group was also significantly more accurate in the LVF-RVF condition than in the RVF-LVF and RVF-RVF conditions. When taken together, it appears that accuracy is highest in the

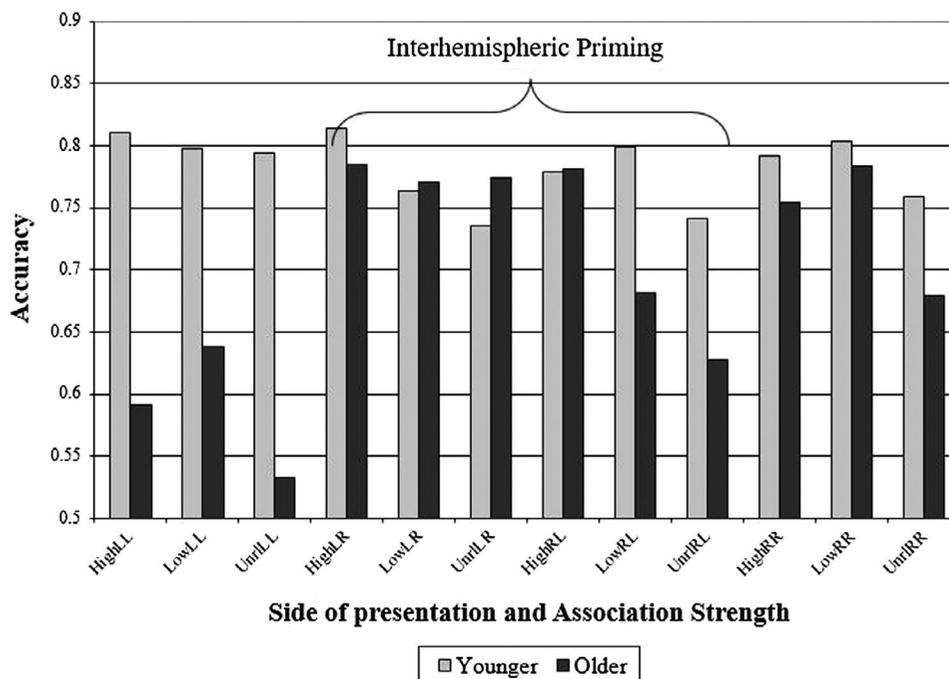
**Figure 1. Comparison of RT data between older and younger participants at the 50 ms SOA revealed that older adults performed comparably to younger adults when prime and target were presented to different VFs. However, in conditions where prime and target were presented to the same VF, RT was significantly longer in the older adult group.**



**Figure 2. Comparison of RT data between older and younger participants at the 750 ms SOA produced similar results. Again, interhemispheric conditions tended to produce faster RTs in older adults, while presenting prime and target to the same hemisphere resulted in much slower RT.**



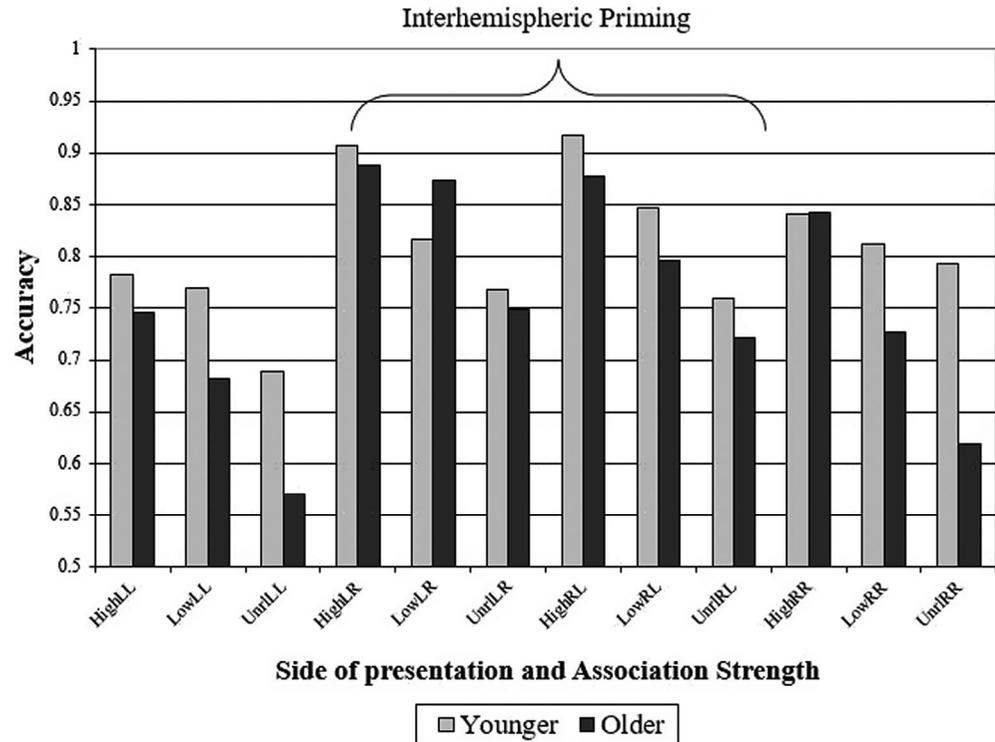
**Figure 3. Comparison of accuracy data between older and younger participants at the 50 ms SOA suggested that older adults were most accurate in interhemispheric conditions, while the younger adults showed good accuracy across all conditions.**



LVF-RVF condition. In general, accuracy also appears to be better in contralateral priming conditions as opposed to ipsilateral priming conditions, regardless of the effects of executive functioning.

In the initial analyses, high, low, and neutral associates were identified with equal accuracy. After covarying for executive functioning, however, the association strength x group interaction missed significance ( $F(2, 66) = 2.79, p < 0.06, 8\%$  of variance explained). Post hoc analyses revealed that for

**Figure 4.** At the 750 ms SOA, older adults were again less accurate for trials in which the prime and target were presented to the same VF. This was especially the case for low and neutral associated trials. Also, a clearer pattern of accuracy varying by level of word association emerged, with accuracy best in high associates, followed by low associates, and neutral associates. This pattern was present in both younger and older participants.



both the younger and older participants, accuracy was best for high associates, followed by low associates, followed by neutral associates. This suggests that executive functioning is related to the accurate identification of remote associates in semantic memory.

### 5. Discussion

The current study supports Cabeza's (2002) HAROLD model; older adults demonstrate a tendency to utilize bilateral resources when performing a task while younger adults complete the same task using unilateral resources. See Table 4 for a summary of findings.

The RT analyses demonstrated that older adults have slower RTs for ipsilateral priming compared with contralateral priming. This lends support for Cabeza's model in that the older adults are at a disadvantage when the prime and target are presented to the same hemisphere and may require more bilateral resources, thus slowing down their performance. This is in contrast to the young adults who have the fastest RTs in the RVF-RVF condition (an ipsilateral presentation). The accuracy analyses indicated that overall, older adults were less accurate than younger adults and showed the greatest accuracy in contralateral conditions versus ipsilateral conditions. Younger adults, however, did not demonstrate a systematic accuracy advantage for any presentation combination. The accuracy and RT findings lend support to the premise that older adults utilize bilateral resources to complete tasks that are accomplished unilaterally in younger adults.

After adjusting for frontal functioning, RT and accuracy patterns across the younger and older groups remained the same suggesting that frontal functioning was not exerting a significant influence upon these variables. The lack of group differences, however, must be considered within the context of the current sample and the finding that the two age groups did not differ significantly according to their linear composites. It may be the case that a sample with a more varied representation of executive functioning scores may produce group differences in the aforementioned variables. The decision to compare an older adult group with a younger adult group was predicated on the assumption that older participants would perform poorer on measures of executive functioning.

**Table 4. Summary of findings**

	<i>F</i>	<i>p</i>	Variance (%)	Post hoc analyses
<i>Reaction time</i>				
Side × group	3.747	0.015	14	For young adults, LVF-LVF and LVF-RVF slower than RVF-RVF For older adults, LVF-LVF and RVF-RVF slower than LVF-RVF and RVF-LVF
(RT results remain stable after covarying for executive functioning)				
<i>Accuracy</i>				
Main effect for group	8.979	0.004	11.50	Older adults are less accurate than younger adults overall
Side × group	3.541	0.019	14	Younger adults were less accurate in the LVF-LVF condition compared with RVF-LVF Older adults were less accurate in the LVF-LVF condition compared with RVF-LVF, LVF-RVF, and RVF-RVF conditions. Also, older adults were the most accurate in the LVF-RVF condition as compared with all other combinations
Group × side × AS × SOA	2.232	0.05	17	At 50 SOA older adults showed less accuracy for low and neutral associates presented to the LVF-LVF compared with LVF-RVF and RVF-RVF. For low associates the RVF-LVF condition had worse accuracy than the LVF-RVF and RVF-RVF. For neutral associates LVF-RVF had higher accuracy than RVF-LVF and RVF-RVF
With addition of executive functioning covariate				
AS × group	2.785	0.069	8	For both groups, accuracy was best for associates that were high, followed by low, followed by neutral
Side × SOA × group	5.801	0.001	28	At both SOAs, both age groups had the poorest accuracy in the LVF-LVF condition

Notes: AS = Association Strength, side = side of presentation for prime and target, SOA = Stimulus onset asynchrony.

While older adults did perform poorer on some measures, they also paradoxically performed better on a measure of verbal fluency. Follow-up analyses utilizing raw scores from the executive functioning measures as opposed to age-corrected *T* scores did not yield different patterns of results. Though the nature of the current sample did not allow for such a comparison, perhaps a more useful dichotomy than older vs. younger would be to compare high performers on an executive functioning battery with low performers. While it is certainly important to study age-related changes in the absence of confounding health and neurological problems, the exclusion criteria may have resulted in restriction of range with regard to prefrontal functioning in the older adult group. Also, the current study used a cross-sectional design in an effort to assess changes that occur with maturation. It is possible that cohort effects are responsible for a portion of the significant findings in the areas of RT and accuracy. A sequential or longitudinal design, though more time consuming and expensive, would provide more clear insight into changes within individuals over time.

In terms of semantic priming effects in general, however, executive ability appears to play an important role in the successful navigation of semantic memory across age groups. Under standard circumstances, high, low, and neutral associates were identified with equal accuracy in the semantic priming paradigm. After controlling for executive functioning, however, an accuracy gradient emerged such that high associates were identified more accurately than low associates, which in turn were identified more accurately than unrelated concepts. Semantic network theory suggests that concepts that are highly related to a prime word will incur greater relative activation than those with weaker relationships (Collins & Loftus, 1975). It might be argued that the frontal executive system would face greatest conflict under the neutral target condition because it would be required to suppress a response to highly activated words in order to process the neutral word (Broen &

Stroms, 1967). Thus, the accuracy gradient found in the present study suggests that as a target word becomes increasingly removed from the prime word in semantic space, the executive systems are required to dampen the cumulative activation of more relevant words.

The current study provides further support for the Cabeza model of hemispheric asymmetry changes in older adults and extends his theory into the realm of semantic priming. It also confirms the value of contrasting ipsilateral and contralateral priming across multiple SOAs. Additionally, the study adds a new layer of understanding to the importance of executive functioning in the navigation of semantic memory. Future research should attempt replication of the current design with a larger sample and with a greater range of executive functioning represented.

#### Funding

The authors received no direct funding for this research.

#### Competing Interests

The authors declare no competing interest.

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#### Citation information

Cite this article as: Executive functioning and lateralized semantic priming in older adults, Emily J. Helder, Virginia Zuverza-Chavarria & R. Douglas Whitman, *Cogent Psychology* (2016), 3: 1182687.

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