

Research Article

Aging-Related Changes in Switching and Cluster Diversity in the Action Verbal Fluency Task Using Hierarchical Clustering Analysis

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ABSTRACT

Purpose: This study aims to establish objective verb clustering criteria in action verbal fluency (VF) using hierarchical clustering analysis (HCA) based on the Lancaster sensorimotor norms. We explored age-related differences in switching and cluster diversity (word retrieval strategies) between younger and older adults and correlations among age, education, working memory (WM) capacity, action VF performance, and word retrieval strategies for each group.

Method: Sixty-two native Korean speakers participated in the study, with 31 young adults ($M_{age} = 27.39$) and 31 older adults ($M_{age} = 70.45$). Participants completed a 1-min action VF task, and generated verbs were classified into 15 clusters based on the Lancaster sensorimotor ratings using HCA. We analyzed switching (shifts between clusters) and cluster diversity (number of unique verb clusters) to assess word retrieval strategies. WM capacity was measured through word-forward and word-backward (WB) tasks.

Results: Older adults demonstrated significantly fewer switchings and lower cluster diversity compared to younger adults, indicating restricted word retrieval strategies. WB task scores in older adults positively correlated with word retrieval strategies and action VF performance. Older individuals with younger age and higher education employed more word retrieval strategies. Both groups exhibited positive correlations between word retrieval strategies and action VF performance.

Conclusions: The novel HCA approach, based on the Lancaster sensorimotor norms, successfully classified verb clusters that revealed aging-related differences in word retrieval strategies and the relationship between WM and these strategies. These results highlight the potential of using the HCA method for verb clustering analyses, particularly in providing qualitative insights into action VF tasks.

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Linguistic and cognitive declines are commonly associated with typical aging and degenerative diseases (de Araujo et al., 2011; Rofes et al., 2019) and often manifest as word retrieval deficits. Word retrieval impairments are the most frequently reported symptoms in neurodegenerative

processes, including dementia and mild cognitive impairment (MCI), a transitional state between typical aging and dementia (Tsantali et al., 2013). The verbal fluency (VF) task is a widely used neuropsychological assessment to detect and monitor cognitive-linguistic declines in the word retrieval process (Piatt et al., 1999; Rofes et al., 2019). In the VF tasks, participants are required to generate as many words as possible that belong to given semantic, phonemic, or verb categories within a limited time window of 30 or 60 s. Three types of VF measures are most commonly used in the literature. Semantic VF tasks

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employ various semantic categories such as animals, supermarket items, or vegetables/fruits. The phonemic (or letter) VF tasks require participants to generate words that start with a given phoneme or letter (Davis et al., 2010; Piatt et al., 1999). The action (also referred to as “verb”) VF task, while receiving relatively less attention than other measures, specifically targets the word retrieval process associated with action or movement (Piatt et al., 1999).

As VF tasks require efficient strategies to search for and retrieve appropriate words within a limited time window, they are known to rely on various cognitive constructs, including executive function of the frontal lobe, working memory (WM), cognitive flexibility, inhibitory control, and attention (Burda, 2010; Zhao et al., 2013). WM, in particular, which is one of the key components of executive functions, plays a crucial role during complex cognitive tasks by simultaneously storing and processing information (Just & Carpenter, 1992). Previous research has emphasized the importance of WM capacity in the successful retrieval of words during VF tasks, particularly through the analysis of error patterns in individuals with Alzheimer’s disease (AD; Miozzo et al., 2013) and those with traumatic brain injury (TBI; Fischer-Baum et al., 2016). Both studies identified WM deficits in patients with AD or TBI, which impaired their ability to monitor previously generated items during the semantic or phonemic VF tasks, leading to an increased occurrence of perseveration errors (Fischer-Baum et al., 2016; Miozzo et al., 2013).

Previous studies have shown that various types of VF tasks contribute to the differential diagnosis of neurodegenerative diseases, such as distinguishing AD from typical aging (Forbes-McKay et al., 2005) or MCI from AD (Vita et al., 2014). For instance, Forbes-McKay et al. (2005) found that individuals with AD produce significantly fewer words during semantic VF tasks, with those words being of higher frequency, more typical, and acquired earlier in life compared to healthy controls. In another study by Marczyński and Kertesz (2006), individuals with semantic dementia exhibited different patterns of average word frequency depending on the category of the semantic VF tasks. Specifically, people with semantic dementia produced words with lower average frequency in a grocery VF task compared to individuals with AD. Conversely, in an animal VF task, individuals with semantic dementia showed higher mean word frequency than those with AD (Marczyński & Kertesz, 2006). Additionally, Vita et al. (2014) demonstrated that the typicality of words generated during semantic VF tasks involving categories such as birds and furniture could help distinguish between people with MCI and AD. They found that individuals with MCI who predominantly generated typical items in the semantic VF tasks were more likely to

develop AD in a 2-year follow-up study (Vita et al., 2014). The results outlined above suggest that psycholinguistic variables, such as word frequency and typicality in different types of VF tasks, may exhibit distinctive patterns, depending on the specific type of neurodegenerative disease.

As performance on VF tasks varies depending on the task type, several approaches to VF analysis have been proposed. The most traditional approach involves calculating and reporting the total number of correct responses. Thiele et al. (2016) reviewed 128 studies that employed VF tasks and found that 84.38% of them relied solely on the number of correct responses as their primary measure. However, VF tasks offer more than just a simple measure of performance based on total numbers; they also provide valuable insights into an individual’s word retrieval strategies, error patterns, and the underlying cognitive constructs associated with linguistic deficits (Thiele et al., 2016). To examine these additional components of VF tasks, analyzing only the number of correct responses may be insufficient to capture the diverse individual characteristics that manifest during the tasks. Gaspers et al. (2012) conducted VF tasks with individuals with mild-to-moderate aphasia, those with cognitive-communication disorders (resulting from TBI, cerebral tumors, and ischemic or hemorrhagic stroke), and healthy controls. They found that while the measurement of correct responses could effectively distinguish individuals with aphasia from healthy controls, it was insufficient to differentiate those with cognitive-communication disorders from healthy individuals. However, when additional measures such as semantic coherence, word frequency, or the number of syllables and phonemes per word were analyzed, individuals with cognitive-communication disorders could be distinguished from healthy controls. These findings suggest that more detailed analyses of VF tasks may be necessary to identify individual characteristics associated with different types of cognitive–linguistic deficits.

To address the limitations of quantitative analyses that focus solely on the total number of responses, researchers have adopted qualitative approaches to better understand how and why participants achieve certain outcomes (Gaspers et al., 2012; McDowd et al., 2011; Rofes et al., 2019, 2020; Troyer et al., 1997, 1998). Troyer et al. (1997, 1998) were the first to introduce clustering and switching analyses in VF tasks. *Clusters* are defined as semantically or phonemically similar subcategories of words, while *switching* refers to the shifts between these clusters. Clustering and switching behaviors reflect variations in the word retrieval strategies that participants employ during VF tasks. Switching behaviors, in particular, are associated with individual differences in prefrontal functions such as cognitive flexibility and inhibition, which

are believed to facilitate word generation (Burda, 2010; Cralidis & Lundgren, 2014). Previous studies have reported that individuals who actively engage in switching during VF tasks tend to generate a greater total number of correct responses (Kosmidis et al., 2004; Troyer et al., 1997, 1998).

To employ qualitative approaches using clustering and switching analyses, it is essential to establish criteria for semantic subcategories based on semantic relationships. For example, in the animal VF task, subcategories could be classified according to the animals' habitats or species (Troyer, 2000). Similarly, in a supermarket items task, subcategories could be classified by product types, such as fruits, vegetables, meats, and beverages (Troyer, 2000). However, for the action VF task, subcategories for clustering analyses are not as well defined, as verbs represent concepts of movement or transition that are difficult to categorize semantically with clarity. Despite these challenges, there have been attempts to apply qualitative approaches to action VF tasks, even with the limitations posed by less distinct clustering criteria.

Paek and Murray (2021) investigated whether individuals with probable AD and healthy controls differ in terms of psycholinguistic variables such as age of acquisition, phoneme and syllable length, and word frequency in responses from the action VF task. The authors categorized the verbs into different subcategories, such as mental-state verbs and action verbs. They found that individuals with AD generated fewer mental-state verbs and tended to produce verbs with fewer syllables and shorter phoneme lengths, earlier age of acquisition, and higher frequency compared to healthy controls. In a more recent study, Fisher et al. (2023) applied a clustering method to the action VF task using the Lancaster sensorimotor norms and examined group differences in clustering and switching between healthy older adults and individuals with AD. The Lancaster sensorimotor norm provides a total of 11-dimensional rating scores for each word, encompassing both perceptual modalities and action effectors features (Lynott et al., 2020). The authors focused on categories of action effectors from the Lancaster sensorimotor norms, excluding five other dimensions in the perceptual modalities such as gustatory, auditory, or interoception. Verb clusters were defined by matching each verb to a single action effector, selecting the one with the highest rating among the available options. However, these analyses have certain limitations. They did not account for all perceptual modality features from the sensorimotor norms, and the verb classification was based solely on the highest rating score, potentially oversimplifying the clustering process.

Despite the challenges associated with the qualitative analysis of action VF tasks, further investigation in this area is warranted. Verbs encompass complex semantic

features that reflect both motor components and sensory features (Williams et al., 2021). These features may offer a sensitive means of detecting subtle changes in cognitive–linguistic abilities (Davis et al., 2010; McDowd et al., 2011; Piatt et al., 1999). As such, developing action VF-related research could provide valuable insights into cognitive–linguistic assessment and early detection of impairments. Various studies employed the action VF in clinical populations with neurodegenerative disease. McDowd et al. (2011) demonstrated that individuals with Parkinson's disease represented significantly lower performance in action VF tasks compared to phonemic or semantic VF tasks. However, adults with AD exhibited the opposite pattern, performing better on action VF tasks relative to phonemic and semantic VF, highlighting distinct cognitive processing associated with retrieving verbs and nouns (McDowd et al., 2011). Davis et al. (2010), along with earlier research (Damasio et al., 1992; Damasio & Tranel, 1993), identified that the retrieval process for nouns relies more heavily on the temporoparietal cortex, whereas verb naming depends more on frontal-subcortical circuits. Therefore, individuals with frontal lobe impairment exhibit significantly more difficulty in retrieving verbs compared to nouns (Damasio & Tranel, 1993). Similarly, adults with behavioral variant frontotemporal dementia show poorer performance on action VF tasks compared to semantic VF tasks (Davis et al., 2010). As a result, action VF tasks provide unique and valuable insights into language abilities that are not fully captured by semantic and phonemic VF measures.

To take the value of the action VF task in detecting cognitive declines and providing additional diagnostic information on the differential diagnosis for clinical populations with neurodegenerative disease, this study aims to establish criteria for verb clustering to conduct the qualitative analysis of action VF tasks. To classify verbs based on their complex semantic features, we employed the Lancaster sensorimotor norm, which offers 11 dimensions encompassing both action effectors and perceptual features. As demonstrated by prior research (Fisher et al., 2023), the Lancaster norm is an effective tool for representing objective rating scores that quantify the complex semantic characteristics of verbs. In the current study, we decided to include both action and perceptual components in our verb classification to capture all domains of verb-related semantic features. This approach has the advantage of incorporating perceptual components associated with verbs, such as conceptual and perceptual verbs (e.g., think, smell, feel), which were not fully addressed in the previous study by Fisher et al. (2023).

To construct objective criteria, we also employed the hierarchical clustering analysis (HCA) method. In Fisher et al. (2023), verb clusters were created by assigning each

verb to a single action effector based on the highest Lancaster norm rating score. While this clustering approach may seem intuitive, it has limitations in fully capturing the complex semantic features of verbs. For example, the Lancaster norm provides the top two motor effector ratings for the word “swim”: 4.053 for foot/leg and 4.158 for hand/arm. A mental image of swimming typically involves both leg and arm movements, making it an oversimplification to assign “swim” to the hand/arm cluster solely because its score is 0.105 points higher than that of the foot/leg component. To address this limitation, we chose the HCA method, which allows for a more reflection of the multidimensional Lancaster semantic scoring components for verbs. Recent studies highlight the necessity of exploring semantic components involved in lexical access using advanced analytical approaches. For example, various network science methods have been adopted to analyze VF tasks (Arias-Trejo et al., 2021; Lebkuecher et al., 2024; Wulff et al., 2022). Lebkuecher et al. (2024) utilized SemNet (A. P. Christensen & Kenett, 2023) to compare the flexibility and resilience of semantic network structures between individuals with multiple sclerosis and neurotypical individuals during the animal VF task. Similarly, Wulff et al. (2022) conducted similarity ratings to examine age-related differences in the characteristics of individual semantic networks during the animal VF task. Inspired by these approaches, our study employs HCA to construct a semantic similarity network among various verbs, maintaining the clustering framework based on Lancaster semantic components. HCA, a statistical technique used to group data samples into distinct, nonoverlapping clusters based on shared characteristics, further strengthens this approach. The smallest distance between data points within the network indicates the strongest connection, suggesting that closely related objects are more likely to cluster together.

Overcoming limitations of previous studies and leveraging methodological advancements, the current study aims to (a) establish verb clusters using the HCA method applied to the Lancaster norms and (b) validate these verb clusters by analyzing whether this classification method adequately captures age-related differences in word retrieval strategies, such as switching and cluster diversity, between young and older adults. Additionally, we examined whether these age-related changes in the action VF task are associated with individual

differences in cognitive constructs (such as WM capacity) and demographic factors such as education.

Method

Participants

Sixty-two individuals participated in this study, with 31 in the younger group ($M = 27.39$, $SD = 2.29$) and 31 in the older group ($M = 70.45$, $SD = 6.26$; see Table 1). All participants satisfied the criteria including (a) native Korean speakers with no report of neurological or psychiatric disorders based on the Health Screening Questionnaire (K. J. Christensen et al., 1991) and (b) the normal range of the Korean Mini-Mental State Examination, adjusted for age and education (> 16 percentile; Kang, 2006). Older adults also met the normal range (> 16 percentile) of the Seoul Verbal Learning Test, which is the subtest of the Seoul Neuropsychological Screening Battery–Second Edition (Kang et al., 2012). All participants provided informed consent before participation, and the study adhered to ethical guidelines as approved by the institutional review board of Ewha Womans University (Approval No. 2022-0112).

An independent t test was conducted to test whether there were differences in education levels between the two groups. The results indicated no significant difference in education between the younger and older groups ($t_{60} = -0.354$, $p = .725$).

A chi-square (χ^2) test exhibited significant differences in gender distribution between the two groups, with the younger group comprising more females and the older group including more males ($\chi^2 = 4.133$, $p = .042$). Independent-samples t tests were conducted to examine potential differences in age and education between genders within each group. In the younger group, no significant differences were found between male and female participants regarding age ($t_{29} = -1.415$, $p = .168$) or years of education ($t_{29} = -0.820$, $p = .419$). Similarly, in the older group, there were no significant differences in age ($t_{29} = -2.017$, $p = .053$) or years of education ($t_{29} = 1.972$, $p = .058$) between male and female participants. Therefore, participants were not separated by gender within each group.

Table 1. Demographic information for participants.

Participant	Age (year)	Education (year)	Gender distribution (male:female)
Younger ($n = 31$)	27.39 (2.29)	15.00 (1.51)	13:18
Older ($n = 31$)	70.45 (6.26)	14.90 (3.18)	21:10

Note. Values are presented as mean (standard deviation).

Tasks

Action VF Task

Participants were required to verbally produce as many action- or movement-related words as possible within a 1-min time window (Choi et al., 2016; Piatt et al., 1999). We also provided three examples of verbs in Korean, such as “drink,” “give,” and “sweep.” All responses were recorded and transcribed. The task score was measured by the number of correct responses. Words that were repeated or belonged to other word classes were excluded from the correct responses.

WM Tasks

We administered two WM measures: the word-forward (WF) and word-backward (WB) tasks (Sung, 2010). Participants were presented with a sequence of words auditorily in a female voice and were then asked to recall the words in either the direct (WF) or reversed (WB) order. Each task included a total of 14 trials. The WF task ranged from three to nine spans, with two trials for each span level, while the WB task ranged from two to eight spans. Each span has two trials. If participants failed to recall both trials at any given span correctly, the task was discontinued. The score was defined as the number of trials correctly recalled.

Analyses

HCA Based on the Lancaster Sensorimotor Norm

To incorporate verb semantic features, such as movements or transitions, into the criteria for verb clustering, we utilized the Lancaster sensorimotor norm, which is recognized for providing objective word features (Fisher et al., 2023). The Lancaster sensorimotor norm (<https://www.lancaster.ac.uk/psychology/l norms/>) offers sensorimotor strength ratings, which range from 0 to 5, for approximately 40,000 English words. The norm represents a verb with 11 different sensorimotor features, including perceptual modalities (gustatory, auditory, visual, olfactory, and interoception) and action effectors (haptic, head, hand/arm, mouth, foot/leg, and torso; Lynott et al., 2020). Since all our participants were native Korean speakers, their responses were translated into English to use the Lancaster sensorimotor norm. We carefully translated each verb individually to preserve the unique meanings of the Korean verbs as reflected in the participants' responses, ensuring that distinct Korean verbs were not merged into a single English term. Examples of all Korean verbs produced by participants and their English translations are provided in Supplemental Material S1. Despite these efforts, challenges inevitably arose when translating Korean verbs that do not have direct English equivalents. These difficulties stem from culture-specific semantic nuances and the specific predicate structures in

Korean, which often encompass multiple semantic or grammatical features. A more detailed discussion of the challenges encountered during the translation process will be provided in the Discussion section. After standardizing the raw rating scores of each sensorimotor feature into z scores, we represented z -score components as vector features for each word. HCA was then adopted to classify the 309 unique verbs generated by participants during the action VF task into verb clusters. A Ward linkage method and Euclidean distance measure were employed to determine the distance criteria between verb clusters. HCA offers the advantage of automatically clustering verbs based on their proximity in semantic space, continuing this process until the threshold distance for distinguishing between clusters is reached. This method allows us to identify which verbs are closely related and observe how subclusters form within larger clusters through a dendrogram, providing a clear visual representation of the semantic relationships among the verbs. We examined closely related verb clusters within the hierarchical structure to determine the optimal number of clusters for classifying distinct verb clusters. The evaluation process was guided by the silhouette score, a metric that assesses the quality of clustering. This approach confirmed that HCA is well suited for adjusting cluster levels, taking into account both the silhouette score and the combinations of words within each cluster. As a result, we identified a total of 15 different types of verb clusters, as shown in Figure 1. For instance, Verb Cluster ID 14 includes words that represent motor-focused mouth movements, while Verb Cluster ID 13 encompasses words related to auditory features associated with mouth movements.

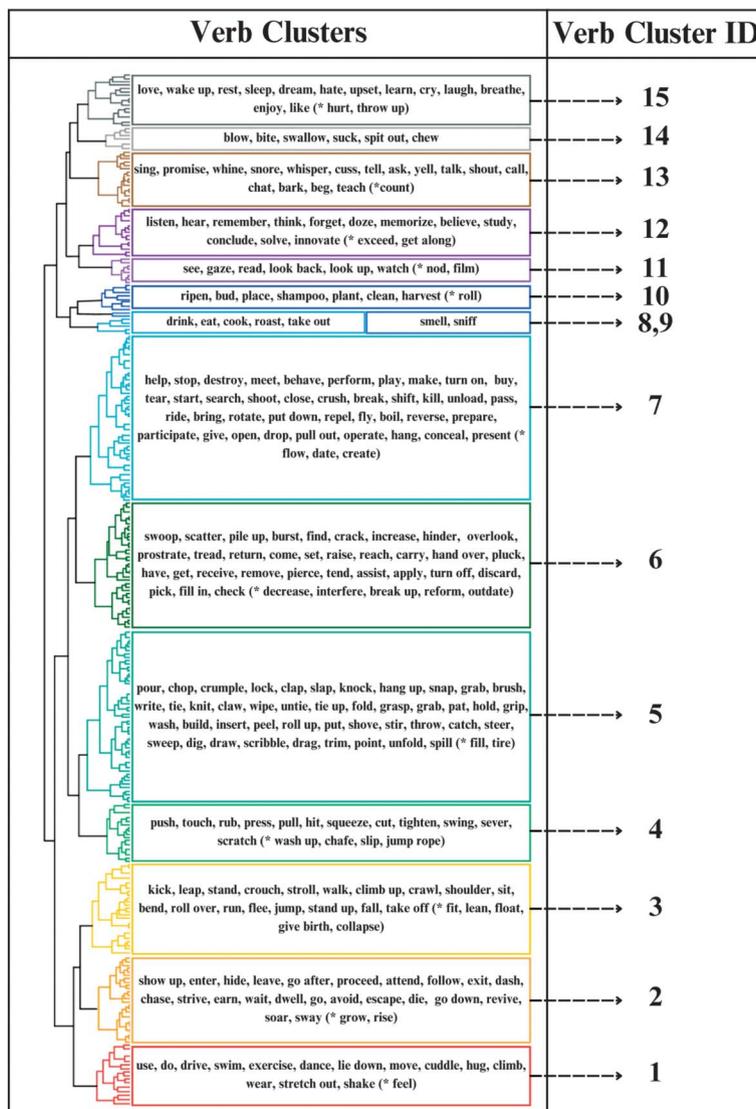
Subjective Rating

Due to the HCA automatic clustering process, a few verbs appeared to be inappropriately assigned to certain verb clusters. To address this, 10 graduate students majoring in speech-language pathology participated in a subjective survey to identify verbs that did not semantically fit within their respective clusters. The raters were provided with all the verbs from each cluster and were asked to select those that did not align well with the cluster's semantic features. Verbs were excluded if over 60% of the raters agreed that they were unsuitable, resulting in the removal of 30 verbs from 309 verbs. The examples of excluded verbs are presented in the Appendix.

Switching and Cluster Diversity Analyses

Following Troyer et al. (1997), we included all participant responses, including errors such as repetitions, in our analysis of switching and cluster diversity. Switching was defined as the shifts between word clusters based on Troyer et al. If adjacent words belonged to the identical verb cluster, they were considered to form a word cluster

Figure 1. Colored dendrogram of verb clusters derived from hierarchical clustering analysis with cluster's ID (right). *Excluded verbs based on the subjective survey results.



within each participant's task performance. Figure 2 provides an example of a participant's action VF task, with words colored differently according to the 15 types of verb clusters identified in the dendrogram by HCA (see Figure 1). In this example, "move" and "use"; "stand up," "fall," and "sit"; "bite," "spit out," and "chew"; as well as "open," "close," and "unload" form distinct word cluster. Switching behaviors between these word clusters are visualized with red arrows, and Figure 2 represents 15 times of switching.

Cluster diversity was measured by counting the number of unique verb clusters that participants employed during the task among the 15 verb clusters established through HCA. For instance, the participant in Figure 2 produced verbs belonging to 10 unique clusters (Verb

Cluster ID: 1, 2, 3, 4, 5, 6, 7, 8, 9, 14). Additionally, since we excluded 30 verbs based on the subjective ratings, those verbs were treated as belonging to one distinct verb cluster when analyzing switching or cluster diversity.

Results

Differences in Word Retrieval Strategies Between the Two Groups

To confirm the differences in the number of total responses, correct responses, switchings, and cluster diversity between the older and younger groups, a one-way analysis of variance was conducted using IBM SPSS 29.0. The basic

Figure 2. Example of calculating the number of switchings and verb clusters from a participant's performance.

Verb Items	Verb Cluster ID
move	1
use	1
drink	8
follow	2
lie down	1
stand	3
fall	3
sit	3
push	4
swoop	6
bite	14
spit out	14
chew	14
smell	9
break	7
kick	3
throw	5
kick	3
open	7
close	7
unload	7
touch	4
open	7
close	7

quantitative analyses of the task performance revealed that the older adults generated fewer total words ($M = 17.61$, $SD = 6.43$) than the younger adults ($M = 23.10$, $SD = 5.29$), $F(1, 60) = 13.433$, $p < .001$. Older individuals also demonstrated a lower number of correct responses ($M = 14.71$, $SD = 5.60$) compared to the younger group ($M = 20.77$, $SD = 4.90$), $F(1, 60) = 20.558$, $p < .001$.

The comparison results of the word retrieval strategies indicated that the older group exhibited significantly fewer switchings ($M = 13.19$, $SD = 4.67$) compared to the younger group ($M = 18.10$, $SD = 4.25$), $F(1, 60) = 18.702$, $p < .001$ (see Figure 3a). Additionally, the younger group demonstrated a significantly higher cluster diversity ($M = 10.19$, $SD = 2.04$) than the older group ($M = 8.71$, $SD = 2.16$), $F(1, 60) = 7.721$, $p = .007$ (see Figure 3b).

Correlation Coefficient and Stepwise Multiple Linear Regression Analyses for Each Group

Pearson correlation coefficients were computed for each group using IBM SPSS 29.0 to investigate the

relationship among variables. In the older group, switching behavior was negatively and significantly correlated with age ($r = -.562$, $p = .001$). However, the number of switchings was positively and significantly correlated with several variables, including education ($r = .430$, $p = .016$), action VF task score ($r = .892$, $p < .001$), cluster diversity ($r = .857$, $p < .001$), and WB task score ($r = .576$, $p < .001$). Generating words from various verb clusters exhibited similar correlation patterns to switching behavior. Specifically, cluster diversity was negatively and significantly correlated with age ($r = -.376$, $p = .037$), while it was positively and significantly correlated with education ($r = .430$, $p = .016$), action VF performance ($r = .807$, $p < .001$), number of switchings ($r = .857$, $p < .001$), and WB task score ($r = .442$, $p = .013$; see Table 2).

In the younger group, performance on the action VF task was significantly correlated with word retrieval strategies, switching behavior ($r = .872$, $p < .001$), and cluster diversity ($r = .668$, $p < .001$). Additionally, the number of switchings and cluster diversity were positively and significantly correlated ($r = .748$, $p < .001$; see Table 3).

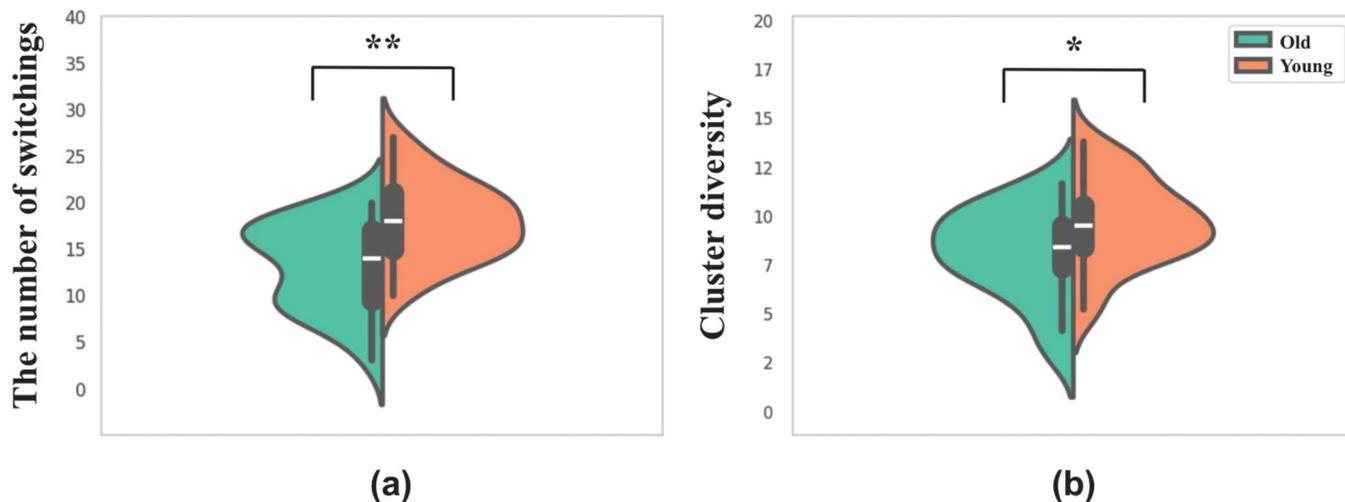
To validate the correlation between action VF performance and word retrieval strategies, stepwise multiple linear regression analyses were conducted for each age group. The action VF task score was designated as the dependent variable, with the number of switchings and cluster diversity included as independent variables.

In the older group, switching behavior ($\beta = .892$) was a significant predictor of the number of correct responses, accounting for 79.6% of the total variance, $F(1, 29) = 112.952$, $p < .001$, $R^2 = .796$. Similarly, in the younger group, the number of switchings ($\beta = .872$) significantly predicted the number of correct responses, explaining 76.1% of the total variance, $F(1, 29) = 92.110$, $p < .001$, $R^2 = .761$.

To summarize the results of correlational and regression analyses, these findings indicate that participants who employed word retrieval strategies, particularly switching behaviors, tended to perform better on the action VF task, across the age groups. Notably, in the older group, participants who were younger had higher levels of education, having greater WM capacity were more likely to utilize these word retrieval strategies during the action VF task.

To further explore the relationships among variables, we applied nonlinear multidimensional scaling (NMDS; see Figure 4). The NMDS analysis in the older group revealed that variables such as the action VF score, the number of switchings, education, cluster diversity, and WM task scores were positioned closely in the reduced dimensional space, indicating a strong association among these variables (see Figure 4a). In contrast, in the younger

Figure 3. The number of switchings (a) and cluster diversity (b) between the groups. * $p < .05$, ** $p < .001$.



group, the variables were relatively more dispersed compared to the older group, suggesting weaker relationships (see Figure 4b). This visualization provides a more intuitive understanding of the underlying structure of the data, complementing correlation and regression analyses.

Discussion

The current study aimed to establish objective verb clustering criteria using HCA for the qualitative analysis of the action VF task and to validate these clusters by examining age-related differences in word retrieval strategies, such as switching and cluster diversity, between healthy younger and older adults. The study demonstrated that applying HCA for verb classification enabled the identification of 15 distinct verb clusters. HCA integrates both action and perceptual component ratings from the Lancaster sensorimotor norms in the verb classification process, effectively capturing the complex semantic features of verbs. This method addresses the limitations of Fisher et al. (2023), which was the first study to apply the Lancaster norms to verb clustering. In the previous study, only action

components were considered, with each verb assigned to a single action category based solely on its highest Lancaster rating score. This approach has the limitation of oversimplifying the semantic features of verbs, potentially grouping verbs with distinct meanings into the same cluster. For example, although “talk,” “laugh,” and “cry” all involve mouth movements, they carry distinct semantic features that cannot be captured by a simplistic clustering based solely on physical actions. “Talk” is typically used for routine communication, whereas “laugh” and “cry” are primarily associated with expressing emotions. In Fisher et al., “talk” and “laugh” were grouped into the mouth cluster, while “cry” was placed in the head cluster. In contrast, our HCA results, which incorporate all dimensional ratings from the Lancaster norms, classified “laugh” and “cry” together in Cluster ID 15 and “talk” in a separate cluster, ID 13. A closer examination of the clusters shows that ID 13 primarily contains words related to concrete actions of the mouth related to verbal actions, such as “sing,” “whisper,” “ask,” “call,” and “chat.” In contrast, Cluster ID 15 includes abstract words associated with emotions, such as “love,” “hate,” “upset,” and “enjoy.” Since we demonstrated the effectiveness of using HCA to classify verbs, we

Table 2. Pearson correlation results in the older group.

Variable	Age	Education	Action VF score	Cluster diversity	No. of switchings
Action VF score	-.597**	.622**			
Cluster diversity	-.376*	.287	.807**		
No. of switchings	-.562**	.430*	.892**	.857**	
WF score	-.136	.410*	.281	.108	.162
WB score	-.256	.490**	.575**	.442*	.576**

Note. Action VF score = number of correct responses to the action verbal fluency task; WF score = number of correct responses to the word-forward task; WB score = number of correct responses to the word-backward task.

* $p < .05$. ** $p < .001$.

Table 3. Pearson correlation results in the younger group.

Variable	Age	Education	Action VF score	Cluster diversity	No. of switchings
Action VF score	-.051	.343			
Cluster diversity	.041	.152	.668**		
No. of switchings	-.014	.302	.872**	.748**	
WF score	-.352	.265	-.016	.003	-.051
WB score	-.435*	.200	.070	.141	.219

Note. Action VF score = number of correct responses to the action verbal fluency task; WF score = number of correct responses to the word-forward task; WB score = number of correct responses to the word-backward task.

* $p < .05$. ** $p < .001$.

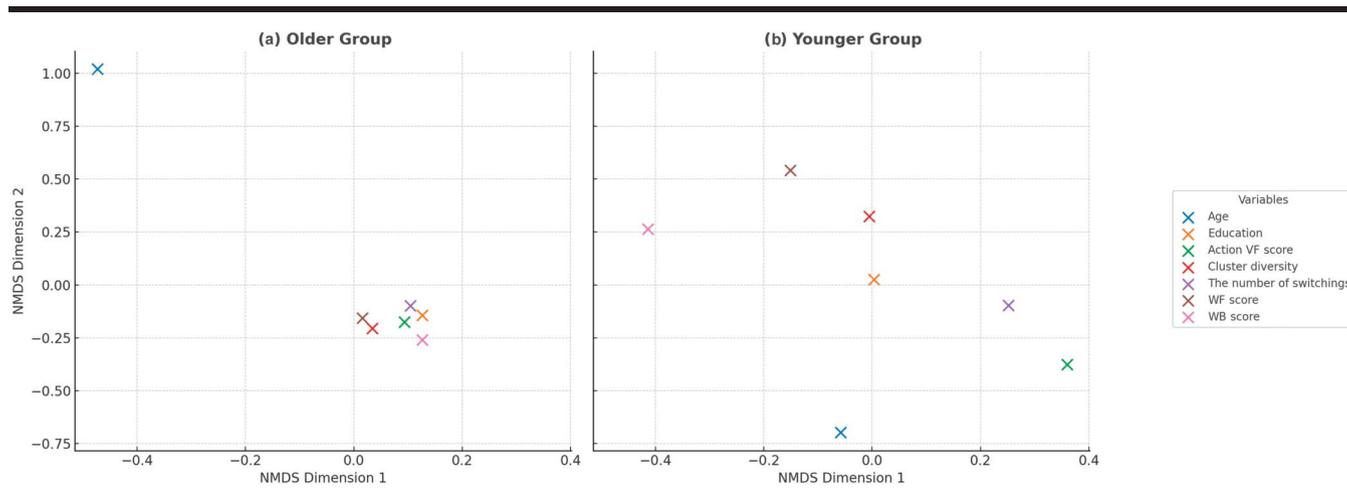
also investigated whether this method can be validated through subjective ratings. Based on subjective ratings, 30 out of 309 verbs (approximately 10% of the total verb set) were excluded. This small portion of exclusions suggests that our HCA clustering results align well with human perception of verb classification.

While the clustering results were promising, there are still several limitations in using HCA for verb clustering. One limitation arises from the data-driven nature of the HCA method. Since HCA sequentially merges data features into clusters, the results may vary depending on the composition and size of the data set (Blei & Lafferty, 2009). Additionally, as HCA has no formal stopping rule, it requires researchers to determine a cutoff point by carefully examining the entire clustering process in the dendrogram (Bratchell, 1989). Although HCA is a valuable tool in linguistic and cognitive research, researchers should be aware of the flexibility in interpreting its results (Yim & Ramdeen, 2015).

Another limitation relates to the translation process. We translated all participants' responses into English to utilize the Lancaster sensorimotor norm for HCA, which currently supports only the English language. This step

was necessary because no Korean resources currently exist that fully capture the semantic characteristics of verbs. In translation, we prioritized preserving the distinct meanings of Korean verbs and avoided merging separate Korean verbs into a single English word. Despite our efforts, we inevitably faced challenges when translating Korean verbs that do not have direct English equivalents while maintaining their original meaning. We addressed this issue by choosing the English translation of the closest meaning, such as translating “chey-ha-ta (have an upset stomach)” to “upset.” However, this approach is still insufficient to fully capture the culture-specific semantic nuances embedded in the original Korean verbs. Additionally, serial verbs are a common predicate structure in Korean and also frequently appear in the action VF task. The serial verb may contain multiple semantic or grammatical features. For instance, each individual verb such as “top-ta (help),” “cwu-ta (give),” and “ka-ta (go)” can be represented as a serial verb form such as “to-wa-cwu-le-ka-ta (coming to give a helping hand).” However, translating such serial verbs into a single verb, such as shifting “to-wa-cwu-le-ka-ta” as “help,” fails to capture the full semantic complexity of the original serial verb. To address the complexity of

Figure 4. The visualization of nonlinear multidimensional scaling among variables for each group. Action VF score = number of correct responses to the action verbal fluency task; WF score = number of correct responses to the word-forward task; WB score = number of correct responses to the word-backward task.



Korean verbs, we break down these serial verbs into distinct verb components when no suitable English equivalent exists. For example, we separate “to-wa-cwu-le-ka-ta (coming to give a helping hand)” into three individual verbs: “top-ta (help),” “cwu-ta (give),” and “ka-ta (go).” Given these challenges in translating Korean to English, we recognize the necessity for resources that fully represent the unique and intricate features of Korean verbs.

Despite these limitations, our HCA approach represents a novel method for clustering verbs, and we consider HCA as a promising alternative for qualitative analysis of action VF task in various areas of cognitive–linguistic research. For instance, we anticipate that applying our verb clustering approach to cross-linguistic studies could provide valuable insights. Under free word retrieval conditions such as in the VF tasks, individuals may tend to generate words with high lexical frequency or familiarity (Crowe, 1998), and these psycholinguistic features may vary depending on cultural and linguistic contexts. Our HCA approach may enhance the exploration of cultural differences by comparing semantic compositions of verb clusters across languages, both quantitatively and qualitatively. Additionally, as HCA is a data-driven method, it minimizes the risk of human bias or error in the clustering process, enabling objective analysis that is not influenced by the researcher’s cultural background. Furthermore, HCA clustering has the potential to identify semantically related verbs, which can be instrumental in developing verb-focused intervention programs. The HCA provides diverse verbs that share common semantic features. These clusters can be valuable for developing verb-based treatment strategies to facilitate shared semantic networks in individuals with aphasia or neurodegenerative diseases.

Another aim of the study was to validate the current clustering method by comparing the usage of word retrieval strategies between healthy younger and older adults. The results demonstrated that older adults exhibited significantly fewer switching behaviors and lower cluster diversity compared to younger adults. These results are consistent with previous findings from qualitative analyses of action and other VF tasks. For instance, Fisher et al. (2023) reported that individuals with AD produced significantly fewer verbs and demonstrated less clustering and switching behaviors than healthy individuals in the action VF task. Troyer et al. (1997) also found that younger healthy adults demonstrated significantly more correct responses and switching behaviors than healthy older individuals in both semantic and phonemic VF tasks. Similarly, Kim and Choi (2021) explored switching strategies across different age groups of older adults—young–old, middle–old, and old–old—in semantic VF tasks. Their results revealed that the old–old group exhibited significantly fewer correct responses and switching behaviors

compared to the young–old group in the animal VF task and compared to the middle–old group in the supermarket VF task (Kim & Choi, 2021). Overall, general findings in VF tasks have consistently demonstrated positive relationships between the number of correct responses and switching or clustering behaviors. This pattern aligns with our results, showing significant positive correlations among the number of switchings, cluster diversity, and correct responses in both young and older groups. These outcomes suggest that participants who employed more switching behaviors and generated a wider variety of meanings of words tended to perform better on the task. The positive correlation result between word retrieval strategies and VF task scores is consistent with previous research on other types of VF tasks (Kosmidis et al., 2004). For instance, Kosmidis et al. (2004) conducted semantic and phonemic VF tasks with 300 healthy adults and found significant positive correlations among the number of correct responses, switchings, and the mean cluster size across both VF tasks. Collectively, these findings suggest that the efficient use of word retrieval strategies, such as switching and cluster diversity, may improve word production performance (Troyer, 2000).

Another consistent observation from the previous studies is that older adults presented limited use of word retrieval strategies. Previous studies have reported that switching and clustering behaviors are associated with frontal lobe functions, which subserve higher cognitive abilities such as executive functions, WM capacity, and cognitive flexibility (Burda, 2010; Cralidis & Lundgren, 2014; Troyer et al., 1997, 1998). These cognitive structures are known to decline with the aging process, which may account for the observed reductions in word retrieval strategies among older adults. The correlational results from the current study are consistent with the speculations that older adults who engage more frequently in switching and clustering behaviors are likely to have higher WM capacity. This is evidenced by the significant correlation coefficients between word retrieval strategies and WM tasks. Interestingly, only the word backward task showed a significant correlation with these behaviors, suggesting that this specific aspect of WM may play a key role in facilitating word retrieval strategies. We employed two tasks of WF and WB as an index of WM capacity. Theoretical debates suggest that forward-span tasks primarily tap into short-term storage or buffer, whereas backward-span tasks require additional computational processes since items must be recalled in reverse order (Engle & Kane, 2004; Just & Carpenter, 1992). A group of researchers argues that WM consists of short-term storage and executive attention, with higher cognitive abilities, being strongly correlated to the executive attention component of WM, rather than just short-term storage (Engle

& Kane, 2004; Gathercole et al., 2004; Yang et al., 2019). This view, which emphasizes the working and computational components of WM, may account for our findings, as only the backward span task was correlated with outcome variables of the action VF task, particularly in older adults who tend to have more limited WM capacity.

The current results that only the WB task score correlated with the action VF measures are partially consistent with previous studies (Fischer-Baum et al., 2016; Kavé & Sapir-Yogev, 2020; Nejati, 2012; Oh et al., 2019). For instance, both Kavé and Sapir-Yogev (2020) and Nejati (2012) conducted semantic and phonemic VF tasks with healthy adults and found significant correlations between the correct responses of these VF tasks and WM capacity, as measured by both forward and backward digit span tasks. Similarly, Oh et al. (2019) reported that both digit span forward and backward scores significantly correlated with semantic VF task performance in individuals with MCI, and they also identified a significant relationship between switching and digit forward task scores. This discrepancy between our results and previous studies could be attributed to differences in the types of WM and VF tasks used. Unlike prior studies, we employed word span tasks and the action VF task. Word span tasks are considered to place greater cognitive demands compared to digit span tasks, as they engage lexical, semantic, and phonological processing (Martin & Ayala, 2004). Additionally, action VF tasks, which primarily involve verb retrieval, are reported to be more cognitively challenging than phonemic or semantic VF tasks, which typically generate nouns (Faroqi-Shah & Milman, 2018; Mätzig et al., 2009). Overall, the observed discrepancy is likely due to the different cognitive demands imposed by the distinct task types of WM and VF measures. Further research is needed to explore the relationships between VF outcomes and WM tasks by employing diverse WM and VF tasks with different computational demands.

In addition to WM capacity, we explored correlations between demographic factors and action VF task variables within older adults. Our findings demonstrated that older individuals with younger age and higher education levels tended to employ more word retrieval strategies, achieving higher action VF task scores. This observation is consistent with previous studies, indicating that decreased VF performance and reduced use of word retrieval strategies are correlated with demographic factors such as age or education (Kim & Choi, 2021; Mathuranath et al., 2003; Troyer et al., 1997). For instance, Kim and Choi (2021) administered both semantic and phonemic VF tasks to older adults and identified that age was negatively correlated with the total number of correct responses and the number of switchings. Similarly, Mathuranath et al. (2003) conducted semantic and phonemic VF tasks with healthy older adults and found

significant positive correlations between both types of VF scores and years of education. They attributed this relationship to the common influence of education on cognitive and linguistic performance. Additionally, the NMDS analysis visually highlighted distinct group differences, showing stronger associations among education, action VF task variables, and WM measures in older adults compared to younger adults.

Conclusions

The current study marks the initial attempt to employ HCA for identifying verb cluster criteria based on the Lancaster sensorimotor norm. This objective clustering method demonstrated its efficiency in verb classification and highlighted the potential of integrating qualitative analysis into action VF task. Based on the established verb clusters, word retrieval strategies, such as switching behaviors and cluster diversity, revealed aging-related differences and relationships with WM capacity in older adults. These findings validate the utility of HCA as an objective methodological tool for verb clustering. While this study primarily focused on the cognitive and linguistic aspects of the action VF task across groups using HCA, future research may benefit from incorporating temporal-based analyses. Several studies have highlighted the importance of temporal indices related to response time measures in various VF tasks (Linz et al., 2019; Orologa et al., 2024). Expanding clustering analysis by integrating these temporal indices could provide additional insights and further deepen our understanding of overall VF processes.

Author Contributions

Yae Rin Yoo: Conceptualization, Formal analysis, Writing – original draft. **Yoonseob Lim:** Conceptualization, Methodology, Writing – review & editing. **Eun Jin Paek:** Writing – review & editing. **Jee Eun Sung:** Conceptualization, Supervision, Writing – review & editing.

Data Availability Statement

The data sets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Appendix

Examples of the Excluded Verbs From Each Verb Cluster

Verb Cluster ID	Excluded verbs
1	feel
2	grow, rise
3	collapse, fit, float, give birth, lean
4	chafe, jump rope, slip, wash up
5	fill, tire
6	break up, decrease, interfere, outdate, reform
7	create, date, flow
8	—
9	—
10	roll
11	film, nod
12	exceed, get along
13	count
14	—
15	grow up, hurt

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