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TITLE:

An Experimental Paradigm for Measuring the Effects of Ageing on Sentence Processing

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sentence processing, ageing, maze task, psycholinguistics, older adults, Mandarin

SUMMARY:

Here, we present a protocol to examine the age-related decline in sentence processing using a maze task that allowed us to localize the processing difficulty at each word of the sentences during reading.

ABSTRACT:

Previous studies have found that older adults have greater difficulties in processing syntactically complex sentences than younger adults. However, the exact regions where the difficulties arise have not been fully identified. In this study, a maze task was implemented to investigate how older adults and younger adults differentially processed two types of sentences with different levels of syntactic complexity, namely subject relative clauses and object relative clauses. Participants were asked to choose between two alternatives at each segment of the sentences. The task required participants to engage in a strictly incremental mode of processing. The reading times for each segment were recorded, allowing the quantification of the difficulty of sentence reading. The task allowed us to identify the exact locations of the processing difficulty and thus facilitate a more accurate assessment of the age-related decline in sentence processing. The results indicate that the effect of ageing was found mainly at the head nouns, but not at other regions of the sentences, a finding which suggests that the maze task is an effective method to identify the exact location of the ageing effect on sentence processing. The implications of this experimental paradigm for investigating the effect of ageing on sentence processing are discussed.

INTRODUCTION:

Sentence processing is an essential process for human beings to comprehend sentences in natural languages. It requires integrating incoming words into the existing sentential structures and establishes relationships between words in the sentence in a way which conforms to the grammatical constraints. As sentence processing is a resource-demanding process, older adults tend to encounter difficulties due to the age-related decline in working memory. Previous studies have found that older adults have great difficulties in comprehending and processing sentences with complex syntactic structures such as relative clauses (RCs): "The reporter whom the senator attacked admitted error"[1]. Most previous studies focused on RCs to investigate the effect of ageing on sentence processing. Compared with younger adults, older adults have lower accuracy and efficiency in RC comprehension. However, despite the extensive studies on RC processing by older adults, it is still not clear which parts of RCs are more difficult to process for older adults as they read sentences word by word. Zurif et al. (1995) found that older adults had greater difficulty at the RC verbs ("attacked") as they were less efficient to assign the patient roles to the objects of the verbs ("reporter")[2]. However, some studies suggest that older adults did not perform differently from the younger controls at any particular region. Rather the difficulties occurred when participants finished reading the entire sentences[3]. Still, several other studies found that older adults performed less efficiently than younger adults at the RC subjects ("the senator") and verbs ("attacked")[4,5]. In other words, the precise locations of the processing difficulties for older adults have not yet been clearly identified.

Sentence processing is an incremental process that requires sufficient cognitive resources. According to the Dependency Locality Theory (DLT)[6,7], the processing difficulties or costs in sentence processing are determined by the distance between the incoming word and the dependent word to which it is attached and thus the costs may vary at different regions in the sentence. The processing costs increase when the distance between the word and its dependent is longer. Therefore, due to the decline of working memory in older adults, they may encounter greater difficulties than younger adults at the words that are located far away from their dependents and are cognitively more costly, such as the verbs ('attacked') of object RCs. Although the DLT was supported by prior work[8,9], it has also been challenged by a number of studies[10]. The study of the precise locations of the processing difficulties in older and younger adults can test the validity of the DLT and help us to understand the relationships between sentence processing and cognitive resources. It can also provide a fine-grained picture of how ageing might influence online sentence processing.

Previous studies on the effect of ageing on sentence processing during reading have mostly adopted self-paced reading[5,11], self-paced listening[4] and cross-modal priming[2]. As an online measure, cross-modal priming tasks can be used to probe the activation of syntactic or lexical information in sentence processing. However, this task can only reveal the processing performance at a certain word or phrase and thus it does not allow us to measure participants' performance at different segments of the sentence to identify where their processing difficulties are mainly located. Actually, so far there has been only one study which used the cross-modal priming task to examine the age-related decline in sentence processing. Zurif et al. (1995)

discovered that older adults encountered greater difficulty in processing English object RCs at the verb regions when the distance between gaps and fillers was longer[2]. The study suggested that there was an age-related decline in RC processing as a result of the lack of working memory resources[2]. However, due to methodological constraints, the study failed to provide information regarding the processing difficulty at other regions of RCs.

As one of the most frequently used approaches in the research into the effect of ageing on sentence processing, self-paced reading (SPR) tasks require participants to read sentences word by word by pressing a specific button. Participants indicate with a press of the button that they have finished reading the word on the screen and then the next word appear, replacing the previous one. The participants repeat this procedure until all words of the sentence are presented, at which point they are required to answer a comprehension question related to the meaning of the sentences they have just read. Reading times (RTs) are recorded and used to measure the processing difficulties for each sentence segment and responses to the sentence-final questions are used to measure the accuracy of sentence comprehension. SPR tasks differ significantly from natural reading because only one word is allowed to be displayed at a time and regressive eye movements are not possible[12]. The unnatural aspect of SPR tasks has the advantage of reducing the number of strategies used by participants and thus the interference of processing strategies on participants' performance can be minimized. Therefore, SPR tasks are helpful for researchers to identify the processing difficulties related to processing every word in the sentences. The major problem with SPR tasks is that they cannot ensure accurate measurement of RTs as participants may delay button-pushing to memorize the sentences or speed up button-pushing to buffer each region for later construction in the sentences[12].

Apart from SPR tasks, eye-tracking has also been frequently used in studies on sentence processing[13-15]. In eye-tracking experiments, full sentences are presented to participants and they are asked to read them naturally. The duration and location of eye fixations and regressions are recorded. The advantage of eye-tracking is that it allows for natural reading and puts little constraints on how participants read sentences[12]. However, the naturalness of eye-tracking also makes it difficult for researchers to assess the exact processing costs because participants might adopt a wide variety of reading strategies such as skimming or word-by-word reading[12]. Therefore, we are not clear whether the fixation location and duration reflect processing difficulties or the application of certain reading strategies.

In this study, we adopted a maze task[16,17], which can solve these problems with SPR tasks, eyetracking and cross-modal priming tasks. A maze task is a more updated reading paradigm and an adaptation of self-paced reading tasks. The task is an approach adopted in psycholinguistic experiments to record RTs as participants read sentences word by word. In the tasks, participants are required to read a sentence by making a choice between two alternatives for each segment of the sentence[16]. The procedure of a maze task is demonstrated in **Figure 1**.

[Place **Figure 1** here]

If the first word of the sentence is *the*, which is followed by the pair *cat* and *on*, the participants are expected to choose *cat* by pressing a button to indicate that the word on the left is the grammatical continuation of the sentence. When the next pair of words (*to* and *ate*) is presented, the participants are expected to choose *ate* because it can serve as the verb of the sentence. This procedure is repeated until they arrive at the end of the sentence. In case they make a mistake, the current trial will be terminated, and the next trial starts. An online demonstration of the maze task provided by Kenneth Forster can be found at http://www.u.arizona.edu/~kforster/MAZE.

The maze task is a highly constrained experimental paradigm in which participants are not permitted to look ahead or back to the previous section of the sentence[18,19]. Each word must be integrated with the existing structure before participants can proceed to read the following word. This method requires participants to process the sentences very carefully and accurately and it reduces the processing strategies available to participants. It allows us to make an objective measurement of RTs in online sentence comprehension. Moreover, the maze task is more sensitive to the processing costs associated with integrating words into sentences[12,16], as it places unusual constraints on the processing strategies available to the participants. In this sense, the maze task is particularly suitable for the studies of sentence processing by older adults. Due to their richer language experience, older adults tend to adopt various compensation strategies such as prediction to make their performance comparable with younger adults[4]. These strategies make the age differences in sentence processing less noticeable. In a maze task, if participants make a response prematurely, they will be forced to respond randomly at the next frame and thus, they are most likely to make an error. Therefore, the task does not allow participants to make predictions and the effect measured by the task is unanticipated in nature. By reducing the number of sentence processing strategies available to older adults[12,16], the maze task allows for more objective assessment of the processing difficulties of older adults during sentence reading.

The maze task was utilized in our study to pinpoint the processing difficulties for older adults in sentence comprehension and to localize the effect of ageing. As older adults generally have slower speed of processing and longer reading times than younger adults, most previous studies evaluated the effect of ageing by measuring the extent to which the effect of syntactic complexity or processing cost is modulated by age, a common practice in the research into the effect of ageing on sentence processing. Most studies chose to use object relative clauses (ORCs) and subject relative clauses (SRCs) as the experimental stimuli as they represent syntactically more complex structures and less complex structures, as exemplified below. Therefore, in this study, we also examined the effect of ageing by evaluating the influence of age on the processing difference between SRCs and ORCs.

a. Subject relative clause, SRC: The girl who chased the boy was wearing a hat.
b. Object relative clause, ORC: The girl whom the boy chased was wearing a hat.

According to Gibson’s Dependency Locality Theory[6,7], sentence (b) is more difficult to process than sentence (a) as there are higher storage costs and integration costs involved in (b) to assign patient role to the head noun *girl*. By comparing participants’ performance in processing SRCs and ORCs, we are able to find out how they process sentences with different cognitive burdens. However, previous studies are divided with regard to their interpretation of the effect of syntactic complexity. Some studies maintained that if the effect of sentence complexity is exacerbated in older adults, it suggests that older adults are more sensitive to processing costs than younger adults[3,20]. Therefore, the amplified effect of sentence complexity is regarded as the evidence for age-related decline in sentence processing. Other studies, however, proposed that an effect of sentence complexity indicated that older adults are capable of allocating cognitive recourses to sentence processing and thus it should be viewed as a sign for the preservation of sentence processing ability in older adults[21]. The two lines of research are divergent in their interpretation of the effect of sentence complexity mainly because the experimental methods used in these studies such as SPR or cross-modal priming cannot tell us whether older adults actually use their working memory resources to integrate the words into the previous sections of the sentence or they cannot integrate the words due to the lack of working memory recourses. The maze task can provide a perfect solution to this problem because participants are forced to integrate the words into the previous structures in this task. Therefore, it is safe to say that the RTs obtained from the maze task represent the actual processing costs or processing difficulty in sentence processing. The maze task provides an effective means to explore sentence processing by older adults. Qiao, Shen and Forster (2002) used the maze task to examine the processing of Mandarin RCs and discovered that this technique was highly sensitive to sentence complexity effect in the processing of Mandarin subject- and object-extracted RCs[19]. The study indicates that the maze task is applicable to the research which is intended to localize the experimental effect in Mandarin sentence processing or lexical processing.

PROTOCOL:

The experiment was approved by the Ethics Committee of Beijing Foreign Studies University and it complied with the guideline for experiments with human subjects. All participants in the experiment provided written informed consent.

1. Stimuli construction

1.1. Construct experimental stimuli on the basis of the specific experimental questions. This protocol is intended to explore the effect of ageing on online sentence processing during reading, and as such, the visual stimuli used in the experiment are two types of RCs, namely SRCs and ORCs, which are the structures most frequently used in the studies of sentence processing by older adults.

1.2. Prepare at least 24 experimental sentences with twelve sentences in each condition and at least 24 fillers that are of various length and structures. The number of fillers can be increased to up to three times of the experimental sentences. The experimental sentences should be counterbalanced across the two conditions.

NOTE: As our study focused on the processing of Mandarin sentences, all the sentences used in the experiment were in Mandarin Chinese. However, the protocol reported here may be also applicable to other languages.

1.3. Plausibility rating: Invite at least 30 participants to rate the semantic plausibility of the experimental sentences using a five-point Likert scale with scores from ‘‘1’’ (the least plausible) to ‘‘5’’ (the most plausible). Make sure the group is similar to the participants in age, gender ratio and education. Make sure they do not take part in the subsequent experiment. Ensure the sentences used in the study are all semantically plausible (> 3) and semantic plausibility does not differ significantly between different experimental conditions.

NOTE: In our study, 15 older adults and 15 younger adults were invited to participate in the plausibility rating (M_{age} = 43.6, SD = 24.1; Female 16, Male 14).

1.4. For each word in the experimental sentences, provide an ungrammatical alternative. In this way, prepare a pair of words for each segment of the sentences, with one of them being the grammatical continuation of the sentence and the other is not. Match the two alternatives in lexical frequency. Participants are expected to choose between the grammatically correct word and the grammatically incorrect one (See **Figure 1** for sample sentences in English). An experimental sentence used in this study is shown in **Figure 2**.

[Place **Figure 2** here]

1.5. Randomization and design. Randomize the sentences and the positions of the two alternatives in the sentences before presenting them to participants. Find the **Selection** tab of the Property Page in the stimulus presentation software (see **Table of Materials**) and set the selection method to **Random**.

1.5.1. Divide the experiment into blocks with each lasting for no more than 10 min.

NOTE: In the study, the experiment consisted of two blocks with 24 sentences in each block. Each block lasted for about 5 min.

1.6. Allow participants to have a break between two blocks. Breaks for about 5 min can be helpful for younger adults. Allow longer breaks for older adults to ensure they can recover from fatigue.

2. Participant screening and preparation for the experiment

2.1. Recruit participants who are native speakers of the language tested. Ensure participants have normal or corrected-to-normal vision. Invite at least 30 younger adults and 30 older adults. Match the two age groups in years of education and gender ratio.

2.2. Ask participants whether they have had neurological, psychiatric or communication disorders before. Exclude the ones who report any history of these diseases.

2.3. To ensure older participants recruited are cognitively healthy, have them complete the Global Deterioration Scale[22] before the experiment as a way of screening. Exclude the participants who score above level two.

2.4. Inform the participants that they should be free from exhaustion, hunger, illness or other conditions that make them uncomfortable on the day of the experiment.

2.5. Invite the participants individually or in groups to the laboratory room.

3. Procedure

3.1. Take participants to the laboratory room and instruct them to sit down at the computer workplace.

3.2. Ask the participants to read and sign the written informed consent forms. Exclude the participants who cannot provide informed consent for any reason.

3.3. Provide verbal instructions to the participants to ensure they are clear about the requirements of the task. Ask participants to choose between the two words or phrases on the computer screen to form a grammatical continuation of the sentences. Inform them that their responses will be timed, so they are expected to respond as quickly and as accurately as possible.

3.4. Provide the written instruction to the participants and ask them to read it carefully. Answer any questions participants may have about the instructions. Present the following message on paper or on computer screen in participants' native language:
"In this experiment, you will read a number of Chinese sentences. However, the sentences will be presented one word at a time. On each screen, two words will be presented and you need to choose the word which can grammatically continue the sentence as quickly as possible. If you choose the word on your left hand side, please press the **F** button on the keyboard and if you choose the word on the right, please press **J**. Please respond as quickly as possible. If you fail to respond in ten seconds, the next trial begins. If you have no further questions, press any key to start practice."

3.5. Ask the participants to complete a small number of practice questions to ensure they understand how to perform the task. Provide participants with feedbacks after they have made their choices regarding which of the two phrases is the grammatically continuation of the sentence. To minimize the disturbance to the natural reading process, only provide feedback when incorrect answers are detected. The feedback is short phrases ("incorrect") in the participants' native language, which are visually presented on the computer screen.

3.6. When participants complete the practice questions, ask them to make a choice as to whether they would like to redo the practice. If they press the button p on the keyboard, the practice session starts all over again and if they press the space bar, the practice session is over and the experimental session begins. Allow them to redo the practice as many times as possible until they are familiar with the procedures of the task. Provide them assistance whenever they encounter any difficulties during the practice session.

3.7. Allow the participants to perform the required experimental task when they are clear about the experimental procedures.

3.8. Present the items on the computer screen as black letters on a white background.

3.9. Have participants read the items and for each segment, choose between the two words placed side by side on the screen with a press of the button on the keyboard (**F** button for the word on the left and **J** button for the word on the right).

3.10. If participants choose the correct answer, present the next pair of words. When they choose a wrong answer, have the sentence terminate and have the next one appear.

3.11. Administer the digital span task from the Wechsler Memory Scale[23] to assess participants' working memory span. Test participants individually.

3.12. Ask participants to listen to a sequence of digits (1-9) that are presented auditorily at the rate of one digit per second.

3.13. Ask participants to repeat the digit sequence in the same order.

3.14. Start from short strings and increase the string length one digit at a time. Stop the test when participants make errors at two trials at a given length.

3.15. Record participants' responses on the record form. Use a digital recording device to record participants' responses.

3.16. Ask participants to complete the questionnaires about their background information, such as age, gender and years of education. Prepare participants' payment during the questionnaire.

3.17. Provide participants monetary compensation for their participation.

NOTE: In our experiment, each participant was paid 20 RMB (about USD$3) for their participation. The amount of payment may vary in different experiments. Other approaches can also be used to motivate participants such as rewards.

4. Data analysis

4.1. Obtain the RTs (ms) for each word in the sentences from the output files of the presentation software.

4.2. Exclude the RTs for the trials that are responded incorrectly from data analysis. In order to reduce the influence of outliners on the results, exclude the RTs above three standard deviations from the means for each participant in each condition.

4.3. Analyze the RTs for the regions of interest in the sentences, using repeated measures ANOVA with RTs as the dependent variable and age group (old, young), type of sentence (SRC, ORC) and region (1-6) as independent variables.

REPRESENTATIVE RESULTS:

This study is intended to examine the effect of ageing on online sentence processing using a maze task. The RTs for each segment in the sentences are used to indicate the processing difficulty. In this study, we explored how a group of older adults (M_{age}= 65.2, SD = 3.04, Range = 59 -74) and younger adults (M_{age}= 19.1, SD = 1.04, Range =18-23) differentially processed Mandarin SRCs and ORCs. The two age groups were matched in education (M_{old} = 12.8, SD = 3.21; M_{young} = 13.2, SD = 0.75; p = .620) and gender ratio (Old: 14 female; Young: 15 female; χ^2 = .067, p = .796). Specifically, the study aimed to explore the overall differences between younger and older adults in processing Mandarin SRCs and ORCs as well as the exact locations of such differences. It was hypothesized that due to the decline in working memory, older adults are more sensitive than younger adults to the experimental manipulation of syntactic complexity and the processing costs associated with integrating words into the previous sentential segments. Therefore, a stronger effect of syntactic complexity or sentence type may be found in older adults than in younger adults at the regions which require more processing resources such as RC head nouns.

The regions of interest in the experimental sentences include the RC noun (*zuojia* ‘writer’), the RC verb (*aimu* ‘love’), the RC marker (*de*), the head noun (*yanyuan* ‘actor’) and main clause verb (*xihuan* ‘like’). The mean RTs for each region are presented in **Table 1** and graphically summarized in **Figure 3**.

[Place **Table 1** here]

[Place **Figure 3** here]

Analysis was made to examine the effect of randomization order on the participants’ performance and found that the effect of randomization was not significant. ANOVA was performed with group (old, young), type (SRC, ORC) and region (1-6) as predictors and RTs as the dependent variable. Group is the between-subjects variable. Type and region are the within-subjects variables. The results revealed a significant main effect of group (F_1 (1, 58) = 171.25, p < 0.001, η^2_p = 0.71, F_2 (1, 23) = 273.13, p < 0.001, η^2_p = 0.52), a significant main effect of type (F_1 (1, 58) = 14.9, p < 0.001, η^2_p = 0.10, F_2 (1, 23) = 12.78, p < 0.001, η^2_p = 0.03), a significant interaction between group and region (F_1 (1, 58) = 100.15, p < .001, η^2_p = .64, F_2 (1, 23) = 118.12, p < .001, η^2_p = .44), and a significant interaction between type and region (F_1 (1, 58) =18.43, p < 0.001, η^2_p = 0.11, F_2 (1, 23) = 28.43, p < 0.001, η^2_p = 0.02). The three-way interaction between group, type and region was significant (F_1 (1, 58) = 5.13, p < 0.05, η^2_p = 0.05, F_2 (1, 23) = 2.71, p < 0.05, η^2_p = 0.01).

To facilitate the interpretation of these results, we analyzed the data for each word using 2 (sentence type) x 2 (group) mixed ANOVAs by items and participants. In the SRC verb (*aimu* ‘love’)/ORC noun (*zuojia* ‘writer’), there was a significant main effect of group (F_1 (1, 58) = 122.93, p < 0.001, η^2_p = 0.10, F_2 (1, 23) = 337.06, p < 0.001, η^2_p = 0.53), a significant main effect of RC type

(F_1 (1, 58) = 34.82, $p < 0.001$, $\eta^2_p = 0.03$, F_2 (1, 23) = 49.98, $p < 0.001$, $\eta^2_p = 0.07$). Older adults have longer RTs than younger adults and the RTs for SRCs are longer than those for ORCs.

In the SRC noun (*zuojia* 'writer')/ORC verb (*aimu* 'love'), there was a significant main effect of group (F_1 (1, 58) = 174.98, $p < 0.001$, $\eta^2_p = 0.15$, F_2 (1, 23) = 377.25, $p < 0.001$, $\eta^2_p = 0.43$). The effect of sentence type was significant by items (F_2 (1, 23) = 43.98, $p < 0.01$, $\eta^2_p = 0.02$). Older adults read this segment significantly more slowly than younger adults. No other significant interaction effect was found.

In the RC marker *de*, there was a significant main effect of group (F_1 (1, 58) = 177.66, $p < 0.001$, $\eta^2_p = 0.15$, F_2 (1, 23) = 489.25, $p < 0.001$, $\eta^2_p = 0.45$). Younger adults read the RC marker faster than older adults.

At the head nouns (*yanyuan* 'actor'), there was a main significant effect of group (F_1 (1, 58) = 371.07, $p < 0.001$, $\eta^2_p = 0.32$, F_2 (1, 23) = 53.21, $p < 0.001$, $\eta^2_p = 0.04$), a significant main effect of RC type (F_1 (1, 58) = 13.28, $p < 0.001$, $\eta^2_p = 0.02$, F_2(1, 23) = 346.30, $p < 0.001$, $\eta^2_p = 0.34$), and a significant interaction effect between group and RC type (F_1 (1, 58) = 5.14, $p < 0.05$, $\eta^2_p = 0.01$, F_2 (1, 23) = 4.25, $p < 0.05$, $\eta^2_p = 0\ .01$). Pair-wise comparison shows that for older adults, the SRCs were more difficult to process than ORCs; for younger adults, however, there was no significant difference between SRCs and ORCs. This finding suggests that older adults were more sensitive to the experimental manipulation of sentence complexity or processing costs and they had greater difficulties than younger adults in processing syntactically more complex SRCs.

At the main verb (*xihuan* 'like'), a significant main effect of group was found (F_1 (1, 58) = 174.99, $p < 0.001$, $\eta^2_p = 0.15$, F_2(1, 23) = 124.02, $p < 0.001$, $\eta^2_p = 0.12$). Younger adults performed faster than older adults.

To further explore whether the observed effect at head nouns was relevant to working memory, we performed a correlation analysis between working memory span and RT differences between SRCs and ORCs. The results revealed a significant negative relation (r = -0.41, $p < 0.05$), which suggests that participants with higher working memory span were less affected by syntactic complexity. As younger adults (M =16.40, SD = 2.78) had larger working memory span than older adults (M = 12.17, SD = 2), they tended to be less affected by the manipulation of syntactic complexity.

FIGURE AND TABLE LEGENDS:

Figure 1. A sample display of the sequential frames in a maze sentence. The figure shows that there are two alternative words in each frame, only one of which can continue the sentence.

Figure 2. Example of two experimental sentences. This figure shows that participants were presented two Chinese words in each frame and were required to choose the one which can grammatically continue the sentence. The words on the frame are pin-yin with the English equivalents provided in parentheses.

Figure 3. Mean reading times (RTs) by group and region. The figure displays the average reading times for older adults and younger adults for each region in the sentence. The error bars represent the standard deviation of the data.

Table 1. Mean reading times by group and word. The table presents the mean reading times and the standard deviations for each age group in each region.

DISCUSSION:

In this study, a maze task was used to find the exact location for the effect of ageing on sentence processing. The study examined how older adults and younger adults differentially processed Chinese SRCs and ORCs. In the task, participants were instructed to read a sentence by choosing between two alternatives, only one of which was the grammatical continuation of the sentence. They were required to make the choice as quickly and as accurately as possible. If participants chose the correct alternatives in the sequence, the selected words constituted a grammatical sentence. If they chose the wrong alternative, the current trial was terminated and the next trial began. The results suggest that the age-related difference was found only in the head nouns (*yanyuan*, 'actor') of the sentences. It was at the head nouns that the older adults encountered greater difficulties than younger adults in sentence processing. This might be because the head nouns are the areas where the parser starts to establish connections between the gap and the filler and integrate them to complete the assignment of semantic roles. According to the DLT, the processing costs of RCs are determined by the distance between the filler and the gap to which it is attached. In Chinese SRCs, the distance between the head noun and the gap is longer than that in ORCs, so it takes more processing resources to associate the head noun with the gap. Due to the working memory decline in older adults, the increased processing costs at the head nouns in SRCs make it difficult for them to process efficiently. In contrast, younger adults had sufficient working memory resources to process the sentence even if the processing costs increased at the head nouns. Therefore, they tended to be less disrupted by the increase in processing costs at head nouns than older adults. The finding indicates that older adults are more disrupted than younger adults by the increased processing costs during sentence reading. The findings support the DLT. It should be noted that as Chinese RCs are different from postnominal RCs in that they are prenominal, the finding that there was greater processing difference between SRCs and ORCs in older adults cannot be generalized to the languages with postnominal RCs such as English because the processing costs at the head nouns do not differ between SRCs and ORCs in postnominal structures. According to the DLT[6,7], it is at the RC verbs that the processing difference between English SRCs and ORCs is maximal. However, as most previous studies on the processing of postnominal RCs by older adults used SPR tasks, they are not very helpful to reveal the exact location of the processing difficulty. Therefore, further investigation is needed to explore where the processing difficulties are located during the processing of postnominal RCs.

These findings show that the protocol is successful in identifying the exact location of the ageing effect on sentence processing. Compared with SPR tasks or cross-modal priming tasks, the maze task allows for a more fine-grained analysis of the ageing effect on sentence processing as this approach is more sensitive to the differences in processing costs or difficulties in different types of sentences. By requiring the participants to choose the word that can grammatically continue the sentence between two alternative words, the task forces them to integrate the words with the existing structure before proceeding to the next segment. Unlike SPR or cross-modal priming tasks that allow older adults to adopt various processing strategies, which might be potentially disrupting for the identification of their processing difficulties, the maze task reduces the availability of processing strategies and thus contributes to a more objective assessment of processing difficulties. Therefore, the reading times measured by the maze task can accurately reflect the processing difficulties encountered by older adults. The maze task has been applied in prior studies on the processing of both postnominal RCs[12,16] and prenominal RCs[19] and was found to be applicable in both situations. Therefore, the protocol offers an effective means to investigate the effects of ageing on sentence comprehension in languages with prenominal RCs as well as those with postnominal RCs.

The major limitation with this method is that it is highly unnatural, so it is not applicable to mimic the natural process of reading. For the studies that intend to find out how older adults read texts naturally, eye-tracking might be a better choice. However, the maze task is a suitable approach to investigate sentence processing under the highly constrained experimental conditions[18].

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DISCLOSURES:

The authors declare that they have no competing interests.

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Figure 1

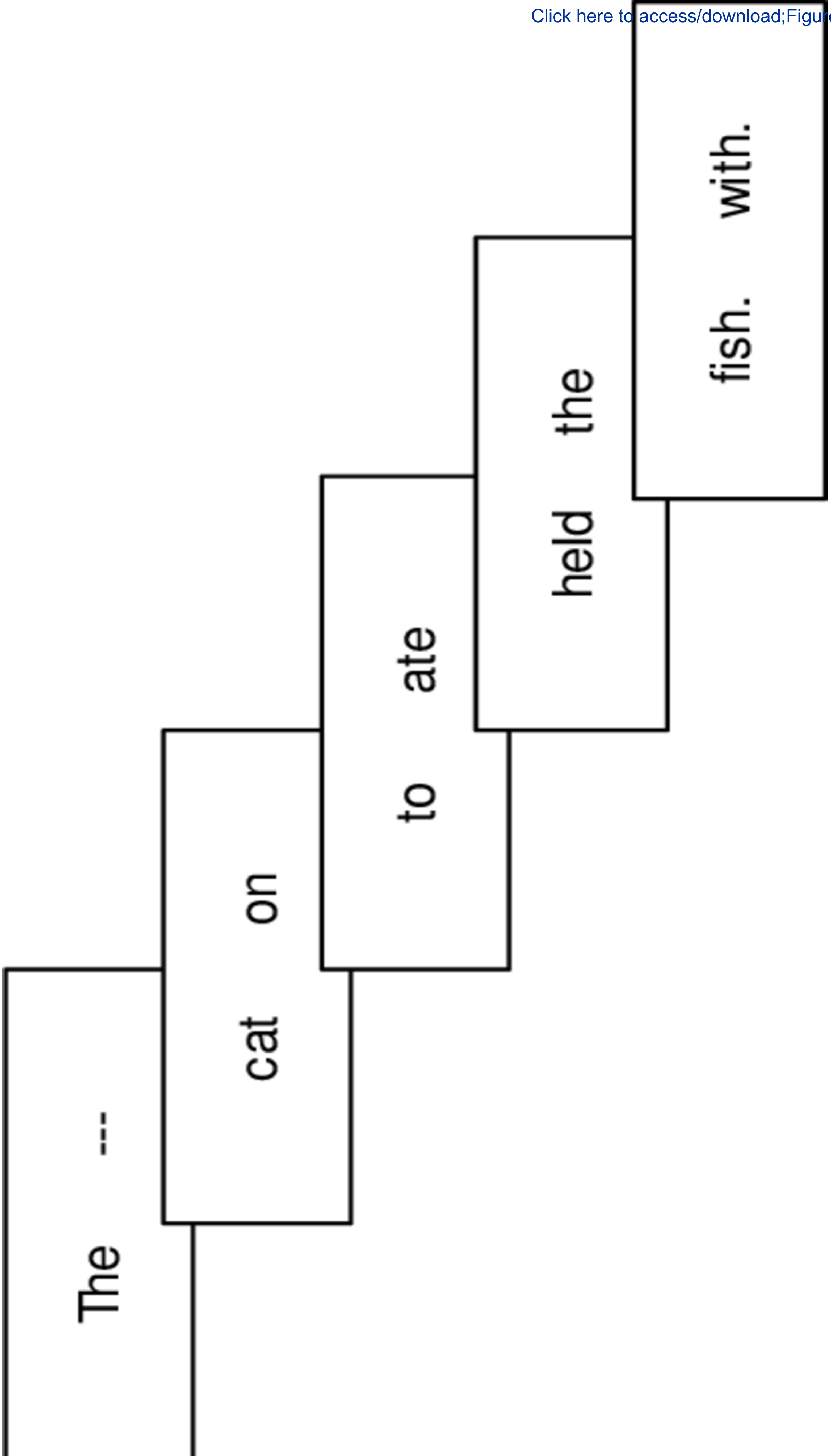

Figure 2

‘The actor whom the writer waited for obviously likes singing.’ (ORC)

‘The actor whom the writer waited for obviously likes singing.’ (SRC)

Figure 3

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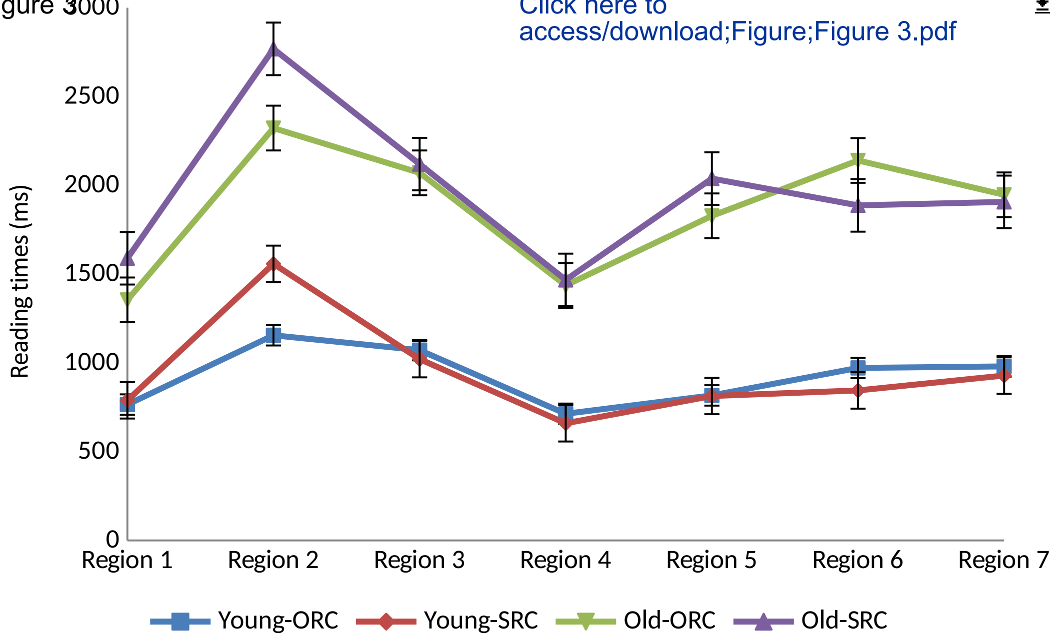

Table 1 Click here to access/download;Table;Table 1.xlsx

Group	Type	Region 1		Region 2		Region 3		Region 4		Region 5	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Old	SRC	1589	1044	2768	1197	2119	961	1467	826	2038	1282
	ORC	1354	834	2322	941	2070	870	1436	694	1828	878
Young	SRC	789	434	1558	677	1020	437	659	223	812	341
	ORC	765	519	1155	494	1071	388	713	245	816	333

Region 6		Region 7	
Mean	SD	Mean	SD
2035	1123	1986	982
2078	1024	1937	938
848	331	928	428
972	464	972	465

Name of Material/Equipment	Company	Catalog Number	Comments/Description
Computers	N/A	N/A	Used to present stimuli and record subjects' responses.
E-prime	PST	2.0.8.22	Stimulus presentation software
The Digital Working Memory Span Test	N/A	N/A	Used to assess subjects' working memory span. From W
The Global Deterioration Scale (GDS)	N/A	N/A	Used to assess subjects' general cognitive status. From

/echsler (1987).

Reisberg, Ferris, de Leon and Crook (1988)

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Dear Editor and Reviewers,

Thank you for giving us the chance to revise the paper. We have revised the paper in response to the extensive and insightful editorial and reviewer comments. The problems pointed out by the editor and reviewers have all been addressed. Below, we would like to outline our responses to these comments.

Editorial comments

General:

1. Please take this opportunity to thoroughly proofread the manuscript to ensure that there are no spelling or grammar issues.

Authors' response: we have proofread the manuscript carefully and thoroughly. The spelling and grammar errors have been corrected.

2. Please ensure that the manuscript is formatted according to JoVE guidelines–letter (8.5" x 11") page size, 1-inch margins, 12 pt Calibri font throughout, all text aligned to the left margin, single spacing within paragraphs, and spaces between all paragraphs and protocol steps/substeps.

Authors' response: We have revised the format of the manuscript to make it conform to the journal guidelines.

3. Please avoid the use of personal pronouns (you, your).

Authors' response: Thank you. Personal pronouns were not used in the manuscript except in the experimental instructions presented to the participants. In the protocol, when the experimenters provide instructions and guidance to the participants, they use "you" to address the participants. In other words, the pronoun "you" is not intended to address the readers of this paper. It was quoted directly from the instructions provided to the participants in our experiment.

4. For in-text formatting, corresponding reference numbers should appear as numbered superscripts after the appropriate statement(s). Please number references by the order they appear in the manuscript.

Authors' response: We have revised the format of the references according to the above requirements.

Protocol:

1. The amount of protocol highlighted is rather short; please expand the highlighting to at least 1 page and/or expand the amount of detail given in the highlighted section.

Authors' response: We have expanded the highlighting and the amount of details in the highlighted section. The revised highlighted section provides a more detailed description of the protocol.

2. Please add more details to your protocol steps. Please ensure you answer the "how" question, i.e., how is the step performed? Alternatively, add references to published material specifying how to perform the protocol action. If revisions cause a step to have more than 2-3 actions and 4 sentences per step, please split into separate steps or substeps.

Authors' response: Thank you. We have provided more details to describe the protocol steps. We explained how the steps are performed. The steps with multiple actions or sentences were split into sub-steps.

Specific Protocol steps:

1. 1.1: Around how many sentences should be prepared?

Authors' response: At least twelve sentences in each condition should be prepared. We have added a substep in the protocol to specify the number of sentences which should be included in the experiment (line 230-233).

2. 1.2: How many people should evaluate plausibility? Can these be any group of people or should they be similar to the subjects?

Authors' response: The group should include at least thirty people and they need to be similar the subjects in age and education. We have clarified this in the revised manuscript (line 239-242).

3. 2.1: Are all of these specific details of your experiment? This should be written as such, then, and perhaps be a Note or in the Introduction/Results. Also, how many subjects are recommended?

Authors' response: Some of the details are specific for our experiment. We have revised the description and included specific details in the Results section or Notes. We recommend at least thirty subjects in each age group. This has been added to the manuscript (line 278-280).

4. 2.2: Please provide a citation for the GDS.

Authors' response: The following citation has been added for the GDS.
Reisberg, B., Ferris, S. H., de Leon, M. J., Crook, T. The Global Deterioration Scale for assessment of primary degenerative dementia. *The American Journal of Psychiatry*. **139**, (1982).

5. 3: Can you provide the specific code you used here as supplementary material?

Authors' response: Yes. The code has been uploaded as supplementary materials.

Figures:

1. Figure 3: Please label the y-axis.

Authors' response: We labeled the y-axis.

Discussion:

1. Please include critical steps in the procedure as well as any modification and/or troubleshooting steps in the Discussion.

Authors' response: We added the critical steps in the Discussion section (line 485-490).

References:

1. Please ensure references have a consistent format.

Authors' response: We have revised the format of references to make sure it is consistent.

Table of Materials:

Please ensure the Table of Materials has information on all materials and equipment used, especially those mentioned in the Protocol.

Authors' response: Thank you. We have added more information to ensure the Table of Materials include a complete list of all materials and equipment used in our study.

<u>Reviewers' comments:</u>

Reviewer #1:

Manuscript Summary:

This study tests at what point difficulty of processing sentences with relative clauses occur for older adults using a G-maze task. The results show that older adults had a harder time processing sentences with subject-extracted relative clauses relative to object-extracted relative clauses at the head noun even though this difference was not apparent in younger adults. The experiment seemed to be set up well and the results were clearcut, however, with revisions, I believe that the manuscript can become more interesting.

Authors' response: Thank you for your appreciation of our work. We have followed the reviewer's suggestions to improve the manuscript.

Major Concerns:

My main concern is that this manuscript did not clearly explain why it is necessary to discover exactly where the processing differences between older and younger adults occurs. The manuscript did discuss how there are inconsistencies as to when/where the differences between older and younger adults occur, but was not clear as to why finding this out would be important. Although I understand that JoVE is mainly a methods journal, it is still important to know the theoretical reasons as to why it is important to test out whether a method can be applied to a new research question.

Authors' response: Thank you for the comments. We added a paragraph (line73-86) in the Introduction to discuss the theoretical implications for exploring the location of the processing differences between older and younger adults.

> *My second concern applies to prenominal and postnominal relative clauses. There have been numerous studies showing that whether it is subject- or object-extracted relative clauses that is more difficult to process might depend on whether the relative clause occur before the head noun or after (see e.g., Staub, 2010; Carreiras et al., 2010). My understanding is that Chinese has prenominal relative clauses, so a discussion on how applicable the method and the finding of this study are to languages with postnominal relative clauses would be interesting.*

Authors' response: Thank you. We agree that the processing difficulty of relative clauses (RCs) is closely related to whether the RCs occur before the head nouns or after. Chinese RCs are different from postnominal RCs (e.g. English RCs) in that they are pronominal. Therefore, the findings that processing differences occur at head nouns are not applicable to postnominal RCs because head nouns are the first region in postnominal structures and are not influenced by the structural difference between SRCs and ORCs. The method used in our study has been applied in prior studies on the processing of both postnominal RCs (e.g. Forster, Guerrera & Elliot, 2009, Witzel, Witzel & Forster, 2012) and pronominal RCs (Qiao, Shen & Forster, 2012) and was found to be applicable in both situations. In the revised manuscript, we added more discussion on how applicable the method and findings are to postnominal RCs.

> *My third main concern is that the study only tells us that it was at the head noun that the older adults showed different pattern of results from the younger adults. Why did older adults find subject-extracted relative clause more difficult than object ones at the head noun? Why did younger adults show no difference between these two relative clause at this region? Some kind of discussion is necessary.*

Authors' response: We agree that it is necessary to explain the major findings of this research. We have added more information in the Discussion section to account for the findings regarding the age difference in the location of processing difference between subject-extracted relative clauses and object-extracted relative clauses.

> *Something that would be helpful is a review of relative clause processing using eye tracking. Although there was a discussion of how maze tasks might be more advantageous than moving-window tasks (both are considered as self-paced reading tasks), there was not mention of studies using eye tracking. Indeed, Staub (2010) found very similar findings to Forster et al. (2009)*

Authors' response: Thank you. We agree that eye tracking needs to be included in our discussion. It is indeed is a very important method for the studies on sentence processing. We have reviewed the previous studies of relative clause processing using eye tracking, discussed the advantages and disadvantages of this method and also compared it with maze tasks.

The Section 3 Procedure section mentions that a digital span task was administered. This is a working memory span task. Throughout the manuscript, there was no other mention as to why this task was administered or how it was analyzed.

Authors' response: Thank you. The test was administered to explore the relationship between working memory span and the observed processing difference between SRCs and ORCs. As working memory decline is the most prominent cognitive change in old age, many of the age-related changes in sentence processing are attributed to working memory decline. The primary purpose of this analysis is to explore whether the ageing effect was relevant to working memory decline. We have clarified the purpose of this task and presented the results of the analysis at the Results section in the revised manuscript.

Lastly, the results section is labelled as "Representative Results." Please clarify what this means. Did you not analyze all the datasets? What does it mean by "representative"?

Authors' response: We have followed the Author Guidelines to provide a concisely written description of a representative outcome following the use of this protocol. As JoVE is a methodology-oriented journal, the focus of the Results section was on whether the data can confirm the effectiveness of the protocol. We have analyzed all the datasets, but only elaborated on the findings regarding whether the protocol is effective. The irrelevant details were not emphasized in the Results section.

Minor Concerns:

1. To make it clear throughout the manuscript, please make sure to clearly state that this study tested processing differences between subject- and object-extracted relative clauses. This includes the abstract as well.

Authors' response: We followed the reviewer's suggestion to clarify that this study tested the differences between SRCs and ORCs in abstract, Introduction, Results section and Discussion section.

DeDe (2015) was cited as a study using self-paced reading. In fact, this study employed self-paced listening. I have not checked the other studies (He et al., 2017 and Liu et al., 2019), but it might be helpful to double-check whether other studies indeed used a reading task and not a listening task.

Authors' response: Thank you. We agree that DeDe (2015)'s study was cited incorrectly and we have corrected the inaccurate description of this study. We also double-checked the other studies mentioned in the paper and confirmed that they used reading tasks, not listening tasks.

3. In some parts of the manuscript, the word "subjects" were used instead of "participants." Most of the time, I don't find this a problem, but since this study discusses subject relative clauses, it might be helpful to use "participants" when you are referring to participants.

Authors' response: Thank you. We agree and have replaced "subjects" with "participants" in order to avoid confusion.

4. Example sentences of the actual items with translations and transliterations would be helpful in the Stimuli section.

Authors' response: We have provided the actual Mandarin sentences used in the experiment, transliteration and their English translation (see Figure 2 for the revised example sentences).

5. Basic information as to how many items there were in each condition, whether the items were counterbalanced, number of participants in each speaker group were missing in the Methods section.

Authors' response: Thank you. We have added the required information including the number of items in each condition, whether items were counterbalanced and the number of participants in the Methods section.

6. In the Methods section, it sounded like the study has not been conducted yet. Has it? If so, some use of past tense would help.

Authors' response: The study has been conducted. The JoVE Author Guidelines require the use of imperative voice throughout the protocol, so most sentences in the protocol were in imperative voice. We did not use past tense because the Methods Section is not intended to describe any specific experiment. Rather the primary purpose of the Methods section is to introduce a protocol which can be potentially useful and applicable in other studies.

7. In Step 3 Procedure section, a portion of it was highlighted. It was not clear why.

Authors' response: We have followed the instructions in Author Guidelines to highlight the steps which will be used for filming.

8. In psycholinguistic studies, it is customary to report both participant analyses (F1) and item analyses (F2). Only one F ratio was reported for each analyses, and because the number of items or the number of participants were not reported, it was not possible to figure out which analyses were reported in the manuscript (based on degrees of freedom). Please make sure to report both analyses.

Authors' response: Thank you. We agree and have reported both F1 and F2 in the revised manuscript.

9. In addition, please report what type of ANOVA was conducted.

Authors' response: Thank you. We have reported that.

Reviewer #2:

Manuscript Summary:

I liked the use of Ken Forster's work to examine the working memory decrement that happens in most adults. It was clear from the graph that there is a difference in processing speed between older and younger adults.

Authors' response: Thank you very much for your appreciation of our work.

Major Concerns:

I helped Forster with the original study, so I was very glad to have the opportunity to comment on your project. I am not sure why the authors chose to omit data that was more than 3 standard deviations outside the mean. Also, I did not see the omnibus (overall) ANOVA discussed, only the specific noun ANOVAs. Forster took great care to establish the maze task as a viable measure of processing speed in American English. He was uncertain if the task would work in other languages. This paper needs to cite an article that establishes that the maze task works in Mandarin or that a forced choice paradigm works in Mandarin syntactic decision tasks as in American English syntactic decision tasks.

Authors' response: Thank you very much for the constructive comments and feedbacks. We followed the practice of previous studies (e.g. DeDe et al., 2004) to consider the RTs over 3SDs outside the means as outliners and removed them from subsequent analysis. We followed the reviewer's suggestion to perform the omnibus AVONA and the results have been reported in the Results section. Moreover, we cited Qiao, Shen & Forster (2002)'s paper to establish that the maze task works well in Mandarin. Qiao, Shen & Forster (2002) used the maze task to examine the processing of Mandarin relative clauses and discovered that the task can effectively solve the long-standing issue regarding the processing difficulty between Mandarin subject- and object-extracted relative clauses.

This work would have been better if a third group was included: young adults with low working memory.

Authors' response: Thank you for the comments. As the primary purpose of this study was to explore the effect of ageing on sentence processing, we were more interested in how old adults performed differently from young adults in sentence comprehension. As ageing is typically accompanied by working memory decline, in this study, we consider working memory decline as a part of ageing process and did not differentiate the two processes. In fact, working memory was mainly used to reflect the general cognitive status of the both groups of subjects in our study. However, we agree that including a group of young adults with low working memory may help us to differentiate the effect of age with the effect of working memory and this can be useful for us to further understand the reasons for the effects we have observed. Therefore, we consider this as an important issue for future exploration.

Please make it clear in the results that you are testing two things- the overall difference *between the groups and where the differences occur.*

Authors' response: Thank you for the suggestion. We have followed the reviewer's suggestion to revise the Results section to clarify the two key points we intended to test. The research hypotheses and data analysis were also adjusted to correspond to the two points.

Line 271- the overall ANOVA between young/old SRC/ORC needs to be included even if it was not significant. Then, the explanation needs to include the effect size even if it is not significant so that future researchers can calculate the number of participants needed for future studies. The mean processing time for each sentence by young, by old, by SRC and by ORC including the standard deviation also needs to be included. It would be nice to see a table of mean processing time by word by group.

Authors' response: Thank you for the suggestion. We followed the reviewer's suggestion to perform the overall ANOVA and reported the effect size. A table (Table 1) was added to present the mean processing times by word, age group and sentence type.

line 271-314- It is Not standard practice to do an ANOVA on each word as it seems to have happened here because you inflate the type 1 error rate of finding an effect when there really is none. You could do a post hoc analysis by individual word or word type (noun, verb, article) - Tukey or LSD or Bonferroni

Authors' response: Thank you for the suggestion. We agree and have followed the reviewer's suggestion to perform an overall ANOVA with group, sentence type and region as predictors.

line 281- There is no such thing as marginally significant. It is either equal to or less than .05 or it is not. If you obtained .054, that rounds to .05 which is significant. Given the previous comment that this should be part of the overall analysis and not a separate analysis, I am not sure that this comment is helpful to you.

Authors' response: The comments are very helpful. We agree and have redefined .054 as significant. An overall ANOVA has been performed and the results were presented in the Results section.

Figure 3- it is unclear what R1, R2, R3 mean

Authors' response: R1, R2 and R3 refer to the first region, the second region and the third one in the experimental sentences. In the revised manuscript, we replaced R1, R2 and R3 with "Region 1", "Region 2" and "Region 3", which make it easier for readers to understand the meaning.

Line 346- Foster should be Forster

Authors' response: We have corrected it.

Minor Concerns:

On line 135, the Guerrero Forster Elliot paper should also be cited. On this same line, Witzel, Witzel& Foster, should be Witzel, Witzel& Forster. Please don't forget the first r in his name.

Authors' response: Thank you. We have followed the reviewer's suggestion to cite Forster, Guerrero & Elliot's paper. The spelling mistakes have all been corrected.

Lines 178 and 179 do not need to be included, however that the participants were paid and how much should be included. Please be sure that all the verbs are in the past tense. That issue starts at line 180.

Authors' response: Thank you. Lines 178 and 179 were included because the Author Guidelines require the ethics statement to be included at the beginning of the protocol section. The Author Guidelines also require the use of imperative voice throughout the protocol, so most sentences in the protocol were in imperative voice. We did not use past tense because the Protocol Section is not intended to describe any specific experiment. Rather the purpose is to introduce and describe a method which can be potentially useful and applicable in other studies.

We have followed the reviewer's suggestion to specify the exact amount of money paid to the participants in the Notes (line 369).

Line 187, you need to mention that All experimental stimuli are in Mandarin. This wasn't clear until the end of the paper.

Authors' response: We agree and have added information in the revised manuscript to clarify this (line 235-237).

In Line 188, for the plausibility rating, it isn't clear what age group was tested and if they were both men and women. Please include how many men, how many women, their mean age and sd of age.

Authors' response: For the plausibility rating, both older and younger adults were tested. They are similar to the participants in gender ratio, which means both men and women participated in the rating. The demographic details have been provided in the Notes (line 247-248).

In line 193, please include the specification that there is a choice between the grammatically correct (syntactically correct) and the grammatically incorrect (syntactically incorrect). This would be a good place to refer to figure 1.

Authors' response: Thank you. We specified that participants needed to choose between the correct and incorrect alternatives. We also referred to figure 1 in this place.

In line 200, please include how many sentences are in each block.

Authors' response: We have included the number of sentences in each block (line 268-269).

In line 209, please include the mean age, the age range and the sd of age for each group; the number of men and women.

Authors' response: Thank you. We provided the demographic details of the participants in the Results section (line 390-394).

In line 210, please include specifics on the education- One of the reasons that some of the words may produce slower effects in the older generation could be attributed to a frequency effect.

Authors' response: Thank you for the comments. We have added the details about education to the Results section (line 393). We agree that frequency can have influence on the reading times. However, in this study, we were more interested in the age difference in sentence processing. Although frequency can influence the performance of both younger and older adults, we have not found any evidence showing that frequency has greater effect on older adults than younger adults. Besides, in this study, when we developed the experimental stimuli, we ensured that there was no significant difference in lexical frequency and the number of strokes for the Chinese characters between the two conditions (SRC and ORC). Therefore, the effects of lexical frequency and number of strokes have been controlled.

line 234, was feedback given to the participants? If so, that should be stated.

Authors' response: Yes. Feedback was given to the participants. We have clarified this in the revised manuscript (line 320-325).

In line 248, in the original study, the incorrect responses were analyzed separately for patterns in the data. Patterns that showed up were unanticipated order effects; specific word effects that were unanticipated. Please include mention of this in your paper as this analysis is very important. Also, I did not see an analysis of the randomization order. That ANOVA should be done as well and reported.

Authors' response: Thank you. In this study, the reading times for incorrect answers were discarded and not included in the subsequent analysis as we think they did not represent normal sentence processing. We agree that this needs to be emphasized in the paper and have added the information in the Methods section. We also followed the reviewer's suggestion to make an analysis of randomization order and reported the results.

line 242, it is unclear which digit span task was done and what the reference was for this task. Did you use the OSPAN from Bleckley and Durso, 2003 or a different one? Also, the mean score for each group should be listed along with the sd (standard deviation)

Authors' response: We administered the digital span task from the Wechsler Memory Scale (Wechsler, 1987). The mean scores and SD for each group have been listed in the Results section (line 462-463).

line 250, Which ANOVA did you do? repeated measures?

Authors' response: We used repeated measures ANOVA. We have clarified this in the revised manuscript.

Coding files

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Supplemental Coding Files

CODE.txt