Research Note

Coordinating Words and Sentences: Detecting Age-Related Changes in Language Production

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ABSTRACT

Purpose: The purpose of this study was to examine whether older adults exhibit reduced abilities in coordinating lexical retrieval and syntactic formulation during sentence production and whether an individual's working memory capacity predicts age-related changes in sentence production.

Method: A total of 124 Korean-speaking individuals (79 young and 45 older adults) completed a lexical priming sentence production task. The participants described a target picture (a dog biting a monkey) after reading either an agent (dog) or a theme (monkey) prime word. The proportion of passive sentences was used as the dependent variable.

Results: When the theme noun was primed, older adults produced fewer passive sentences than young adults. Working memory tasks significantly predicted individual differences in the sentence production of older adults.

Conclusions: With aging, the ability to efficiently formulate syntactic structures in coordination with varying lexical information declines. Among older adults, age-related changes in these sentence production processes are associated with reduced working memory. Our constrained language production task is sensitive to detecting aging effects.

According to a recent report by the World Health Organization, one in six individuals in the world will be 60 years or older by 2030. The aging population is increasing rapidly, resulting in significant social and financial pressure on families and the government. One of the greatest fears associated with aging is the risk of being exposed to neurodegenerative diseases, such as dementia. Considering that dementia is one of the diseases that cannot be reversed or cured, early detection and prevention have become extremely important. For the early detection of neurodegenerative symptoms, many neuropsychological testing batteries have been developed, including various cognitive domains, such as memory, attention, and language. Memory impairments are one of the most frequently observed symptoms associated with dementia; a decline in language functioning is believed to occur not until the later stage of the disease (Emery, 2000; Kertesz

& Kertesz, 1988; Ortiz et al., 2021). However, by the time that memory deficits become noticeable to caregivers, it is likely that the age-related decline in cognitive-linguistic functioning is already in an advanced stage.

More recently, attempts have been increasingly made to capture early symptoms of language changes by analyzing connected speech samples obtained from picture description tasks or storytelling procedures for older adults at risk (e.g., Filiou et al., 2020; Slegers et al., 2018). However, analyses of connected speech samples take a significant amount of time and effort, as well as advanced linguistic coding skills. Therefore, a simpler way of administering and scoring the language tasks that can sensitively evaluate language abilities in aging populations needs to be developed. The current study proposes that the lexical priming paradigm during sentence production reliably detects subtle aging-related changes in the domain of language production.

Language production involves a complex process that requires cognitive resources from a wide array of cognitive-linguistic domains, including lexical–semantic activation, syntactic formulation, working memory (WM), and others.

Considering these complex and cognitively demanding features associated with producing language at the sentence level, examining individuals' abilities in sentence production may serve as a potentially good method to detect aging-related changes in cognitive-linguistic domains in aging populations at risk for neurodegenerative diseases.

Previous studies examining the effect of aging on language production have focused mostly on specific aspects of sentence production. For example, studies focusing on word production show that lexical retrieval becomes less efficient in older adults, when various linguistic factors, such as lexical frequency, familiarity, and typicality, are manipulated, leading to increased tip-of-the-tongue behaviors (Burke et al., 1991; James & Burke, 2000; Shafto et al., 2007). Other studies focus on syntactic processing with minimal cognitive demands on lexical retrieval, reporting relatively preserved syntactic processing among older adults (Davidson et al., 2003; Hardy et al., 2020; Lee et al., 2022). However, when production tasks require multifaceted processes, including, for example, both lexical and syntactic processing, aging effects become more apparent (e.g., Agmon et al., 2023; Kemper, 1987; Kemper et al., 2004; Sung, 2015; see also Zurif et al., 1995, for evidence in sentence comprehension). For example, age-related reduction in complex sentences (e.g., fewer embeddings) has been reported in spoken narrative compared to young adults (Agmon et al., 2023) and in a longitudinal study of written diaries (Kemper, 1987). Thus, the degree of cognitive-linguistic demands of the experimental paradigm may contribute to the extent to which aging effects manifest themselves in sentence production. However, few studies systematically have investigated how lexical–semantic activation at the word level affects syntactic formulation in sentence production for older adults. The current study employs a lexical priming-based sentence elicitation paradigm to examine aging-related decline in sentence production abilities.

Researchers mostly use a lexical priming paradigm for single word-based tasks, such as naming or lexical decision tasks. For example, after hearing a prime word, "nurse," one would make a faster lexical decision for "doctor," because residual activation from the prime word makes activation of a semantically related target word easier. Albeit few, studies also used lexical priming in the context of sentence production to investigate whether varying degrees of lexical accessibility would influence structural choices that speakers make as sentence production unfolds incrementally (J. K. Bock & Warren, 1985; J. Bock, 1987; Lee, 2020; McDonald et al., 1993; Slevc, 2011; Weirick & Lee, 2022). Lee (2020) examined the effects of auditory lexical priming on production of English transitive (active/passive) sentences in healthy adults and persons with aphasia. The participants heard either an agent ("dog") or a theme prime ("mailman") and then they described a target transitive event (e.g., "a dog chasing a mailman"). After the auditory prime of a theme noun, both participant groups were more likely to produce passive structures ("a mailman is chased by a dog") compared to when they heard an agent prime (see also Slevc, 2011, for similar findings in dative sentences). Lexical priming affects syntactic production because speakers tend to choose structures, allowing for earlier mention of easier-to-retrieve (more accessible) words.

In the current study, we used lexical priming to better assess age-related changes in sentence production in Korean. We call this paradigm lexical priming sentence production task hereafter. As Figure 1 shows, the participants read aloud a prime word (e.g., "monkey") presented on the computer screen and describe an action scene (e.g., "a dog biting a monkey") using a sentence. Given that reading the prime word "monkey" activates the theme noun "monkey" to a greater degree than the agent "dog," participants are more likely to produce a passive word order (e.g., "the monkey is bitten by the dog"). However,

Figure 1. Sample trial for the lexical prime sentence production task, depicting the theme prime condition.
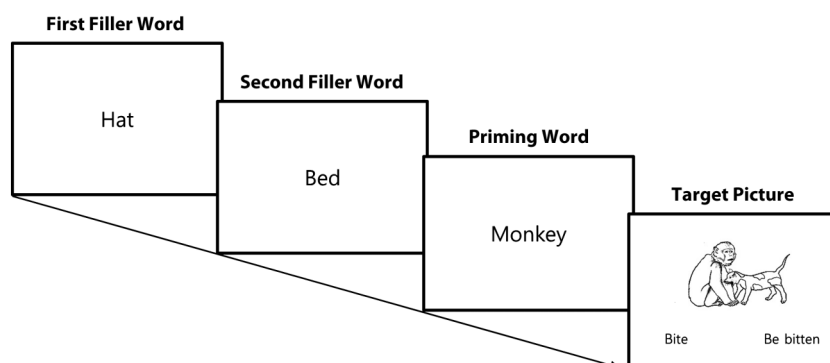
the passive formulation is less frequent and more difficult than the active counterpart (Grodzinsky et al., 1999; Sung et al., 2017, 2020). Therefore, the successful use of the prime word during sentence production assumes flexible coordination between lexical and syntactic processes, presumably tapping into higher cognitive-linguistic resources.

Although it is not clearly understood what specific cognitive resources support such lexical-syntactic coordination, speakers' WM capacity may play a crucial role (Slevc, 2011; Weirick & Lee, in prep). WM capacity is often referred to as a cognitive construct that subserves the ability to efficiently allocate processing resources to multiple demands (Just & Carpenter, 1992; Kane & Engle, 2000). Individual differences in WM can be measured by their performance in a dual task. For example, participants might listen to a series of sentences while performing the plausibility judgment and simultaneously recall the final words of each sentence. Those who have larger WM capacity would score higher on such dual-task paradigms (Daneman & Carpenter, 1980; Tompkins et al., 1994). Considering that the current lexical priming production task requires speakers' ability to flexibly produce different sentence structures in response to varying degrees of lexical (theme or agent) activation, we posit that this paradigm taps into the WM capacity. Indeed, some evidence suggests that differences in individuals' cognitive-linguistic capacity may modulate how successfully they coordinate lexical retrieval and sentence formulation (Lee, 2020; Lee et al., 2015; Slevc, 2011). For example, Lee (2020) found that participants with aphasia show reduced lexical priming effects on syntactic (active/passive) production compared to healthy adult controls, although the participants' WM measures were not obtained. By specifically comparing verbal WM load versus no load conditions, Slevc (2011) found that young adults showed reduced syntactic flexibility and produced accessible words early less frequently under the concurrent verbal WM load condition. However, none of the previous studies directly examine how individual differences in the WM capacity of aging populations relate to their sentence production abilities using the lexical priming paradigm.

Furthermore, this is the first attempt to apply this paradigm to a verb-final language with case-marking systems, such as Korean. Korean passivization occurs in a similar way to English, in that the theme is moved to the subject place. The moved theme noun in the subject position is marked by a nominative case marker, and the agent is marked by an oblique case marker, forming a by-phrase as in the English passive form, followed by the verb. This results in a syntactic form of Subject (with a nominative case marker) + by-phrase (with an oblique case marker) + Verb (with passive morphemes), compared to the active structure of Subject (with a nominative case marker) + Object (with an accusative case marker) + Verb.

The current study addresses two research questions. First, we examine if older adults exhibit reduced lexical priming effects during sentence production, as indicated by the reduced production of passive sentences when the theme word is primed, compared to young adults. We hypothesize that older adults are less efficient in manipulating syntactic structures using the prime word, resulting in a lower proportion of passive sentences under the theme-primed condition. Second, we investigate if an individual's WM capacity predicts the magnitude of priming effects. We measure WM capacity by varying the cognitive-linguistic demands using digit- and word-span tasks administered both forward and backward. The word-span tasks are imposed with greater linguistic demands than the digit-span tasks, given that word-span tasks are involved in the activation of lexical–semantic components associated with words in the recall task, whereas digits contain relatively fewer lexical–semantic features than words (Eom et al., 2016). A backward recall task is supposed to be harder than a forward recall task, given that participants need to reverse the order of the items that they listen to. Combining the two features of linguistic burdens and the rearrangement of the order of the items, word-span backward tasks are assumed to be the hardest condition among the four measures of WM tasks (digit-forward [DF], digit-backward [DB], word-forward [WF], and word-backward [WB]). We predict that the WM task with the greatest demands is sensitive to predicting performance in the proportion of passive sentence production under the theme-prime condition, where older adults are hypothesized to demonstrate the greatest inefficiency in terms of lexical-syntactic coordination.

Method

Participants

A total of 124 individuals participated in the study (79 young and 45 older adults). The young group (22 men and 57 women) had a mean age of 25.85 years ($SD = 3.35$; range: 19–39) and a mean of 14.77 years of education ($SD = 1.60$; range: 10–16). The older group (17 men and 28 women) had a mean age of 68.47 years ($SD = 6.88$; range: 60–83) and a mean of 14.31 years of education ($SD = 2.58$; range: 8–18). There were no significant group differences in education ($p = .283$). All the participants were native Korean speakers. They met all of Christensen's health screening criteria (Christensen et al., 1991); had no history of medical, neurological, or psychiatric diseases; and showed normal performance in the Korean version of the Mini-Mental State Examination (Kang, 2006). The current study was approved by the institutional review board (No. 2020–0127), and informed consent was obtained from all the participants prior to their participation.

Materials

Lexical Priming Sentence Production Task

A total of 36 target pictures were prepared. Each target picture presented a transitive action involving an agent (the entity who initiates the action) and a theme (the entity who is acted upon). At the bottom of the picture, verbs corresponding to the transitive action were presented in active and passive voice forms. Prior to presenting the target picture, the participants were shown a sequence of stimuli that included two filler words followed by a priming word (either in the agent condition or in the theme condition). The priming words consisted of 18 agent and 18 theme nouns, depending on the prime word condition, and they were all randomly arranged. The semantic categories of the prime words corresponding to the agent and theme were animals and occupations (e.g., cop, teacher). The filler words were selected from different semantic categories, including fruits, vegetables, clothing, furniture, and transportation.

To prevent participants from using strategies, the agent was positioned on the left side for half of the trials and on the right side for the other half. In addition, we counterbalanced the positions of the active and passive written verbs across the target pictures. The order of presentation of the items was pseudorandomized, such that no more than two items were presented consecutively in the same prime condition.

WM Tasks

We administered the four WM tasks to all the participants to measure their WM capacity. The DF and WF tasks began with Span 3 and increased to Span 9, while the DB and WB tasks began with Span 2 and increased to Span 8. In the forward tasks, participants had to repeat a sequence of digits or words in the order of their presentation. In the backward tasks, participants had to repeat a sequence of items in the reverse order of their presentation. The DF and DB tasks were taken from the Korean version of the Wechsler Adult Intelligence Scale (Yeom et al., 1992), and the WF and WB tasks were taken from Sung (2011). The score was calculated by the number of correctly recalled trials.

Experimental Procedures

An example of the lexical priming sentence production task was provided in Figure 1. During the task, participants read aloud the two filler words and the prime word prior to describing the target pictures. The participants were instructed as follows: "During this experiment, you will be asked to read words or describe images. When you see only written words, please read them out loud. When you see images and words, describe what's

happening in the picture in a sentence. You can use one of the written words provided." In the agent prime condition, the prime word was the agent in the target picture (i.e., "dog" in Figure 1), whereas in the theme condition, the prime word was the theme noun in the target picture (i.e., "monkey" in Figure 1). The filler words were embedded across the experimental list to keep the nature of the lexical priming task implicit. In addition, no explicit instructions were given regarding which sentence structure to use.

All experiment stimuli were presented using PowerPoint on a computer screen. The experimenter manually advanced the stimuli by pressing the space bar on the keyboard upon participants' completion of speech. There was no time limit on participants' responses. In cases where participants self-corrected, their final response was recorded.

Analysis

The examiners recorded, transcribed, and scored the participants' responses that were produced as sentences when the target image was displayed on the monitor. The two authors of this study randomly selected 25% of the data set and then recoded it. Subsequently, we conducted a reliability check and found that the interreliability was 100%.

Only the correct responses, which contained the agent, theme, and verb corresponding to the target image, were included in the analysis. Next, active sentence responses were coded as "0," and passive sentence responses were coded as "1," regardless of the prime condition. These binary dependent variables were then used for statistical analysis.

We classified the incorrect responses as follows: (a) noun phrase (NP) deletion: One of the two NPs in a sentence was omitted; (b) NP reversal: The two nouns were swapped and no longer matched the target picture; and (c) NP replacement: One of the two nouns was substituted with a noun not present in the picture. Based on the criteria, a total of 34 incorrect responses out of 2,844 (1.2%) in the young group and 112 incorrect responses out of 1,620 (6.3%) in the older group were removed from the analysis. Table 1 provides examples of various types of incorrect sentences. Additionally, the proportion of sentences by prime condition between groups is presented in Table 2.

Results

Aging Effects on Priming

We performed the generalized linear mixed-effects model (GLMM) analysis using the "glmer" function from

Table 1. Examples of incorrect responses on the lexical priming sentence production task.

Error type	Prime word (prime condition)	Target words	Example of incorrect response	Example of expected correct response
Errors in case marker assignment	Judge (theme)	Singer-Judge-Hold/Be held	Singer-Nom. *Judge-Acc. be held	Singer-Nom. Judge-Obl. be held
NP deletion	Firefighter (theme)	Nurse-Firefighter-Push/Be pushed	*Φ (null) Firefigher-Acc push	Nurse-Nom. Firefighter-Acc. push
NP reversal	Tiger (agent)	Tiger-Lion-Bite/Be bitten	*Lion-Nom. *Tiger-Acc bite	Tiger-Nom. Lion-Acc. bite
NP replacement	Deer (agent)	Deer-Pig-Bite/Be bitten	*Giraff-Nom. pig-Acc. bite	Deer-Nom. Pig-Acc. bite

Note. Nom = nominative case marker; Acc = accusative case marker; Obl = oblique case marker; NP deletion = either of the two noun phrases is deleted in a sentence; NP reversal = the two nouns are reversed, leading to the sentence that does not match with the target picture; NP replacement = either of the two nouns is replaced with a noun that was not presented in the picture.

*Indicates where errors occurred.

the *lme4* package in R 4.2.1 (Bates et al., 2014). In this model, the sentence type (0 = *active*, 1 = *passive*) across all prime conditions was the dependent variable. Group (young vs. older) and prime condition (agent vs. theme) and their interaction were included as fixed factors. Random intercepts were included for both the subject and the item. Statistical significance was set at $p < .05$ for all analyses. We set the younger group as the reference level for the group and agent prime as the reference level for the prime condition.

There were significant main effects for both the group and prime type variables. Specifically, the older group produced fewer passive sentences than the young group (β = −0.46677, SE = 0.21822, z = −2.139, p = .03244). Overall, the participants produced passive sentences more frequently in the theme prime versus agent prime condition (β = 1.09259, SE = 0.09003, z = 12.135, $p < .0001$). Furthermore, a significant interaction was observed between the group and prime condition (β = −0.47515, SE = 0.16453, z = −2.888, p = .00388), suggesting that the older adults exhibited reduced priming effects compared to the young adults (see Figure 2). The summary of the GLMM is provided in Table 3.

### Classification of the Aging Groups

We employed a stepwise discriminant function analysis using SPSS (Version 26.0), which is used to identify the most relevant and informative features for discriminating between variables. Using this model, our aim was to determine which prime condition best differentiated older adults from younger adults. The predictor variables included the proportion of passive constructions for the agent and theme prime types, and the dependent variable was the group. The results revealed that the passive proportion in the theme prime condition was a significant predictor in the discriminant function (Wilk's lambda = .878, χ^2 = 15.8, $p < .001$). According to the discriminant function, 68.9% of the older adults were successfully classified as the older group, and 67.1% of the young adults were classified as the young group. To summarize, 67.7% of the total cases were accurately classified.

WM and Priming Effects

Using the stepwise selection method, we performed multiple regression analyses. The purpose of these analyses

Table 2. Proportion (%) of sentences by syntactic structure between groups.

		Group			
Prime condition	Sentence type	Young *M (SD)*	Older *M (SD)*	*t* value	*p* value
Agent prime	Active	75.25 (19.49)	73.4 (16.28)	−2.248	.026
	Passive	22.57 (19.15)	14.20 (12.05)	2.248	.026
	Incorrect	2.18 (4.12)	12.35 (12.81)	−3.021	.004
Theme prime	Active	56.68 (23.48)	66.05 (19.07)	−4.116	< .001
	Passive	40.79 (22.20)	22.22 (18.17)	4.116	< .001
	Incorrect	2.53 (6.88)	11.73 (12.32)	−3.264	.002
Grand total	Correct	98.8 (2.3)	93.7 (9.93)	3.393	.001
	Incorrect	1.2 (2.3)	6.3 (9.93)	−3.393	< .001

Figure 2. Interaction between the group and prime condition.
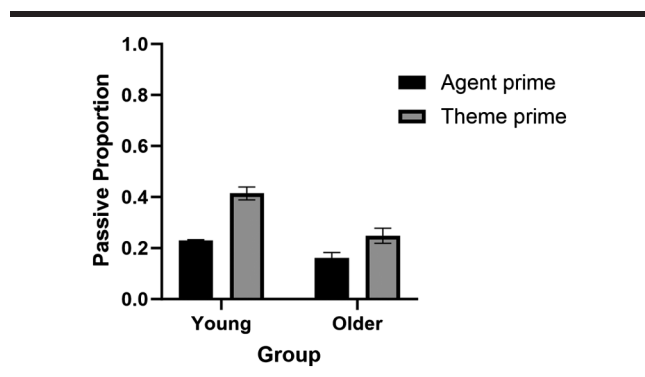
was to identify the most accurate predictor of the passive proportion in relation to agent and theme prime conditions across the four WM tasks: DF, DB, WF, and WB in both groups. For the passive proportion in the agent prime condition, the results revealed that none of the WM measures entered the equation as significant factors for both groups. For the passive proportion in the theme prime condition, the results revealed that none of the predictors entered the equation as significant factors for young adults. On the other hand, for the older adults, the results revealed that the score on the WB task is a significant predictor for the passive proportion, $F(1, 43) = 4.700$, $p = .036$, $R^2 = .099$. The score on the WB task showed a significant positive correlation with the passive proportion in the theme prime condition ($r = .314$, $p = .036$), suggesting that the older adults with higher scores on the WB task tended to produce more passive sentences in the theme prime condition. The correlations between the word-span task and the passive proportion of the theme prime condition for each age group were provided in Figure 3.

Discussion

Using a lexical priming sentence production paradigm, the current study investigates whether abilities in sentence production decline as people age. The analysis of age differences on priming effects reveals that older adults

demonstrate reduced lexical priming effects during sentence production, as confirmed by the significant two-way interaction between age group and prime type. Compared to young adults, older adults generate a significantly lower proportion of passive sentences under the theme prime condition. Furthermore, the discriminant analysis confirms that an individual's ability to produce passive sentences in the theme prime condition is highly predictive for both young and older adults. The results indicate that older adults are less efficient in incrementally formulating sentence structures (e.g., passive rather than active word order) using the primed word. Using a carefully controlled and relatively simple production task, we were able to successfully detect age-related changes in coordinating lexical–semantic retrieval and sentence formulation. This study is one of the first few to examine how aging impacts a speaker's ability to simultaneously coordinate both word- and sentence-level processes (Hardy et al., 2020; Weirick & Lee, 2022; for aphasia, see also Lee, 2020).

The current task used overcomes some limitations of prior studies examining aging effects in language production. Previous studies investigating age-related decline in language functions are primarily confined to either lexical–semantic retrieval tasks (e.g., confrontation naming tasks; Burke & Shafto, 2004; Gertel et al., 2020; Verhaegen & Poncelet, 2013) or broader fluency measures of language production (e.g., pauses, fillers) in connected speech samples (James et al., 2018; Lee et al., 2019). It is relatively well known that deficits in lexical–semantic retrieval, assessed through single word–based naming tasks, are one of the prominent symptoms that can be detected in the early stage of cognitive-linguistic degeneration. However, single word–based tasks do not assess individuals' ability to formulate sentences. Disfluency measures in connected speech do not sufficiently tell us about the specific nature of underlying deficits, compared to the intensity of labor and coding skills required for the analysis. For example, the increased production of disfluencies among older adults may reflect inefficiencies at various levels of language production, including lexical retrieval, sentence formulation, and message encoding. Notably, however, the current paradigm using a constrained sentence

Table 3. Summary of the generalized mixed-effects model.

Item	Estimate	Standard error	z value	p value
Intercept	−1.49745	0.14593	−10.261	.0000***
Group	−0.16677	0.21822	−2.139	.03244*
Prime condition	1.09259	0.09003	12.135	.0000***
Group × Prime condition	−0.47515	0.16453	−2.888	.00388**

Note. Model equations: Response type ~ Group * Prime condition + (1|Subject) + (1|Item). Reference levels are as follows: Group = young adults; Prime condition = agent prime.

*$p < .05$. **$p < .01$. ***$p < .001$.

Figure 3. Correlations between the word-span task and the passive proportion of the theme prime condition for each age group. WF = word-span forward task; WB = word-span backward task.
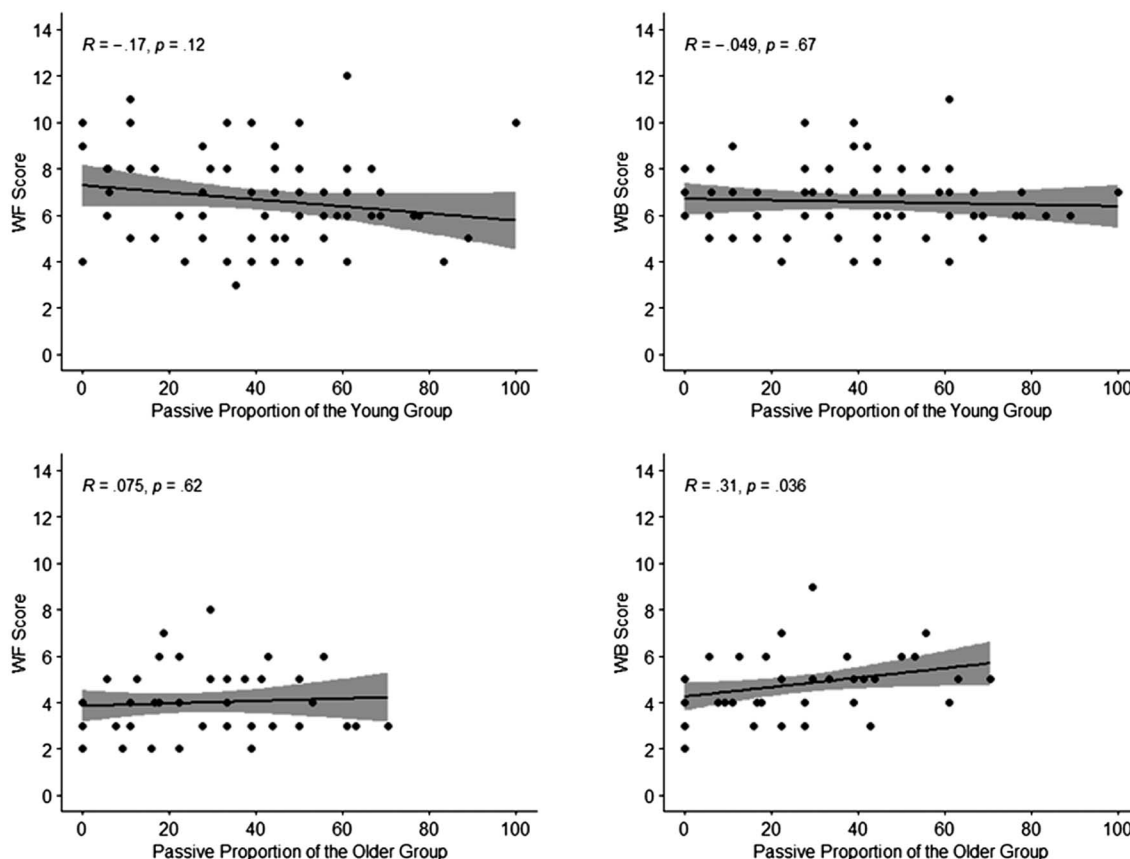
production task successfully detects older adults' reduced ability to take advantage of lexical–semantic information to formulate sentences differently from young adults.

Our findings further suggest that this age-related decline in lexical-sentence coordination among older adults is at least partly attributable to reduced WM capacity. Only the word-span backward task emerged as a significant predictor of older adults' production of passive sentences under the theme prime condition. This finding is consistent with our hypothesis that the WM task that is most linguistically heavy with greater cognitive demands significantly accounts for language production abilities in older adults. That is, those who have greater WM capacity are more likely to efficiently produce and vary more complex syntactic structures using previously given lexical–semantic information. The ability to keep lexical items activated by simultaneously coordinating syntactic structures is required to successfully perform the current task, and such ability seems to be closely related to WM capacity. This pattern appears to be particularly strong in the older adult group because the demands of the task are sufficiently taxing on their reduced WM capacity. This

finding is consistent with previous research, showing that aging-related difficulties can be identified only when the WM demands are high in both the comprehension domain (Caplan et al., 2011; Caplan & Waters, 2003; DeDe et al., 2004; Waters & Caplan, 2001; Sung et al., 2017) and production modality (Altmann & Kemper, 2006; Hardy et al., 2020; Kemper et al., 2003; Sung, 2015).

In conclusion, the current study finds an aging-related decline in the ability of older adults to efficiently formulate syntactic structures in sentence production when their abilities are tested using a constrained paradigm (e.g., a lexical priming sentence production task). Older adults clearly demonstrate greater difficulties in coordinating syntactic structures using previously provided semantic information, and the patterns of their inefficient sentence production are related to their reduced WM capacity. The study is novel, given that the aging effects at the sentence level are examined under the combined paradigm of sentence production with lexical–semantic activation. Furthermore, only a few studies examine older adults' sentence production abilities and their relation to WM capacity using the constrained production paradigm. Compared

to existing constrained sentence production tasks, such as the Northwestern Assessment of Verbs and Sentences–Sentence Production Priming Test (Cho-Reyes & Thompson, 2012), the current study adopts a lexical priming paradigm. This approach permits a more detailed investigation into the interplay between lexical encoding processes and the formulation and selection of syntactic structures. Unlike previous studies, which primarily focused on sentence-level production accuracy, the current paradigm offers the advantage of measuring the flexibility in coordinating syntactic structures, utilizing the lexical items that have been primed.

There are limitations to the current study. The current findings are limited to offline behavioral data, failing to reveal whether and how aging influences the real-time coordination of words and syntactic structures as sentence production unfolds. More investigations are needed to include real-time sentence processing measures, such as eye-tracking or event-related potentials of the electroencephalogram, to identify the locus of aging in the incremental processing of sentence production. Furthermore, because the current study included only a verb-final language, future studies should test how aging impacts incremental sentence production across diverse languages using a similar paradigm.

Author Contributions

Data Availability Statement

Data are available on request from the authors.

Acknowledgments

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