Scandinavian Journal of Psychology, 2023, 64, 479–485 DOI: 10.1111/sjop.12908

Empirical Article

Effects of task types and time interval conditions on age-related decline in verbal working memory

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Jo, E., Choi, S. & Sung, J. E. (2023). Effects of task types and time interval conditions on age-related decline in verbal working memory. *Scandinavian Journal of Psychology*, *64*, 479–485.

Age-related differences in working memory (WM) components were investigated by manipulating the time interval and interference effects between phonological and semantic judgment tasks to identify tasks to best discriminate between younger and older groups. The 96 participants (young = 48; old = 48) prospectively performed two task types of WM, with phonological and semantic judgment tasks, which were administered while varying the three interval conditions: 1-s unfilled (UF), 5-s UF, and 5-s filled (F). The main effect for age was significant in the semantic judgment task but not in the phonological judgment task. The main effect for the interval conditions were significant in both tasks. A 5-s UF condition applied to a semantic judgment task could significantly differentiate the older group from the younger group. Differential effects of time interval manipulation in semantic and phonological processing are involved in WM resources. The older group could be differentiated by varying the task types and interval conditions, indicating that the semantic-related WM burdens may contribute to a superior differential diagnosis of aging-related WM decline.

Key words: Aging, working memory assessment, semantics, phonology, time interval.

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INTRODUCTION

Cognitive decline slowly progresses during the normal aging process (Light, 1991), and cognitive decline affects the language-processing ability, which involves timely access to and retrieval of linguistic information (Stine-Morrow, Miller & Hertzog, 2006) that are supported by cognitive abilities, including working memory (WM) (Daneman & Merikle, 1996). Baddeley and Hitch (1974) first defined WM as a limited-capacity system that simultaneously ensures information processing and storage.

A proportional decline in working memory with increasing age has been reported (Bopp & Verhaeghen, 2005, 2020; Jaroslawska & Rhodes, 2019). Researchers have tried to determine the cause of WM decline with age, and several studies have reported that WM decline in older adults is attributable to deficits in inhibitory ability (Cansino, Guzzon, Martinelli, Barollo & Casco, 2011; Zanesco, Witkin, Morrison, Denkova & Jha, 2020). Cansino and colleagues examined age-related WM decline by dividing the inhibition function into access and deletion processes, according to the framework work proposed by Hasher, Zacks and May (1999), and found that older adults used the access process as efficiently as young adults, but did not use the deletion process (Cansino *et al.*, 2011). The access process ignores concurrent distractions, whereas the deletion process stops processing of irrelevant information (Hasher *et al.*, 1999). In contrast, some studies reported that WM decline in older adults was attributable to deficits in the attentional maintenance (Einstein, McDaniel, Manzi, Cochran & Baker, 2000; Hasher *et al.*, 1999; West & Craik, 2001), whereby the maintenance of information during delays led to worse performance in older adults compared with young adults (Einstein *et al.*, 2000; Hasher *et al.*, 1999; West & Craik, 2001). The time-based resource-sharing (TBRS) model indicates that the information that is to be maintained decays over time when performing tasks that require both processing and maintaining information because limited attentional resources are shared between the processing and maintaining information functions (Barrouillet, Bernardin & Camos, 2004).

Additionally, the pattern of the age-related deterioration in language processing varies depending on the linguistic characteristics. Some studies have reported that semantic processing is preserved in older adults, and semantic knowledge such as vocabulary increases across the life span (Alwin & McCammon, 2001; Verhaeghen, 2003). However, other reports indicate that semantic processing is impaired in older adults (Haarmann, Ashling, Davelaar & Usher, 2005; Taylor & Burke, 2002; Verhaegen & Poncelet, 2013). Age-related decline in phonological processing was observed during language production, whereas phonological processing was preserved during language comprehension (Burke & MacKay, 1997; Shafto & Tyler, 2014). The difference in the pattern of language processing may depend on the linguistic characteristics (semantics, phonology) or might be attributable to each processing being carried out at a different level in language processing. Dell's interactive activation (IA) model of language processing includes three levels of word-component representations (phonological, lexical, and semantic) and operates under the assumption that the processing would begin at the phonological level and then spread to the lexical and semantic levels during the comprehension processing; however, during the production process, the processing would spread in the opposite direction (Dell, 1986).

Therefore, it is necessary to consider linguistic characteristics (semantics, phonology) and memory load variations (time delay, and interference) to investigate age-related WM decline. Researchers have developed WM tasks previously to evaluate WM capacity and examine the extent to which WM capacity decreases with aging such as the n-back (Bopp & Verhaeghen, 2020; Kirchner, 1958), the reading span (Daneman & Carpenter, 1980; Schroeder, 2014), the digit span (Bopp & Verhaeghen, 2005; Jaroslawska & Rhodes, 2019; Wechsler, 1981), and the operation word span tasks (Fournet, Roulin, Vallet *et al.*, 2012; Turner & Engle, 1989). However, few WM tasks have been developed based on linguistic characteristics and memory load variations.

Recently, the Temple Assessment of Language and Short-term Memory in Aphasia (TALSA) (Alwin & McCammon, 2001) was created to assess language and verbal WM abilities in aphasia. TALSA can be used to identify WM processing impairment depending on linguistic characteristics (semantics, phonology) and memory load variations (time delay, and interference). Given its characteristics, TALSA has been used in several studies to access WM abilities in aphasia (Taylor & Burke, 2002; Verhaeghen, 2003). However, no assessment tool is available to evaluate WM abilities based on linguistic characteristics and memory load variations in normal older people. Therefore, in the current study, we assess language and WM decline among older Koreans by manipulating task types and interval conditions and by creating a modified Korean version of TALSA.

The purpose of the current study was to: (1) to investigate age-related differences in WM components by manipulating the time interval effects (1-s unfilled vs. 5-s unfilled vs. 5-s filled) in each of phonological and semantic judgment tasks; (2) to examine which tasks can be used to best discriminate between young and older groups; and (3) to examine which tasks were significantly correlated with traditional WM (tWM) capacity measures using digit- and word-span tasks in each age group.

We hypothesized that age differences would exist in each WM task according to language characteristics (semantics, phonology) and that the time interval effects (1-s unfilled, 5-s unfilled, 5-s filled) will differ depending on age in each WM task. Based on the age-related differences in inhibition function predicted by Hasher's framework (Hasher *et al.*, 1999), we hypothesized that while the age effect would not be significant for the 1-s interval condition, it would be significant for the 5-s interval conditions with increased time delay and interference. In addition, because of this prediction, we conducted discriminant analysis to determine the combination of task type (semantic, phonological) and time interval condition (1-s unfilled, 5-s unfilled, 5-s filled) that could best discriminate between young and old adults. Furthermore, as we expected differences in WM performance measured by specifying task types and time interval conditions depending on the traditional WM (tWM) capacity measured with digit- and word-span tasks, we conducted a correlation analysis to find out which combination of task type and time interval conditions are related to tWM capacity.

METHODS

Participants

The participants of this study were 48 cognitively normal young adults and 48 cognitively normal older adults who fulfilled Christensen's health screening criteria and did not have medical, neurological, or psychiatric diseases. In addition, the participants performed normally in the Korean-Mini Mental State Examination (K-MMSE) (Kang, 2006). The demographic characteristics of young and older groups are shown in Table 1. The current study was approved the Institutional Review Board of Ewha Womans University (No. 78–23), and the written consent was obtained from all participants.

Material

Semantic category judgment task (*SCJT*). We modified the semantic category judgment task (SCJT) of TALSA (Martin, Minkina, Kohen & Kalinyak-Fliszar, 2018) to determine whether the two items belonged to the same semantic category for ascertaining semantic abilities in word processing. This task comprises 60 items, which fall into animate and inanimate cateories. The animate category is subdivided into fruits, vegetables, and animals, and each subcategory consists of 10 items. The inanimate category is subdivided into clothing, kitchenware, and transportation, and each subcategory consists of 10 items.

Phonological rhyming judgment task (*PRJT*). We modified the rhyming recognition task of TALSA (Martin et al., 2018), which is the phonological rhyming judgment task (PRJT), to determine whether the two items rhymed to probe phonological abilities in word processing. This task comprises 20 word-pairs (10 rhyming and 10 non-rhyming), and all words were two syllable words. The participants had to decide whether each word pair rhymed by examining the final syllable.

tWM capacity measures. We employed four tasks as the tWM capacity measures, digits-forward (DF), digits-backward (DB), words-forward (WF), and words-backward (WB). The DF and DB tasks were taken from the Korean version of the Wechsler Adult Intelligence Scale (K-WAIS) (Yeom, Park, Oh, Kim & Lee, 1992). Each task consisted of 14 trials. The DF task ranged from Span 3 to Span 9 with two trials for each span, but the DB task ranged from Span 2 to Span 8 with two trials for each span. When participants failed to recall both trials in a specific span, the task was terminated. The score was measured by the number of correctly recalled trials. The WF and WB tasks were taken from Sung (2011). The procedures and the number of trials from word-span tasks were identical to digit-span tasks.

Prior to analyzing the data obtained from the tWM capacity measures, we conducted an exploratory factor analysis by using a principal component extraction procedure for each age group to explore whether the four tWM capacity measures could be represented as a single factor. A single-factor solution accounted for 66.48% and 63.73% of the total variance for the young and older groups, respectively. The sum score of the four tasks served as a composite index of the tWM capacity measure, which is based on previous studies that reported that composite scores of WM measures increased reliability and stability (Waters & Caplan, 2003), in further analyses.

Procedure

The procedures of the WM tasks, the SCJT and the PRJT, were identical to those of TALSA (Alwin & McCammon, 2001). The time interval between two stimuli of both WM tasks was assessed for the effects of time delay and interference on performance. Three interval conditions existed: 1-s unfilled (1-s UF); 5-s unfilled (5-s UF); and 5-s filled (5-s F). Each UF condition occurred only during a time interval between the two stimuli without fillers. However, the F condition presented four numbers between the two stimuli as fillers for 5 s. As fillers, four of the single-digit numbers from 1 to 9 were randomly presented.

In the SCJT, two items were presented in succession. The first appeared on a screen for 3 s and disappeared before the second item appeared. The second item appeared after one of the three intervals conditions and

Table 1. *Demographic characteristics of the participants*

	Young (*n* = 48)	Old (*n* = 48)
Age, years (range)	24.02 ± 4.06 (18–38)	64.58 ± 4.14 (60–74)
Gender, male/female	20/28	21/27
Education, years (range)	14.02 ± 1.85 (12–16)	13.40 ± 2.26 (9–18)

Note: Values are presented as mean ± standard deviation.

remained on the screen for 1,500 ms. The task was to determine whether the two items belonged to the same category and to record a response by pressing keys on a keyboard labeled YES or NO.

In the PRJT, two items were presented in succession, and the participants decided whether these items rhymed. However, unlike the two items that were presented only visually in the SCJT, these two items were presented both visually and acoustically. Except for this change, the test progressed in the same manner as the SCJT. All items were presented through the E-prime program. The rapid serial visual presentations of both tasks are shown in Fig. 1.

Statistical analysis

The outcome measure was the number of correct responses for each task type and interval condition, and the accuracy was calculated as a percentage.

First, the differences in the accuracy between age groups based on interval conditions were examined using a two-way analysis of variance (ANOVA) for each WM task. The significant results of the ANOVA were verified by post hoc comparisons using a Bonferroni correction. Second, a stepwise discriminant analysis was performed to examine which tasks or task types and interval conditions best discriminated between the two age groups. In addition, receiver operating characteristic (ROC) curve analyses were performed to examine the accuracy of age-group differences, which is based on task types and interval conditions to discriminate between the two age groups. Finally, Pearson correlation coefficients were computed between the tWM capacity measure and the accuracy of each task type and interval condition in each age group. All statistical analyses were performed using IBM's SPSS statistics 21.0 (Armonk, NY, USA).

RESULTS

Intergroup differences in accuracy based on interval conditions in each WM task

The percentage of accurate responses for each task served as a dependent measure. We performed two-way mixed analyses with age groups as a between-subject factor by using the interval conditions (1-s UF vs. 5-s UF vs. 5-s F) as within-subject factors in each of the two WM tasks: the SCJT and the PRJT. Figure 2a provides descriptive information on the means and standard error for each group, task type, and interval condition.

In the SCJT, a significant difference in the main effect occurred for the groups ($F_{1,\ 94}$ = 9,030; p = 0.003; partial η^2 = 0.088), with the older group performing significantly worse than the young group. The difference in the main effect for the interval conditions was significant ($F_{2,\ 188}$ = 24.851; $p < 0.001$; partial η^2 = 0.209). A follow-up post hoc analysis conducted using a Bonferroni correction demonstrated that performance in the 5-s UF condition was significantly worse than in the 1-s UF condition ($p < 0.001$), and that performance in the 5-s F condition was significantly worse than performance in the 1-s UF condition (p = 0.002). Moreover, performance in the 5-s UF condition was significantly worse than performance in the 5-s F condition (p = 0.002). The results of a two-way interaction between the groups and the interval conditions were not significant ($F_{2,\ 188}$ = 0.672; p = 0.512; partial η^2 = 0.007).

In the PRJT, the main effect for the groups was not significant ($F_{1,\ 94}$ = 1.077; p = 0.302; partial η^2 = 0.011), whereas the main effect for interval conditions was significant ($F_{2,\ 188}$ = 11.303; $p < 0.001$; partial η^2 = 0.107). A follow-up post hoc analysis conducted using a Bonferroni correction demonstrated that performance in 5-s F condition was significantly worse than performance in 1-s UF condition ($p < 0.001$) and the 5-s UF condition (p = 0.024). However, the analysis revealed no significant difference between performance in the 1-s UF and 5-s F conditions (p = 0.094). However, the result of a two-way interaction between the groups and the interval conditions was not significant ($F_{2,\ 188}$ = 0.032; p = 0.955; partial η^2 = 0.000).

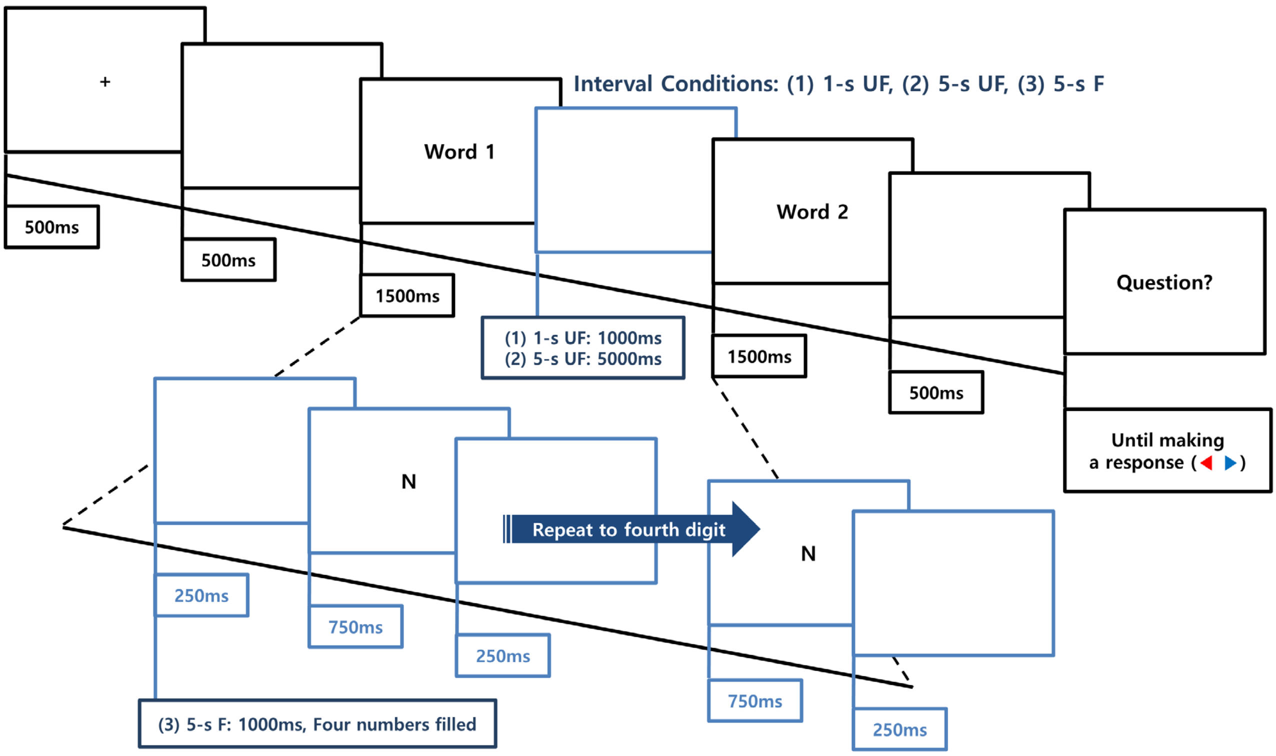

Fig. 1. Rapid serial visual rresentations of the SCJT and the PRJT.

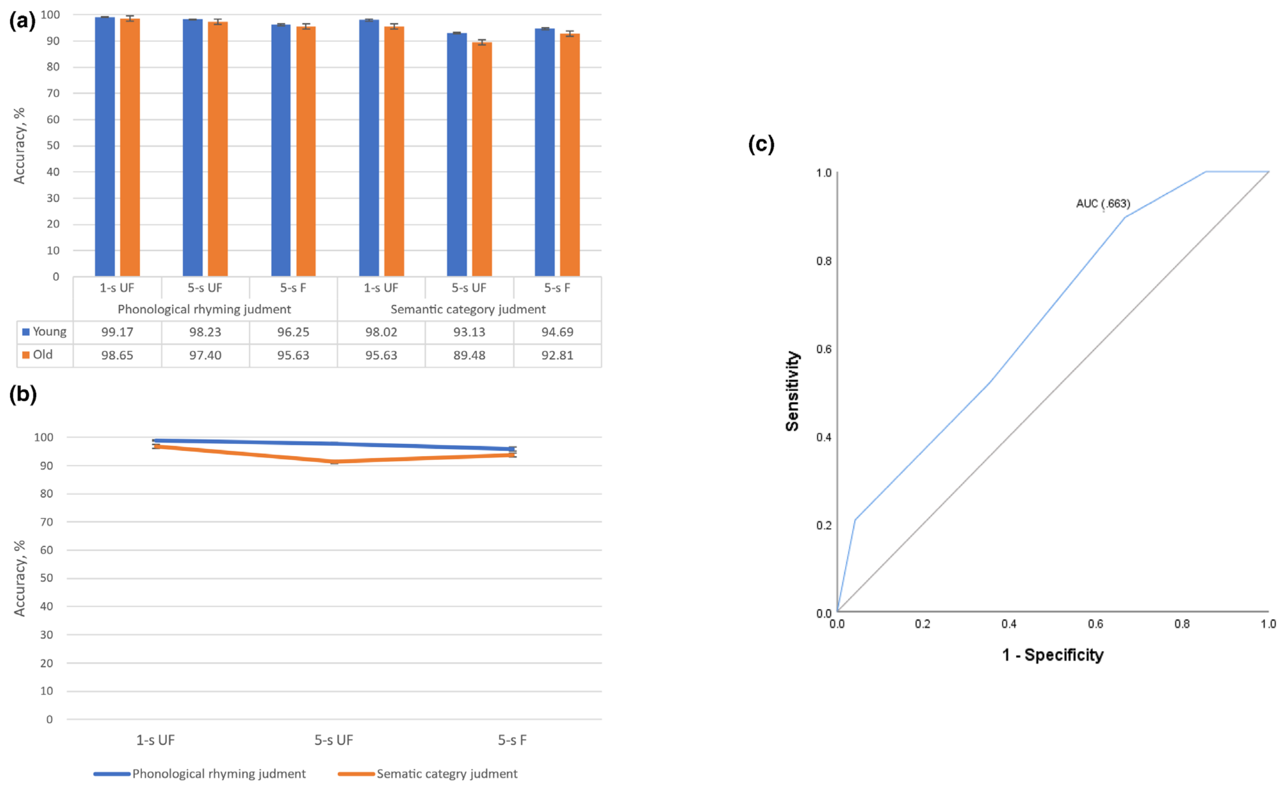

Fig. 2. (a) Mean and standard error of accuracy in each task type and interval condition for both age groups. (b) Two-way interaction between the task types and interval conditions. (c) ROC curves for the accuracy for the 5-s UF condition of the semantic category judgment task in comparison between young group and older group.

Discriminant analysis between age groups

We performed a stepwise discriminant analysis to examine which tasks could best discriminate between the two age groups. The independent variables were accuracy-based factors for the task types (SCJT vs. PRJT) and interval conditions (1-s UF vs. 5-s UF vs. 5-s F). The stepwise method begins with no variables in the model. At each step, the variable with the largest F that exceeds the criterion value is entered into the model, with a default criterion value of F as 3.84.

As a result of the stepwise procedure, only the 5-s UF conditions of the SCJT remained from the six independent variables. The model demonstrated that the 5-s UF conditions of the SCJT was the most accurately discriminated task between the younger and older groups ($\chi^2 = 9.499$, Wilks' Lambda $= 0.636$, $p = 0.001$). According to the lambda value of the whole formula and the discriminant function derived from the discriminant analysis, the specificity of this task in classifying young adults as young adults was 52.1%, and the sensitivity of classifying older adults as older adults was 64.6%. In addition, 58.3% of the total group cases was accurately discriminated.

The ROC curve analysis revealed that the accuracy of the SCJT in 1-s and 5-s UF conditions differentiated between the young group and the older group compared to those of the other interval conditions. The areas under the curve (AUC) values between the young group and the older group for the three interval conditions of each task and the ROC curve graph for the 5-s UF condition of the SCJT are presented in Table 2 and in Fig. 2c, respectively.

Pearson correlation coefficients between the tWM capacity measures and the accuracy of each task type and interval condition

Pearson correlation coefficients were computed between the variables, including the tWM capacity measure, the accuracy of three interval conditions, and the two task types in each age group. Although the tWM capacity measure for the young group was not significantly correlated to any task types and interval conditions, the tWM capacity measure for older group was significantly and positively correlated only with the 5-s UF condition of the SCJT ($r = 0.303$, $p = 0.036$). The detailed results for this analysis are shown in Table 3.

DISCUSSION

In this study, we determined aging-related differences in the WM tasks that emerged when their conditions were manipulated by varying the time intervals (1-s UF vs. 5-s UF vs. 5-s F) between semantic and phonological task types. We found that the effect of the age group was significant in the SCJT, but not in the PRJT. In the SCJT, the group of older adults experienced difficulties in completing the WM task across conditions compared to the younger group. The results are consistent with the findings of previous studies that reported an age-related decline of semantic processes (Haarmann *et al.*, 2005; Taylor & Burke, 2002; Verhaegen & Poncelet, 2013). In the PRJT, however, there was no significant difference between the younger and older groups. The results are consistent with the previous studies reported that

Table 2. *AUCs for the three interval conditions of each task in a comparison between the young and the older groups*

Task types	Interval conditions								
	1-s UF			5-s UF			5-s F		
		95% CI			95% CI			95% CI	
	AUC	LL	UL	AUC	LL	UL	AUC	LL	UL
Phonological rhyming judgment	0.542	0.427	0.658	0.543	0.427	0.658	0.574	0.458	0.690
Semantic category judgment	0.678	0.569	0.786	0.663	0.556	0.771	0.568	0.453	0.683

Note: UF = unfilled, F = filled, AUC = area under the curve, CI = confidence interval, LL = lower limit, UL = upper limit.

Table 3. *Correlation coefficients between the tWM capacity measure and the accuracy of each task type and interval condition in each age group*

Group	Phonological rhyming judgment task			Semantic category judgment task		
	1-s UF	5-s UF	5-s F	1-s UF	5-s UF	5-s F
Young	0.035	0.062	0.203	−0.212	0.017	0.209
Old	−0.041	0.036	0.145	0.230	0.303*	0.248

Note: UF = unfilled, F = filled.
$^*p < .05$.

phonological processes are preserved in older adults during language comprehension (Burke & MacKay, 1997; Shafto & Tyler, 2014). Thus, the different effects of age in each task might be related to the IA model and could include the semantic and the phonological levels (Dell, 1986). Nonetheless, age-related difficulties in language processing occurred at the semantic level, but not at the phonological level.

Furthermore, we found that the effects of time interval manipulations were significant in both WM tasks. First, the time delay effects affected the SCJT, but not the PRJT. The 5-s UF condition elicited worse performance than the 1-s UF condition in the SCJT, although the differences between 1-s UF condition and 5-s UF condition were not significant. The TBRS model includes the assumption that the memory traces of the information to be maintained fade away whereas focusing to process such information because WM shares limited attentional resources between processing and maintaining information (Barrouillet *et al.*, 2004). These results can be accounted for by the TBRS model, given that the cognitive load increases under a prolonged interval condition that requires greater attentional resources to maintain information over time.

Second, the interference effects affected the PRJT, whereas these did not affect the SCJT. In the PRJT, the 5-s F condition generated inferior performances than the 5-s UF did. The results indicate that the F condition elicited significant interference effects in the phonological judgment in the same time interval. Therefore, it is likely that the digit-based filled condition interferes with maintaining phonological information over time and that this phenomenon can be accounted for by the shared WM resource hypothesis (Kim *et al.*, 2005; Navon & Gopher, 1979; Smith, Jonides & Koeppe, 1996), wherein two entities of digit-related information processing and phonological rhyming judgment possibly rely on a shared WM resource pool.

The SCJT produced opposite patterns that demonstrate inferior performance on the 5-s UF than the 5-s F. The counterintuitive results suggest that the contributions of filled information inserted by additional digits differed depending on the task types. The digit-based filled condition serves as an interference for the PRJT, which is based on the shared WM hypothesis between digit presentation and phonological processing. In contrast, the SCJT does not seem to recruit the same WM resources as that of digit information, indicating that semantic processing may tap into a separate WM resource pool that does not overlap with digit-related information processing. With reference to the SCJT, this filled information contributes to the recruitment of greater WM resources by inhibiting the irrelevant information of digits to ensure the maintenance of the relevant semantic information, leading to superior performance on the UF condition for the SCJT. These are interesting findings, given that WM resources in relation to digit-insertion as a filler that differentially affected the task types.

In the case of PRJT, the results of the time interval effect are consistent with the results of Martin *et al.*'s (2018) study of TALSA for aphasia patients. However, in the case of SCJT, the results for the time interval effect differed from those of Martin *et al.*'s study, wherein no significant difference between the 1s-UF condition and the 5s-UF condition on the category judgment task was found, despite poorer performance in the 5s-F condition compared to the 5s-UF condition (Martin *et al.*, 2018).

We further explored whether digit-related filled interference effects are related to WM capacity, as measured by a composite index of more traditional tasks using digit and word span tasks. The correlational results among the tWM capacity measures and the current WM conditions revealed that significant and positive correlations exist between the tWM composite index and the 5-s UF semantic task condition of the current WM paradigm only for the older group. These correlational results are in line with the results from the discriminant analyses, which suggested that the 5-s UF condition in the SCJT emerged as a significant factor for differentiating the older adults from younger adults. The results indicate that the 5-s UF condition in the SCJT can best detect the differences in WM performance associated with aging. These findings are aligned with previous studies which reported that aging-related impairments predominantly emerged in the semantic domains at an early stage (Taylor & Burke, 2002; Verhaegen & Poncelet, 2013) and extend further from the findings of the differential effects of WM resources related to the digit fillers according to the task types described above; therefore, these differential effects of WM resources that are related to the digit fillers appear more prominently in older adults. In addition, these results are consistent with those of previous studies that reported age-related impairments in maintaining information over delays (Einstein *et al*., 2000; McDaniel, Einstein, Stout & Morgan, 2003; West & Craik, 2001). However, given the relatively lower specificity for young (52%) and older adults (64.6%) under the 5-s UF condition in the SCJT, the discriminant analysis results need to be interpreted with caution. The low specificity is likely associated with the small effect size of age group in the SCJT ANOVA results. Future studies should include more sample sizes to confirm the current findings.

LIMITATION

Our study has some limitations to be described. First, both young and old groups showed high accuracy (>95%), which was close to the upper limit across the tasks and conditions. Although aging effects emerged in the accuracy of the WM tasks, further studies are required to employ other outcome measures including response times or real-time measurements, such as eye-tracking and event-related potential (ERP) measures. Second, the current study presented only single-digit numbers as fillers. However, more studies are needed to ascertain different interference factors by adding more diverse types of fillers depending on the task types, given the likelihood that the types of fillers may contribute differentially to eliciting WM demands and interferences based on the characteristics of verbal WM domains.

CONCLUSION

This study has some interesting clinical and empirical implications, given that the results demonstrated differential effects of digit-related interference manipulation on the semantic and phonological processing mechanisms that are involved in WM resources. Notably, the older group can be differentiated by varying the WM conditions, which indicates that semantics-related WM burdens may offer a more suitable differential diagnosis of aging-related WM decline.

ACKNOWLEDGMENT

This research was partly supported by the National Research Council of Science & Technology (NST) grant by the Korea government (MSIT) (No. CAP21052-000), the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (2022R1A2C2005062) and Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2022R1I1A4063209).

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Received 30 June 2022, Revised 19 January 2023, accepted 24 January 2023