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Effects of Age and Working Memory Load on the Comprehension of Passive Sentences

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Abstract

The ability of older adults to comprehend sentences may decline due to the cognitive changes in working memory. Therefore, an increase in working memory demands during sentence comprehension would result in poorer performance among older adults. To test this hypothesis, the present study explored the effects of age and working memory load on sentence comprehension using a sentence-picture matching task. 35 older adults and 35 younger adults were required to match Mandarin passive sentences (high working memory load) and active sentences (low working memory load) with pictures. Passive sentences were found to be more difficult than active sentences for all participants. Older adults responded to passive sentences more slowly than younger adults. However, no significant age difference was found in accuracy of responses. Accuracy on the comprehension of passive sentences was marginally correlated with the effect of syntactic complexity among older adults. Compared with younger adults, older adults were more disrupted by the increased working memory load in the comprehension of passive sentences, but they can compensate for the decline in the accuracy of comprehension by spending extra time on sentences with higher working memory load.

Keywords: age, working memory, sentence comprehension, passive sentence

1. Introduction

There is plenty of evidence that the ability to comprehend sentences becomes less accurate and slower among healthy elderly (Caplan, et al., 2011; Stinemorrow, Noh& Shake, 2010; Waters & Caplan, 2005). Aging has generally been found to result in the decline in working memory (WM). According to the Capacity Constrain Theory, the WM resources possessed by individuals are limited and thus, syntactic processing will deteriorate if working memory load is increased by such factors as syntactic complexity (Just & Carpenter, 1992).

Previous studies of language comprehension by older adults provide evidence showing that older adults found it particularly difficult to comprehend and process embedded syntactic constructs such as relative clauses as these structures have higher demands for working memory resources (Kemper, 1986). These difficulties can be accounted for as the decline in the ability of older adults to temporarily store or retain in working memory some linguistic elements during sentence processing (King & Just, 1991). Syntactic processing requires the construction of the filler-gap dependency relations and the assignment of semantic roles for the arguments in the sentences. According to the syntactic movement theory in the Transformational Generative Grammar, the filler in a sentence is moved from its initial syntactic position and thus, leave behind a gap (or trace). It has been suggested that the longer linear distance (or a larger number of lexical items) intervening between the gap and the filler will increase the difficulty in comprehending the sentence as the features of the filler have to be temporarily retained in the working memory before the gap is found. The linear distance between gaps and fillers can determine the working memory load for sentence comprehension (Van Dyke & Johns, 2012). Miyake, Carpenter, and Just (1994) pointed out that with the increase in working memory demands, elderly individuals will make more mistakes in sentence comprehension and their processing speed will also be compromised. However, if they have sufficient working memory resources, their performance will remain largely intact.

Previous studies generally used relative clauses to study how sentence comprehension is affected by working memory and age differences (DeDe, et al., 2004; Waters & Caplan, 2001, 2005). However, little attention has been given to other syntactic structures such as passive sentences. Passive sentences differ from relative clauses in that they do not contain embedded structures, making them comparatively easier than relative clauses. Studies of the comprehension of passive sentences by older adults may provide additional evidence regarding the relations between language comprehension and WM capacity. So far, there have been only a few attempts to address the comprehension of passive sentences among older adults. Mack et al. (2013) investigated the neural basis of English passive sentence processing among 14 younger adults and 13 older adults. Subjects were required to complete a sentence picture verification task while their neutral activation activities were recorded using functional Magnetic Resonance Imaging. It was found that compared with active sentences, passive sentences displayed different patterns of activation in the brain. The left temporo-occipital regions and inferior frontal gyrus were more active when passive sentences were being processed. However, the study failed to reveal any significant differences in neural activation patterns between younger and older adults. In this study, working memory was not taken into consideration and consequently, we are not sure whether the lack of significant age differences was related to the working memory capacity of the participants.

Sung et al. (2017) examined the effect of different WM loads on the processing of Korean passive sentences (canonical and non-canonical) among older and younger adults using a sentence comprehension task. The study found that sentences with canonical word order were easier to comprehend than sentences with non-canonical word order for all subjects regardless of their ages. The effect of WM on sentence processing outweighed the aging effect. With the increase of age, WM load has greater effect on the comprehension of passive sentences. This indicates that subjects with higher WM capacity tend to be less vulnerable to aging. WM capacity plays a more important role in sentence comprehension among older adults.

Hardy, Messenger and Maylor (2017) studied the differences in the production of English passive structures between different age groups using a priming task. Contrary to the study by Sung et al. (2017), Hardy, Messenger and Maylor (2017) discovered that older and younger adults displayed similar priming effects in the production of passive sentences, which indicates that the ability of older adults to produce passive sentences was largely unaffected by aging. However, this study did not consider the working memory differences.

Although previous studies of relative clause comprehension revealed that the decline in working memory capacity among older adults is a major reason for their difficulty in sentence comprehension (DeDe et al., 2004), it is not clear whether this findings apply to the comprehension of passive sentence as well. As most prior studies of sentence comprehension by older adults focused on English or Korean, there is a need to cross-validate the effects of age and working memory on sentence comprehension in other languages such as Mandarin Chinese in order to expand our knowledge about how age and working memory jointly influence sentence comprehension. Unlike English or Korean passives, Mandarin passives are the Subject-Object-Verb (SOV) structures with a passive marker BEI (“被”) following closely behind the grammatical subjects. These structures may result in different demands for working memory resources and thus different performance of older adults during sentence comprehension. The studies of Mandarin passive and active sentence comprehension can provide additional evidence to cross-validate the findings from participants speaking English or Korean and allow us to view the effects of age and WM from a cross-linguistic perspective.

The present study intends to explore the comprehension of Mandarin passive sentences among a group of older adults and younger adults in China. We designed two working memory load conditions: passive sentences (high WM) and active sentences (low WM), as shown in the example below.

(1a).记者攻击了政客(active/low WM load)

The journalist attacked the politician.

(1b).记者被政客攻击了(passive/high WM load)

The journalist was attacked by the politician.

Chinese passive sentences (1b) have a non-canonical SOV word order with a passive marker BEI(“被”) following right behind the grammatical subjects and therefore they are structurally different from the canonical Subject-Verb-Object (SVO) word order that active sentences (1a) follow. Chinese passive sentences are considered to be structurally more complex than active sentences. The theme in a Mandarin passive sentence is usually the grammatical subject and the agent is represented by an adjunct prepositional phrase. In the Transformational Generative Grammar, passive sentences are derived from active sentences by the movement of noun phrase (NP). According to the movement-based account, the theme is moved from its original grammatical object position after the verb to the subject position in the sentence, leaving behind it a gap which is co-indexed with the moved NP. Due to the syntactic movement, a syntactic reanalysis is required to comprehend passive sentences, in which the trace needs to be identified and co-indexed with the moved noun phrase located at the subject position. Thus, passive sentences are syntactically more complex and require more working memory resources for computation than active sentences. In this study, passive sentences were regarded as a high working memory load condition and active sentences were considered to be a low working memory condition.

As prior research found that older adults encountered greater difficulties in comprehending the sentences with increased syntactic complexity and working memory load, such as relative clauses (Kemper, 1986, 1987; Kemper, Thompson, & Marquis, 2001), we predict that in comprehending passive sentences which are syntactically more complex and cognitively more demanding, older adults will show longer RTs and lower accuracy in their responses than younger adults. However, in processing simple sentences which are syntactically less complex and less demanding for working memory resources, older adults may not differ significantly from younger adults. The age difference will be greater in the high working memory condition. Working memory load and age interact with each other to influence sentence comprehension.

2. Methods

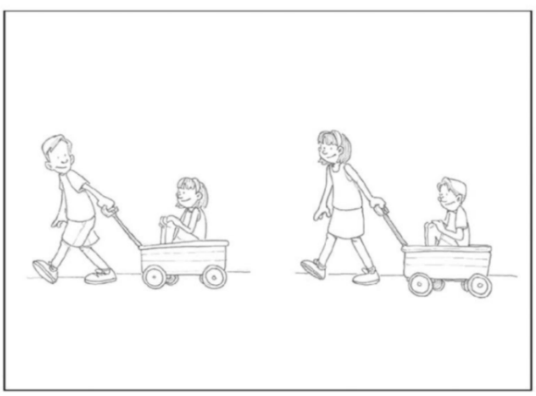
2.1 Participants

In this study, thirty-five older adults (mean age: 66.38, SD: 1.71; 23 female) and thirty-five younger adults (mean age: 20.05, SD: 2.94; 19 female) participated in a sentence picture matching task. None of them has suffered from psychiatric disorders. The Edinburgh Handedness Inventory (Oldfield, 1971) was used to measure righthandedness and the results indicated that all participants were right-handed. Older adults were required to complete the Global Deterioration Scale to assess their neurological health conditions (Reisberg, et al., 1982) and results indicated that all of them were neurologically healthy (level < 2). There was no significant difference between two groups in educational attainment as measured by the years of education (older adults: mean = 13.1, SD =2.79; young adults: mean = 14.2, SD = 1.15; p>.05). The gender difference between older adults and younger adults did not reach significant level (older adults: 65.7% female, and young adults: 54.2% female).

In order to assess participants' general cognitive ability, we administered the Wechsler Adult Intelligence Scale (Wechsler, 2003) to all participants before the experiment began. The scale consists of four sections: working memory index, perceptual organization index, processing speed index, and verbal comprehension index. The results of ANOVA showed that older adults and younger adults did not differ in verbal comprehension index, $F(1,69)=.24$, $p=.623$. This indicates that older adults and younger adults had no significant differences in vocabulary and world knowledge. However, younger adults outperformed older adults in working memory, $F(1,69) = 133.42$, $p<.05$, $\eta^2_p= .79$, perceptual organization, $F(1,69) = 101.82$, $p<.05$, $\eta^2_p= .75$, and in processing speed, $F(1,69) = 143.50$, $p<.05$, $\eta^2_p= .81$.

2.2 Materials

This study used sixty sentences, including thirty passive sentences and active sentence. Each sentence was paired with two pictures with reversed thematic roles and only one of them was consistently matched with the sentence. Thirty fillers with various structures and length was also used, including BA structure, relative clause, topicalization and so on. The sentences were randomized before being presented to participants. The experimental materials used in the present study include forty pictures from the Northwestern Assessment of Verbs and Sentences (Choreyes& Thompson, 2012) coupled with fifty pictures used in other research which is irrelevant to the purpose of this experiment. A sample stimulus is presented in Figure 1.



Picture 1(left)女孩被男孩拉着(passive) The girl is being pulled by the boy.

Picture 2(right)女孩拉着男孩(active) The girl is pulling the boy.

Figure 1. Sample stimuli for testing sentence comprehension (Choreyes& Thompson, 2012)

2.3Procedure

Participants completed the test individually in a laboratory setting. All tasks were completed in one session. Before the test, they were instructed about the task requirement and contents and were required to complete five practice questions repeatedly until they fully understood the procedures. In the test, participants were first presented visually a sentence and two pictures and were required to indicate with a button press(“1” for picture 1 and “2” for picture 2) as quickly as possible which picture matched the meaning of the target sentence. The next question started automatically if no response to the question was detected within twenty seconds. Two responses (“1” and “2”) were balanced across the two conditions. Participants gained one point for every correct answer they produced and no point for incorrect responses. After the test, participants were provided monetary compensation for their participation. The experiment took about fifty minutes.

3. Results

3.1 Accuracy of Comprehension

A mixed 2 (sentence type: passive vs. active) by 2 (age group: older vs. younger) ANOVA was performed on accuracy (proportion of correct responses to comprehension questions). Post hoc tests were used to explore the significant interactions identified through ANOVA. Group means are shown in Figure 2.

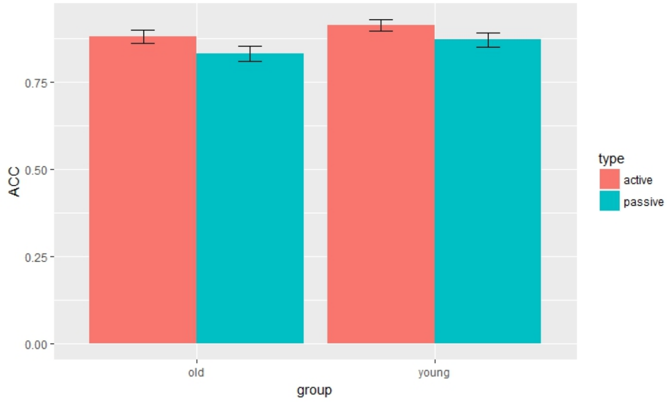


Figure 2. Accuracy (proportion correct) by sentence type and age group

The results of ANOVA found that there was a significant main effect of sentence type, F(1, 69)=18.36, p<.05, η^2_p =.35. No significant main effect of age or interaction effect was found, F(1, 69)=.71, p=.25, F(1, 69)=.35, p=.55. The comprehension accuracy for active sentences was significantly higher than that for passive sentences for both younger and older adults (ps<.05), indicating that passive sentences were more difficult to process than active sentences. Besides, older adults comprehended all sentences as accurately as younger adults. The interaction between age and sentence type was not significant, indicating the asymmetry in processing difficulty between passive and active sentences did not differ between different age groups.

3.2 Reaction Times

In analyzing RTs, we excluded all trials which were not responded correctly. RTs greater than 5s were also deleted, as they might reflect that participants did not engage in normal sentence processing. Moreover, RTs more than 3 standard deviations from the average were regarded as outliers and excluded from data analysis. Given that older adults generally performed more slowly than younger adults, data trimming was performed on a subject by subject basis. Together, these procedures resulted in 22.8% trials deleted.

RTs were analyzed with a 2 (sentence type: passive vs. active) by 2 (age group: old vs. young) ANOVAs. Age is the between-subjects factor and sentence type is the within-subjects factor. Post hoc tests were performed to further explore the specific associations between different variables. Figure 3 shows the RTs for the two age groups.

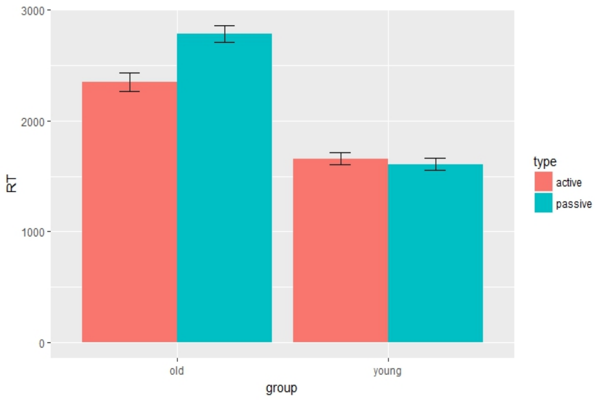


Figure 3. Reaction times by sentence type and age group

The results of ANOVA demonstrated that there was a significant main effect of age, F(1, 69)=130.43. $p<.01$, $\eta^2_p=.79$, main effect of sentence type, F(1, 69)=21.28. $p<.01$, $\eta^2_p=.38$, and significant interaction between sentence type and age, F(1, 69)=61.69. $p<.05$, $\eta^2_p=.64$. Post Hoc test further found that older adults responded to both active and passive sentences significantly more slowly than younger adults ($p<.05$). Both younger and older adults responded to active sentences much more quickly than passive sentences ($p<.05$). Most importantly, the effect of sentence type was greater among older adults, which shows that compared with younger adults, the processing of passive sentences caused more disruptions to older adults.

3.3 Correlations

As participants generally spent longer time reading passive sentences to compensate for the performance decline caused by the additional working memory load, correlation analysis was performed to explore whether the additional time spent in comprehending passive sentences was correlated with higher comprehension accuracy among the two groups. Difference scores (passive minus active sentence) were computed to assess the magnitude of syntactic complexity effect or the effect of working memory load and were then correlated with the accuracy (proportion correct) of passive sentence comprehension. The purpose of correlation analysis was to explore whether the extra time participants have spent on the more cognitively demanding passive sentences was correlated with the higher accuracy in their responses to comprehension questions. If there is a significant positive correlation between difference score and accuracy, it shows that participants have improved their comprehension accuracy by spending extra time or engaging themselves in effective additional processing (Caplan et al., 2011). This would provide evidence for a more effective compensatory processing strategy. On the contrary, negative or no significant correlations would indicate that longer reaction times did not result in higher accuracy and thus the compensatory processing was ineffective. In this study, the correlation between syntactic complexity effect (i.e., passive minus active) and accuracy on passive sentence comprehension reached marginal significance (r = .23, $p=.07$) among older adults. However, the correlations between accuracy and syntactic complexity effect did not approach significance among younger adults.

4. Discussion

This study examined the effects of age and working memory load on the comprehension of Mandarin passive sentences. Given that working memory declined among older adults (Kemper, 1986, 1987; Kemper et al., 2001), we predicted that older adults would comprehend sentences in a less accurate and efficiency way than younger adults. We also predicted that as the working memory load for passive sentences is higher, older adults would encounter greater difficulty in this condition compared with younger adults, which will be reflected in their declined performance.

However, contrary to our hypothesis, the results indicate that older adults and younger adults did not differ significantly in the accuracy of sentence comprehension in either passive or active sentence condition. Both groups found passive sentences to be more difficult to comprehend than active sentences. The asymmetry in comprehension difficulty between passive and active sentences was not inflated among older adults as we have expected. This finding suggests that the two age groups displayed similar patterns of comprehension difficulty in all conditions regardless of WM load. This is inconsistent with Sung et al. (2017)'s study which found that working memory had greater influence on the performance of individuals with advancing age. The inconsistency may derive from the different experimental stimuli used in the two studies. Sung et al. (2017) used two types of Korean passive sentences with reversed order of grammatical subject and object (SOV vs.OSV) as the target structure. The subjects and objects in these passive sentences were all followed by case markers which provided important clues for the identification of the grammatical roles. Case-marker processing is an indispensable step in the interpretation of Korean passive sentences. Previous studies found that case-marker processing in Korean sentences was cognitively demanding for older adults and there was a significant age difference in case-marker processing (Sung, 2017). As a result, compared with Mandarin Chinese, a language without case-markers, Korean sentences are more likely to elicit aging effects. These language-specific syntactic features might account for the inconsistency between our study and Sung et al. (2017).

There are two possible reasons for the lack of differences between the two age groups in comprehension accuracy. First, it might be because the passive sentences used in the present study were all short sentences and thus the linear distance measured by intervening words between the gap and the filler was relatively short. As a result, the processing costs might not be high enough to differentiate older adults from younger adults. Older adults had sufficient resources to meet the demand for processing short passive sentences and thus they were able to achieve an equally high level of accuracy as younger adults.

Another possible reason is that older adults might resort to some compensation strategies to make their performance comparable with younger adults. They might have spent longer time processing the more difficult passive sentences. This can be supported by the results of correlation analysis. The results of correlation analysis revealed a marginally significant positive relationship between reaction times and accuracy in the comprehension of passive sentences among older adults, but no such pattern was found for younger adults. This finding indicates that older adults spent longer time on the syntactically more complex passive sentences and the longer reading times improved their comprehension to achieve an equally high level of accuracy as younger adults. This pattern indicates effective compensatory processing because older adults allotted more processing resources to emit more precise answers to the comprehension questions and thus made their comprehension accuracy comparable with younger adults (Caplan et al., 2011). As Starns and Ratcliff (2010) proposed, longer RTs can be an effective strategy for compensating for the decline in accuracy and older adults were more likely than younger adults to trade the speed of responses for higher accuracy. The finding of the present study is largely consistent with the idea of implementing an effective compensation strategy on the part of older adults. This finding was also supported by Caplan et al. (2011)'s study. Caplan et al. (2011) examined the comprehension of relative clauses by older adults and found that there were positive correlations between effects of syntactic complexity and the accuracy of relative clause comprehension. However, contrary to the present study, DeDe (2015) found a non-significant negative correlation, rather than a positive correlation. This inconsistency may be the result of differences in the type of effect. The positive relationship identified in the present research was associated with effects of syntactic complexity, while the negative relationship discovered by DeDe (2015) was related with effects of animacy configuration.

Another finding which also deserves our attention is that older adults generally responded more slowly than young adults in all WM load conditions. This finding can be explained by the Processing Speed Theory according to which, increased age in adulthood is universally related with a decline in the speed (Salthouse, 1996). This reflected an overall slowed processing in older adults. In additional to general slowing, older adults showed greater sensitivity than younger adults to the WM load or syntactic complexity. This study found that compared with younger adults, older adults' speed of responses declined more dramatically in high WM load conditions. Although younger adults' reaction times also increased in the high WM load condition, the change was less dramatic than that of older adults, which showed that younger adults were less disrupted by the high WM load. This finding was consistent with our initial hypothesis that there would be an inflated effect of WM load condition or sentence type on the reaction times of older adults. The results support the view that a higher WM load has a stronger influence on the performance of older adults, which indicated that older adults are more sensitive to the working memory load of sentence comprehension than younger adults.

The current study examined the effect of working memory load and age on the comprehension of Mandarin passive sentences. The results revealed a complicated pattern for age-related decline in sentence comprehension. Working memory load has significant effects on the efficiency of sentence processing by older adults. Older adults are more disrupted by high working memory conditions than younger adults, particularly in the speed of responses. However, older adults might adopt a compensation strategy by increasing the amount of time spent on sentences with high working memory load and engaging themselves in additional processing to achieve a relatively high level of accuracy. This compensation mechanism can help older adults to reduce the actual impacts of aging on sentence comprehension in their daily life. This study provides important insights into the age-related declines in the comprehension of Mandarin passive sentences and expands our knowledge about the role of working memory load in sentence comprehension by older adults. This study has important practical implications in that it widens our knowledge regarding the decline in language comprehension ability among healthy older adults and thus provides the crucial baseline for the studies of language deficits in pathological ageing such as Alzheimer's disease.

This study has several limitations which deserve our attention. First, the study merely examined participants' offline performance in sentence comprehension and we are not sure whether the findings can be generalized to real time processing of sentences. Further studies can use online processing tasks such as self-paced reading or listening to investigate whether there are age differences in online sentence processing as well. Second, as the experiment reported in this paper is behavioral in nature, it cannot uncover the neural mechanisms of the age differences in sentence comprehension. ERP or fmri should be used in future studies to explore the differences in brain activations during sentence comprehension between different age groups, which may contribute considerably to our understanding of language in the aging brain.

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