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Age Effects on Prefrontal Activation in Noun, Verb, and Letter Fluency: An fNIRS Study

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Objectives: This study investigated age-related differences in behavioral performance and prefrontal hemodynamic responses during noun, verb, and letter verbal fluency tasks (VFTs), with a particular focus on identifying task types and neural regions that are most sensitive to aging. **Methods:** Ten young adults and eleven cognitively healthy older adults completed noun, verb, and letter fluency tasks while prefrontal cortical activity was measured using functional near-infrared spectroscopy (fNIRS). Behavioral performance was quantified as the number of words generated. Hemodynamic responses (ΔHbO) were analyzed using permutation-based mixed-effects ANOVA. Stepwise discriminant analysis with permutation testing and bootstrapping was used to determine which fluency task best differentiated age groups. Correlations between behavioral performance and prefrontal activation were examined separately for each group. **Results:** Older adults generated fewer words than young adults across all fluency tasks, with noun fluency yielding higher output than verb and letter fluency in both groups. Discriminant analysis identified verb fluency as the strongest behavioral marker differentiating older and young adults. At the neural level, ventrolateral prefrontal cortex (VLPFC) activation was greater than anterior prefrontal activation across groups, but older adults exhibited significantly reduced ΔHbO responses in the VLPFC. Additionally, verb fluency performance was positively correlated with right VLPFC activation in the older group only. **Conclusion:** These findings indicate that verb fluency is particularly sensitive to age-related changes in lexical retrieval and that reduced engagement of the ventrolateral prefrontal cortex characterizes verbal fluency performance in healthy aging.

Keywords: Verbal fluency, fNIRS, Aging

The Verbal Fluency Task (VFT) is a widely used neuropsychological assessment designed to evaluate a broad range of cognitive and linguistic processes, particularly lexical retrieval (Burke & Shafto, 2004). The VFT includes several types, most commonly noun, verb, and letter fluency. Noun fluency requires the retrieval of words from a specific semantic category (e.g., animals). Verb fluency involves generating words that describe actions or movements, whereas letter fluency requires producing words that begin with a designated letter (e.g., F, A, S in English). While noun and letter fluency tasks are routinely included in standardized neuropsychological batteries, such as the Seoul Neuropsychological Screening Battery-II (Kang et al., 2012), growing evidence has highlighted verb fluency as a particularly sensitive marker of cognitive decline. Recent studies have demonstrated that verb fluency performance is compromised in both typically aging older adults (Kim et al., 2021; Lee et al., 2024; Park et al., 2024) and individuals with dementia (Fisher et al., 2023; Paek & Murray, 2021), underscoring its potential utility in the assessment of age-related cogni-

tive and language changes.

Performance on the VFT requires the retrieval of category-congruent lexical items within a restricted time frame. This process engages not only linguistic knowledge but also multiple executive functions, including initiation of retrieval, response monitoring, semantic organization, and flexible shifting between subcategories (Aita et al., 2019; Bose et al., 2022; Henry et al., 2004). Neurocognitive models of verbal fluency consistently implicate frontal lobe networks in supporting these processes. In particular, regions within the inferior frontal and ventrolateral prefrontal cortices have been broadly associated with multiple components of verbal fluency, including the initiation of search strategies, lexical selection, monitoring of previously produced responses to avoid repetition, and flexible shifting between semantic or phonological subcategories (Amunts et al., 2020; Badre & Wagner, 2007; Hirshorn & Thompson-Schill, 2006).

Consistent with the frontal-executive demands of VFTs, lexical retrieval difficulties are robustly reported in the aging population (Bastiaanse et al., 2016; Henry et al., 2004; Kim et al., 2011; Park et al., 2024, 2025). Compared to young adults, older adults show significantly reduced performance across fluency subtypes. In noun fluency tasks, such as animal naming, older adults generate fewer correct responses, reflecting slower lexical processing speed and reduced efficiency in switching between semantic clusters (Bose et al., 2022). Importantly, VFT subtypes differ in their sensitivity to aging. In a large cohort of cognitively normal adults, Park et al. (2024) demonstrated that letter fluency showed more pronounced age-related decline than noun fluency, and that letter fluency accuracy—together with working memory—most strongly differentiated younger and older adults, highlighting the vulnerability of fluency tasks that place high demands on executive control.

Beyond noun-based fluency, accumulating evidence suggests that verb fluency may be especially sensitive to cognitive decline. Park et al. (2025) compared noun and verb fluency performance between healthy adults and individuals with aphasia and found that both groups produced significantly fewer correct responses in verb fluency than in noun fluency tasks. This pattern of greater difficulty in verb production has been consistently observed across a range of language production tasks, including confrontation naming (Bastiaanse et al., 2016; Crepaldi et al., 2006), picture description (Gordon, 2008; Sung et al., 2016), and sentence completion (Abel et al., 2015), suggesting that verb retrieval imposes inherently greater demands on the language system.

This noun–verb dissociation has been attributed to fundamental linguistic differences between nouns and verbs at both semantic and syntactic levels. At the semantic level, concrete nouns typically exhibit well-structured semantic organization, sharing stable and overlapping features within categories (e.g., *dog, cat*, and *rabbit* share features such as *animal* and *mammal*). In contrast, verbs are characterized by less systematic semantic organization and fewer shared features across lexical items, resulting in more diffuse semantic representations (Vinson & Vigliocco, 2002). Verbs are also more strongly context-dependent and show higher rates of polysemy and homonymy, which further increases processing demands during lexical retrieval (Breedin et al., 1998).

In addition to their semantic representations, verbs carry rich morphosyntactic information—such as tense, aspect, and voice—and determine argument structure by specifying the number and type of arguments required in a sentence (Schneider & Thompson, 2003). These syntactic features place additional demands on grammatical processing systems, even in tasks that require only verb production rather than full sentence construction. Consistent with this view, individuals with aphasia show disproportionately greater difficulty producing verbs with more complex argument structures, exhibiting higher error rates as argument complexity increases (Kim & Thompson, 2000; Thompson, 2003; Sung et al., 2016). Together, these semantic and morphosyntactic properties render verb retrieval more cognitively demanding than noun retrieval, contributing to the greater vulnerability of verbs in both neurogenic language disorders and aging (Bak, 2013).

A growing body of neuroimaging research has investigated VFTs to characterize the neural mechanisms underlying lexical retrieval and age-related cognitive changes. Using functional near-infrared spectroscopy (fNIRS), Herrmann et al. (2006) examined noun and letter fluency in younger and older adults and reported greater hemodynamic responses in ventrolateral prefrontal regions during verbal fluency, with older adults showing attenuated frontal activation, particularly during letter fluency, which places higher demands on executive control. In contrast, Meinzer et al. (2009) observed increased bilateral frontal recruitment in older

German-speaking adults during noun and letter fluency tasks, despite poorer behavioral performance, with pronounced involvement of right inferior frontal regions. This pattern of reduced hemispheric lateralization in aging was further corroborated by Yeung et al. (2016), who reported increased right frontal engagement during noun and letter fluency in older adults.

Beyond fNIRS findings in aging, converging evidence from other neuroimaging modalities further supports the involvement of a distributed fronto–temporo–subcortical network in verbal fluency. Meta-analytic and review work using functional MRI and PET consistently highlights the left inferior frontal gyrus together with medial and dorsolateral prefrontal regions and the anterior cingulate cortex, supporting controlled lexical selection, monitoring, and response inhibition across noun and letter fluency tasks (Costafreda et al., 2006; Price, 2012; Wagner et al., 2014). Metabolic imaging further indicates widespread task-related changes, with [18F] Fluorodeoxyglucose Positron Emission Tomography (FDG-PET) showing increased glucose utilization—particularly in frontal and temporal regions—during active fluency relative to rest (Parks et al., 1988). Structural MRI studies in healthy older adults likewise demonstrate associations between fluency performance and cortical thickness in inferior frontal and broader frontal–temporal–parietal regions, with partially distinct anatomical signatures for letter versus noun fluency (Vonk et al., 2019).

To date, however, most neuroimaging studies examining verbal fluency in aging have focused on noun and letter fluency tasks, consistently reporting age-related alterations in prefrontal activation patterns (Herrmann et al., 2006; Kahlaoui et al., 2012). Across studies, older adults exhibit either reduced prefrontal hemodynamic responses or more bilateral prefrontal recruitment relative to younger adults, reflecting changes in frontal efficiency and compensatory mechanisms. In contrast, neuroimaging research specifically investigating the hemodynamic correlates of verb fluency remains largely unexplored. Given that verb retrieval places greater demands on executive control and semantic integration than noun-based fluency, characterizing its neural underpinnings is critical for advancing our understanding of age-related changes in frontal lobe function.

To address this gap, the current study utilizes fNIRS to investigate behavioral performance and hemodynamic responses in the prefrontal cortex (PFC) during three types of VFTs (noun, verb, and letter) in young and older adults. The specific research questions addressed in this study are as follows:

1. Are there significant differences in the mean number of correct responses generated depending on VFT types (noun, verb, letter) and between age groups (young, older)?
2. Which VFT type best differentiates the older adult group from the young adult group?
3. Are there significant differences in hemodynamic responses (ΔHbO) of the PFC depending on the laterality (right, left), anteriority (anterior, ventrolateral), age groups (young, older), and VFT types (noun, verb, letter)?
4. Are there significant correlations between behavioral performance in VFTs and hemodynamic responses (ΔHbO) of the PFC?

METHODS

Participants

A total of 21 healthy adults participated in this study, consisting of 10 young adults and 11 older adults. All participants were native speakers of Korean and exhibited a normal range (age- and education-adjusted scores ≥16 %ile) of performances in the Korean Mini-Mental State Examination (K-MMSE; Kang, 2006), the Digit Span Test (DST) from the Seoul Neuropsychological Screening Battery-II (Kang et al., 2012) and the Korean version of the short form Geriatric Depression Scale (SGDS-K; Bae & Cho, 2004; <8 out of 15). Normal performance was defined as age- and education-adjusted scores at or above the 16th percentile for the K-MMSE and DST, and a score of less than 8 out of 15 on the SGDS-K. According to a self-report, none of the participants had any vision impairments, a history of brain injury, or learning disabilities. The current study was authorized by the Institutional Review Board (No. 2023-0337), and written consent was acquired from all participants.

An independent samples *t*-test was conducted at a significance level of .05 to examine whether there were statistically significant differences between groups in age, years of education, K-MMSE scores, and DST scores. There were significant differences in age ($p < .001$), K-MMSE ($p = .003$), and DST Backward ($p < .001$).

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Table 1. Descriptive information on participants for each group

Characteristic	Young group[a]	Older group[b]	test statistics	*p*-value
Sex (male:female)	5:5	4:7	-	-
Age (yr)	30.91 (15.67) 24-28	72.80 (4.98) 68-82	-8.08	<.001
Years of education	15.36 (1.29)	14.40 (2.63)	1.08	.293
K-MMSE	29.46 (1.21)	27.30 (1.64)	3.45	.003
DST				
Forward	10.46 (1.69)	11.70 (1.89)	-1.593	.128
Backward	4.91 (.54)	8.90 (2.81)	-4.634	<.001

Values are presented as mean (standard deviation).
K-MMSE = Korean-mini mental state examination (Kang, 2006); DST = Digit span test (Kang et al., 2012).
[a]n = 10, [b]n = 11.

Table 1 provides test statistics with *p* values for each descriptive measure in both groups.

Experimental Tasks and Procedures

We employed three types of VFTs: noun fluency (animals), verb fluency, and letter fluency (words beginning with the Korean letter /ㄱ/), all programmed using PsychoPy (version 2024.2.1). The experimental paradigm consisted of three blocks, each comprising a 30-second rest period, a 30-second control task, and a 30-second VFT, following previously established protocols (Dong et al., 2021). During the control task, participants were asked to repeatedly articulate a sequence of vowels (/a/, /e/, /i/, /o/, /u/) aloud to control for articulatory and vocalization-related effects. The order of the three VFT conditions was counterbalanced across participants to minimize potential sequence effects, ensuring a balanced comparison across task types and age groups.

Prior to the experiment, all participants received instructions explaining the task structure and response requirements. In particular, participants were instructed to rest quietly while viewing a landscape image presented during the rest period, to repeat vowels during the control condition when a fixation cross was displayed, and to generate as many words as possible corresponding to the visually presented category or letter cue (e.g., "동물", "동사", "ㄱ") during each VFT block. For the noun fluency condition, an example category (e.g., *flowers*) was provided during the instruction phase to ensure task comprehension. For the verb fluency condition, participants were instructed to produce single-word action verbs (e.g., *eat, drink*), while avoiding different inflected forms of the same word and full sentence responses. For example, one participant produced verbs such as 간다 (*go*), 달린다 (*run*), 잡는다 (*catch*), 먹는다 (*eat*), 잔다 (*sleep*), and 웃는다 (*laugh*). For the letter fluency condition, participants were instructed to generate words beginning with the specified letter (e.g., when prompted with the letter /ㅅ/, responses such as *apple* were acceptable).

All responses produced by participants during the experiment were recorded. After task completion, incorrect or invalid responses were excluded based on task-specific criteria. For the noun fluency task, excluded responses included repeated words, non-animal words, superordinate category terms when both superordinate and subordinate items were produced (with the superordinate term excluded), production of both adult and juvenile forms of the same animal (with the second response excluded), production of the same animal in different languages (with the second response excluded), mythical or imaginary animals (e.g., *dragon*), and unintelligible responses. For the verb fluency task, repeated responses, non-verb words, and unintelligible responses were excluded (Paek & Murray, 2021). For the letter fluency task, excluded responses consisted of repeated words, proper nouns (e.g., names of people or places), and unintelligible responses.

fNIRS Device

fNIRS data were acquired using a 15-channel functional near-infrared spectroscopy system (NIRSIT LITE; OBELAB Inc., Seoul, Korea). NIRSIT LITE is a lightweight, portable, and wireless device designed for real-time measurement of cortical hemodynamic activity during cognitive tasks. The system employs near-infrared light at two wavelengths (780 nm and 850 nm) to measure changes in oxyhemoglobin (ΔHbO) and deoxyhemoglobin (ΔHbR) concentrations based on their differential absorption properties. The device is equipped with five light sources and 13 detectors, forming 15 measurement channels with a fixed source–detector separation of 3 cm, which is optimal for detecting cortical-level hemodynamic responses from the frontal cortex. All channels were positioned to cover the PFC, and the system was worn comfortably as a headband, allowing stable signal acquisition during overt speech production.

Channel grouping and region-of-interest (ROI) definitions were based on the Brodmann-area–based anatomical mapping provid-

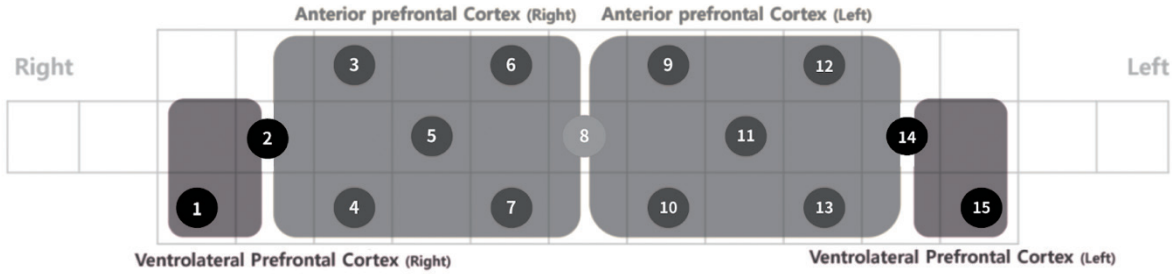

Figure 1. fNIRS channel grouping and prefrontal region-of-interest definitions.

ed by the manufacturer (OBELAB Inc.). Channels were grouped according to hemisphere and prefrontal subregion to enable systematic examination of spatial patterns of cortical activation. Specifically, channels 1 and 2 were assigned to the right ventrolateral PFC (VLPFC), channels 3–7 to the right anterior PFC, channels 14 and 15 to the left VLPFC, and channels 9–13 to the left anterior PFC (Figure 1).

fNIRS Data Preprocessing

Data preprocessing focused on changes in oxyhemoglobin concentration (ΔHbO), as ΔHbO has been shown to be a more sensitive and reliable indicator of task-related cortical activation than deoxygenated or total hemoglobin measures (Aslin et al., 2015). Hemodynamic changes for each channel during each VFT trial were calculated using the Modified Beer–Lambert Law.

Raw optical signals were band-pass filtered between .005 and .1 Hz to attenuate slow drifts and high-frequency physiological noise. A signal-to-noise ratio (SNR) threshold of 30 dB, corresponding to the default quality-control criterion implemented in the NIRSIT Quest preprocessing pipeline, was applied (Dong et al., 2021). Channels not meeting this criterion were excluded from further analysis to reduce the influence of physiological and environmental noise.

Statistical Analyses

All statistical analyses and data visualization were performed using Python and OBELAB Nirsit Scan software (version 3.2.4). Given the small sample size and potential violations of normality assumptions, primary statistical inferences were conducted using permutation-based methods rather than traditional parametric tests.

For behavioral performance, differences in the mean number of correct responses were examined across VFT types (noun, verb, letter) and age groups (young, older) using a permutation-based repeated-measures ANOVA with the Freedman–Lane procedure, in which subject-level residuals were randomly permuted to generate the null distribution based on 1,000 resamples. To identify which VFT type most strongly differentiated the older healthy group from the young healthy group, a stepwise discriminant analysis was conducted, with statistical significance assessed using permutation testing and robustness further evaluated via bootstrapping with 1,000 resamples.

For hemodynamic data, a permutation-based four-way mixed-effects ANOVA (Freedman–Lane) was applied to ΔHbO values in the prefrontal cortex, with laterality (right, left) and anteriority (anterior, ventrolateral) as within-subject factors, age group (young, older) as a between-subject factor, and VFT type (noun, verb, letter) as a repeated-measures factor. To further validate the robustness of the results, bootstrapping with 1,000 resamples was additionally performed, and confidence intervals were derived from the bootstrap distributions.

Finally, associations between behavioral performance and hemodynamic responses were assessed using Pearson's correlation coefficients, computed separately for each age group and stratified by laterality (right, left) and anteriority (anterior, ventrolateral). Statistical significance of correlation coefficients was evaluated using permutation testing to ensure robustness against non-normality.

RESULTS

Behavioral Performance

Descriptively, the mean number of correct responses for older

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adults was 10.82 (SD = 2.71) for noun fluency, 4.82 (SD = 1.94) for verb fluency, and 5.00 (SD = 2.26) for letter fluency. Corresponding values for young adults were 17.80 (SD = 3.52), 11.80 (SD = 2.90), and 10.70 (SD = 3.30), respectively.

A permutation-based two-way mixed ANOVA (Freedman–Lane procedure) revealed a significant main effect of age group ($F_{(1, 19)} = 31.73$, $p < .001$), indicating that older adults generated significantly fewer correct responses than young adults. A significant main effect of task type was also observed ($F_{(2, 38)} = 53.73$, $p < .001$). Post hoc comparisons indicated that noun fluency yielded significantly more correct responses than verb fluency ($p < .001$) and letter fluency ($p < .001$). In contrast, verb and letter fluency did not differ ($p = 1.000$). The interaction between age group and task type was not significant ($F_{(2, 38)} = 1.42$, $p = .255$). Figure 2 illustrates the mean number of correct responses for each task by age group.

A stepwise discriminant analysis revealed that verb fluency was entered at the first step and demonstrated the strongest discriminative power between age groups (Wilks' $\Lambda = .307$, $F_{(1,19)} = 42.84$, $p < .001$; Table 2). The final model including verb and noun fluency was significant (Wilks' $\Lambda = .235$, $\chi^2(2) = 26.09$, $p < .001$) and correctly classified 100% of cases.

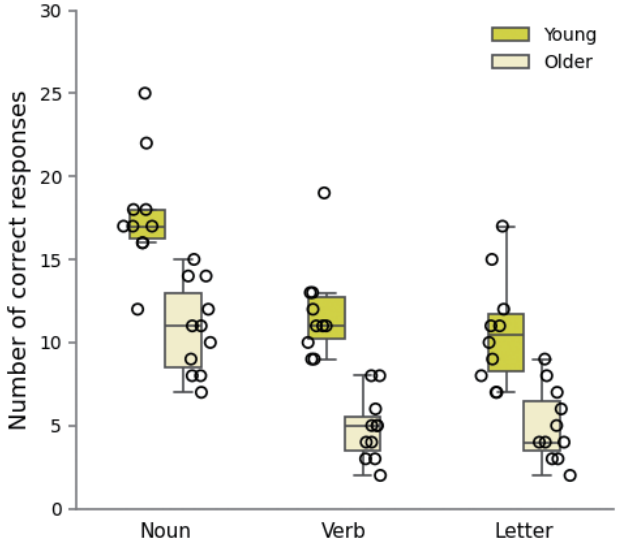

Figure 2. Distribution of correct responses during verbal fluency tasks in young and older adults.

Hemodynamic Responses

Table 3 presents descriptive statistics (mean and standard deviation) of task-related ΔHbO responses by age group (young, older), task type (noun, verb, letter), anteriority (anterior, ventrolateral), and laterality (left vs. right).

A permutation-based four-way mixed ANOVA was conducted on ΔHbO values in the prefrontal cortex, with laterality (right, left) and anteriority (anterior, ventrolateral) as within-subject factors, age group (young, older) as a between-subject factor, and VFT type (noun, verb, letter) as a repeated-measures factor.

The analysis revealed a significant main effect of anteriority ($F_{(1, 19)} = 17.81$, $p < .001$), indicating greater ΔHbO responses in the VLPFC compared to the anterior prefrontal region across groups.

Table 3. Descriptive statistics of ΔHbO responses by group, task type, anteriority, and laterality

Age group	Type	Anteriority	Laterality	
			Left (ΔHbO)	Right (ΔHbO)
Young	Noun	Anterior	-.007 (.062)	-.001 (.060)
		Ventrolateral	.072 (.153)	.086 (.151)
	Verb	Anterior	.042 (.093)	.022 (.081)
		Ventrolateral	.113 (.121)	.078 (.116)
	Letter	Anterior	-.022 (.096)	-.010 (.093)
		Ventrolateral	.043 (.168)	.063 (.155)
Older	Noun	Anterior	.026 (.031)	.014 (.044)
		Ventrolateral	.080 (.121)	.054 (.103)
	Verb	Anterior	.043 (.055)	.019 (.047)
		Ventrolateral	.024 (.090)	.025 (.085)
	Letter	Anterior	.009 (.052)	-.015 (.057)
		Ventrolateral	.030 (.078)	-.039 (.131)

Values represent values mean and standard deviation of ΔHbO responses.

Table 2. Stepwise discriminant analysis predicting age group

Predictor	Step Entered	Wilks' Λ	*F*	*p*	Std. Coefficient	Structure Coefficient
Verb	1	.307	42.843	< .001	.765	.832
Noun	2	.420	26.190	< .001	.559	.650
Letter	—	.465	21.833	< .001	—	.662

Verb fluency was entered at Step 1 and showed the strongest discriminative power.
Overall model Wilks' $\Lambda = .235$, $\chi^2(2) = 26.09$, $p < .001$.
Classification accuracy = 100%.

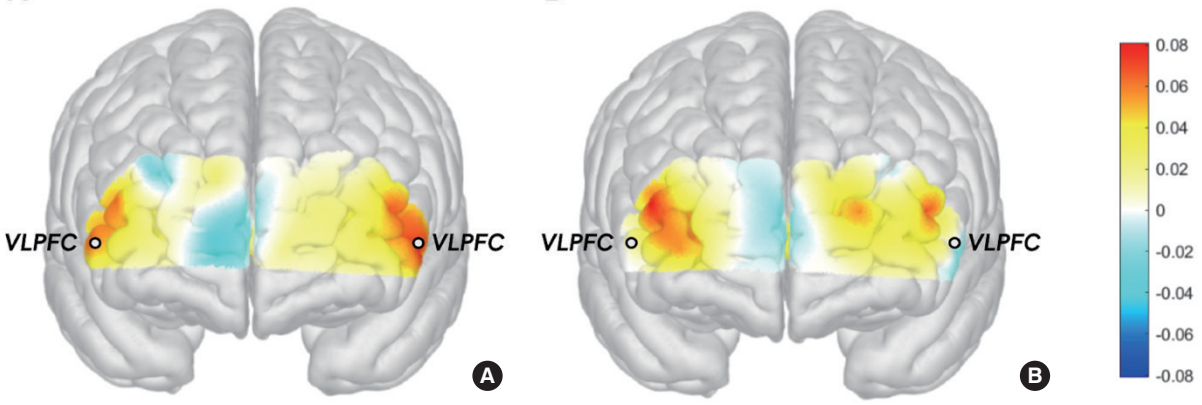

Figure 3. Oxyhemoglobin concentration changes of ventrolateral prefrontal cortex averaging right and left hemisphere during verbal fluency tasks between young (A) and older (B) adults.
VLPFC = ventrolateral prefrontal cortex.

In addition, a significant age group × anteriority interaction was observed ($F_{(1, 19)} = 5.60$, $p = .029$), indicating that older adults exhibited significantly lower ΔHbO responses in the VLPFC than in the anterior PFC compared to young adults.

Figure 3 illustrates group differences of ΔHbO responses in the VLPFC averaged across the right and left hemispheres, showing reduced activation in older adults compared to young adults during VFTs.

Correlation between Behavioral and Hemodynamic Responses

Correlation analyses revealed a significant positive association between behavioral performance and hemodynamic responses in the older adult group. Specifically, the mean number of correct responses in the verb fluency task was positively correlated with ΔHbO in the right VLPFC ($r = .44$, $p = .048$), indicating that older adults who produced more verbs exhibited higher task-related oxyhemoglobin responses in this region.

In contrast, no significant correlations were observed between verbal fluency performance and ΔHbO in the young adult group (all $ps > .05$).

DISCUSSION

The present study examined age-related differences in behavioral performance and prefrontal hemodynamic responses during noun, verb, and letter verbal fluency tasks using fNIRS. Behaviorally, older adults produced fewer words than young adults across tasks, with noun fluency yielding higher output than both verb and letter fluency. Importantly, verb fluency emerged as the strongest behavioral discriminator between age groups. At the neural level, VLPFC activation was greater than anterior prefrontal activation across groups, but this ventrolateral response was significantly attenuated in older adults. Furthermore, verb fluency performance was positively associated with right VLPFC activation in the older group, suggesting that recruitment of this region supports effortful action word retrieval in aging.

At a behavioral level, older adults generated fewer words than young adults across all verbal fluency tasks. This age-related decline in fluency performance aligns with well-documented reductions in processing speed, executive control, and lexical access efficiency associated with normal aging (Henry et al., 2004; Kim et al., 2011; Park et al., 2024, 2025). Across both age groups, noun fluency yielded higher output than verb and letter fluency, reflecting the relatively structured semantic organization and lower executive demands of noun retrieval compared to other fluency subtypes.

Discriminant analysis revealed that verb fluency most strongly differentiated older from young adults, indicating that action word retrieval captures age-related variability in lexical performance more effectively than noun or letter fluency. This finding converges with prior behavioral evidence demonstrating that verb fluency is particularly sensitive to aging and early cognitive decline (Piatt et al., 1999; Park et al., 2024). Unlike noun fluency,

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which benefits from relatively well-structured semantic category organization, verb fluency places heavier demands on executive control, semantic integration, and lexical selection processes (Bak & Hodges, 2003; Piatt et al., 2004). Because these processes rely strongly on frontal systems that are especially vulnerable to aging, even subtle reductions in frontal-executive efficiency may disproportionately affect verb retrieval. Consequently, verb fluency may serve as a sensitive behavioral marker of early or mild age-related changes in lexical access that are not readily captured by traditional noun-based fluency measures.

Importantly, the stronger discriminative power of verb fluency observed in the present study may reflect the cumulative burden imposed by multiple cognitive operations during action word retrieval. In contrast to noun fluency, which allows clustering within relatively stable semantic categories (e.g., animals), verb generation requires continuous updating of search strategies, suppression of semantically overlapping or morphologically related responses, and integration of context-dependent action representations. These demands likely amplify age-related variability in frontal network efficiency, making verb fluency particularly sensitive to subtle executive decline. Moreover, given prior neuroimaging evidence of reduced lateralization or compensatory right frontal recruitment in older adults, heightened executive demands during verb production may further accentuate group differences at both behavioral and neural levels.

At the hemodynamic level, oxyhemoglobin responses differed by anteriority, with overall greater activation observed in the VLPFC compared to the anterior prefrontal region across age groups. However, older adults exhibited significantly reduced ΔHbO responses in the VLPFC compared to young adults. This group difference was most pronounced in the VLPFC, a region implicated in effortful aspects of lexical retrieval, including selection among competing alternatives and suppression of irrelevant responses during word generation (Hirshorn & Thompson-Schill, 2006). Such control-dependent processes are particularly susceptible to normal aging, reflecting declines in processing efficiency and inhibitory control. Consequently, verbal fluency tasks that place sustained demands on controlled retrieval are more likely to reveal age-related differences in ventrolateral prefrontal engagement. Consistent with this interpretation, previous fNIRS studies of verbal fluency have reported attenuated VLPFC activation in older adults, indicating age-related changes in the recruitment of this region during fluency performance (Herrmann et al., 2006; Kahlaoui et al., 2012; Meinzer et al., 2012; Yeung et al., 2016).

Within the older adult group, verb fluency performance was positively correlated with ΔHbO responses in the right VLPFC, indicating that individuals who generated more action words exhibited greater engagement of this region during the task. Accumulating neuroimaging evidence suggests that the VLPFC, including the inferior frontal gyrus, plays a critical role in verb and action word processing, particularly by supporting controlled semantic retrieval and selection among competing lexical alternatives (Hirshorn & Thompson-Schill, 2006). Compared to many noun categories, verbs and action words are characterized by greater semantic representations and weaker categorical structure, often eliciting a broader set of competing representations. As a result, verb fluency places heightened demands on top–down control mechanisms to regulate retrieval and suppress irrelevant alternatives. Consistent with this account, neuroimaging studies of action naming and verb production have repeatedly reported engagement of ventrolateral prefrontal regions during action word retrieval (Perani et al., 1999; Shapiro et al., 2006).

The right-lateralized association observed in older adults is also consistent with prominent models of functional brain aging that propose reduced hemispheric asymmetry and increased recruitment of contralateral prefrontal regions as task demands increase (Cabeza, 2002). From this perspective, greater right VLPFC engagement during verb fluency may reflect an age-related shift toward broader prefrontal involvement to support controlled lexical access as the efficiency of typically left-lateralized language-control networks declines. Empirically, fNIRS studies of verbal fluency in aging have documented reduced hemispheric specialization and increased right frontal involvement in older adults compared to younger adults (Meinzer et al., 2012; Yeung et al., 2016). Importantly, because this association was observed only in the older group and is correlational in nature, it should be interpreted as an age-specific coupling between right VLPFC engagement and verb fluency performance, rather than as evidence of a direct causal or compensatory mechanism.

Clinically, the present findings suggest that incorporating verb

fluency tasks into routine cognitive assessments for older adults may improve the early detection of subtle executive–language changes that are not readily captured by noun- or letter-based fluency tasks alone. Given that verb retrieval imposes greater demands on semantic integration and executive control, verb fluency may serve as a more sensitive probe of frontal lobe function in aging populations. Furthermore, the observed association between right ventrolateral prefrontal activation and verb fluency performance indicates that neurophysiological measures such as fNIRS may provide complementary information beyond behavioral scores, particularly in individuals who perform within the normal range yet exhibit altered neural recruitment patterns. This combined behavioral–neural approach may be valuable in identifying individuals at risk for accelerated cognitive decline.

Several limitations warrant consideration. First, the modest sample size may have limited statistical power, particularly in detecting subtle associations between neural activation and behavioral performance. Second, although fNIRS provides advantages in ecological validity and tolerance for overt speech, it is restricted to cortical surface regions and is susceptible to age-related vascular changes that may influence hemodynamic responses. Third, the cross-sectional design precludes conclusions regarding whether the observed right-hemispheric recruitment reflects compensatory mechanisms or reduced neural efficiency. Longitudinal studies are needed to clarify the functional significance of these activation patterns over time. Finally, future research should directly compare verb, noun, and letter fluency within the same neuroimaging framework to more precisely delineate subtype-specific neural mechanisms.

In conclusion, the present study provides novel evidence that verb fluency is closely linked to ventrolateral prefrontal engagement in older adults, offering valuable insights into the neural mechanisms supporting action word retrieval in aging. These findings may inform future research on cognitive aging and neurodegenerative disorders by highlighting the importance of task-specific and region-specific neural markers. In particular, the sensitivity of verb fluency to frontal executive engagement suggests that action-based language measures may serve as an important component in the early identification of age-related cognitive vulnerability. Future studies that further examine these mechanisms using longitudinal designs and multimodal neuroimaging approaches may contribute to the development of strategies for maintaining cognitive function and preventing dementia in aging populations.

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국문초록

명사, 동사, 글자 유창성 과제에서 나타나는 노화에 따른 전전두엽 활성화 비교: fNIRS 연구

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배경 및 목적: 본 연구는 명사, 동사, 글자 구어 유창성 과제에서 나타나는 연령에 따른 행동 수행력 차이와 전전두엽 혈역학 반응을 확인하고, 노화에 가장 민감한 과제 유형과 뇌영역을 조사하였다. 방법: 인지적으로 건강한 노년층 11명, 청년층 10명이 명사, 동사, 글자 구어 유창성 과제를 수행하는 동안 기능적 근적외선 분광법(fNIRS)으로 전전두엽 피질 활성을 측정하였다. 행동 수행력은 산출된 단어 수로 정량화하였고, 혈역학 반응(ΔHbO)은 순열 기반 혼합효과 분산분석으로 분석하였다. 단계적 판별분석을 통해 연령 집단을 가장 잘 구별하는 구어 유창성 과제를 확인하였다. 결과: 노년 집단은 모든 과제에서 청년 집단에 비해 적은 단어를 산출하였다. 판별분석 결과 동사 구어 유창성이 연령 집단 구별에 가장 강력한 행동 지표였다. 혈역학적 반응 수준에서는 복외측 전전두피질(VLPFC) 활성이 전방 전전두피질보다 높았으나, 노인 집단은 VLPFC에서 유의하게 감소된 ΔHbO 반응을 보였다. 또한 노인 집단에서만 동사 유창성 수행력과 우측 VLPFC 활성 간 정적 상관이 나타났다. 논의 및 결론: 동사 유창성은 연령 관련 어휘 인출 변화에 특히 민감하며, 복외측 전전두피질 참여 감소가 건강한 노화에서 나타나는 언어 유창성 수행의 특징임을 시사한다.

핵심어: 언어 유창성, fNIRS, 노화

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