TITLE:
Dissociation of the Confounding Influences of Expectancy and Integrative Difficulty Residing in Anomalous Sentences in Event-Related Potential Studies

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SHORT ABSTRACT:
We present a protocol to dissociate the intertwining factors of integrative difficulty and unexpectedness in semantically anomalous sentences by applying multiple repetitions to enhance participant's expectancy for anomalous sentences. The dissociation helps to investigate the major contributor of elicited event-related potentials (ERP) effects such as N400 in language studies.

LONG ABSTRACT:
The confounding factors of unexpectedness and semantic integration difficulty naturally residing in anomalous sentences in language studies make it difficult to determine the underlying processing mechanism of ERP components. Unlike the traditional static approach of manipulating expectancy through corpus frequency or cloze probability, this protocol proposes a dynamic method to enhance participants' expectancy for rarely-met anomalous sentences by multiple repetitions while maintaining their semantic integration difficulties. To address the time cost increase resulting from multiple repetitions, this protocol proposes to repeat only the strictly simplified core structure extracted from the anomalous sentence before presenting

the semantically enriched, much more informative complete anomalous sentence containing the anomalous core structure to reinitiate the semantic integration processing. The complete anomalous sentence elicited a P600 effect. It suggests that the participants did not give up processing the anomalous information after repetitions and the same semantic integration difficulty was successfully reinitiated. Importantly, the representative experimental results reveal that the greatly attenuated N400 effect caused by multiple repetitions was not recovered by the follow-up reinitiated semantic integration difficulty. It suggests that the attenuated N400 effect should be mainly attributed to the enhancement of expectancy for anomalous information by multiple repetitions. The experimental results show that this method can effectively enhance participants' expectancy for anomalous sentences while retaining the semantic integration difficulty.

INTRODUCTION:

Anomalous sentences are widely used by linguists to study online cognitive processing of normal languages. For example, in event-related potentials (ERP) studies, sentences with semantic anomalies (e.g., "He spread the warm bread with ***socks***.") were reported to elicit an N400 effect[1] (but also see some other studies reporting a semantic P600 effect[2,3]), while sentences with syntactic difficulties or anomalies (e.g., "The woman persuaded ***to*** answer the door…") were reported to elicit a P600 effect[4,5]. These electrophysiological components are widely used as reliable indicators for investigating the normal temporal courses of processing information from different aspects of language, such as syntax and semantics.

Anomalous sentences cause great difficulties for semantic integration processing during comprehension. However, confounding factors such as unexpectedness (i.e., any anomalous expression is naturally an unexpected expression) make it difficult to determine the true cognitive process underlying the observed effect elicited by anomalous sentences. For example, if an N400 effect is elicited by an anomalous sentence, it is unclear whether it is caused by unexpectedness[6,7,8] or integrative difficulty[1,9,10].

To ascertain whether it is expectancy or semantic integration difficulty that contributes to the elicited electrophysiological effect, we need to dissociate these two factors. Traditionally, expectancy is often measured by corpus frequency (in word studies) or cloze probability (in sentence studies). The widely applied method to manipulate expectancy in traditional experiments is by choosing stimuli with high and low scores in expectancy to form expected and unexpected groups. This method is effective in manipulating expectancy and has produced abundant insightful results.

However, as a static approach to manipulating expectancy, it has one limitation: it is hard for the expected and unexpected groups to have the same semantic integration difficulty. With this manipulation, the stimuli selected for the expected and unexpected groups have to be different; thus the semantic integration difficulty is

altered when we manipulate expectancy by using different stimuli with different expectancy values or cloze probabilities). While we may find unexpected but reasonable expressions (i.e., unexpected expressions made up of words that can be successfully integrated into a reasonable message), it is possible that the integrative efforts required by these unexpected but reasonable expressions are different from those required by normal expressions. If the differences are not controlled, significant differences in brain responses might ensue, as clear evidence demonstrates that the integrative processing of unexpected but reasonable new metaphorical expressions triggers brain responses quite different from those triggered by conventional metaphors[11,12].

To address this issue, we propose a new method to dynamically enhance participants' expectancy for anomalous sentences while trying to maintain the semantic integration difficulty. Specifically, we quickly familiarize participants with unfamiliar anomalous sentences and thus enhance their expectancy through multiple repetitions. Importantly, multiple repetitions do not change the stimulus itself; therefore, the semantically anomalous information itself remains unchanged (i.e., the critical word still cannot be successfully integrated into the context).

However, the brain might give up integration after learning that the anomalous information cannot be successfully integrated into the previous context at all (i.e., the integration processing might be absent so that there is no integration difficulty). Therefore, this protocol proposes to repeat only the core anomalous information extracted from the anomalous sentence first, and then use the complete anomalous sentence which contains the identical anomalous information as a semantically enriched version of this core anomalous information, to initiate new semantic integration processing in the repetition condition. With the identical anomalous information in the semantically enriched complete anomalous sentence and the initiated new semantic integration processing, we assume that the semantic integration difficulty triggered by the anomalous information in the complete anomalous sentence after multiple repetitions should remain almost the same as that triggered by the anomalous information before repetitions (regardless of the status of semantic integration processing during repetitions). Hence, we assume the factor of semantic integration difficulty in the semantically enriched complete anomalous sentences remains the same after repetitions as in the correspondingly simplified core structures, but the expectancy is greatly enhanced.

Based on these assumptions, we compare the N400 effect elicited by semantically enriched complete anomalous sentences containing the repeated core anomalous information with that elicited by newly-met complete anomalous sentences, to investigate the major contributor of this elicited ERP effect. The working hypotheses are as follows: according to previous studies, the N400 effect would be significantly attenuated by repetitions. On the basis of the attenuated N400, if the newly initiated semantic integration of the same anomalous information causes recovery of the

attenuated N400 effect to a level similar to that elicited by the same type of anomalous information contained in newly-met anomalous sentences with no repetitions, then it suggests that the semantic integration difficulty is the dominant contributor of the elicited N400 effect; otherwise it suggests that unexpectedness is the major contributor.

PROTOCOL:
The present protocol was approved by the Institutional Review Board of Tsinghua University.

1. Stimuli construction

1.1. Construct critical anomalous sentences for the repetition and non-repetition groups

1.1.1. Prepare an adequate number of correct sentences for the construction of anomalous sentences (no less than 40). For example, “These two components were **separated** by a centrifugal device.” Try to use only emotion-free sentences as much as possible.

1.1.2. Construct anomalous sentences based on the correct sentences and then allocate half to the repetition group and half to the non-repetition group.

1.1.2.1. For example, allocate the sentence “These two components were **participled** by a centrifugal device” to the repetition group and “These two components were **semicoloned** by a centrifugal device” to the non-repetition group. Ensure that the two groups of anomalous sentences are highly comparable in elements such as plausibility, violation type and length.

1.1.3. Mix all anomalous sentences with a group of normal sentences (i.e., sentences without integration difficulty) in a random manner to form a list of normal and anomalous sentences.

1.1.4. Invite a group of native speakers (no less than 30 persons) to score the acceptability of the anomalous sentences using a 1–7-point scale, with a high value representing high acceptability.

1.1.5. Select enough pairs of appropriate anomalous sentences (no less than 35) for use as stimuli based on the acceptability scores. Anomalous sentences should be as low as possible in acceptability (e.g., with scores lower than 2). Ensure that the two anomalous sentence groups are not significantly different in the acceptability score (repeated measures analysis of variance is recommended).

1.2. Prepare corresponding stimuli for these critical anomalous sentences for

repetitions

1.2.1. For the repetition group, extract the core anomalous elements from the complete anomalous sentence to form a core structure for repetition (e.g., for studying the N400 effect, extract the core elements causing semantic incongruity).

1.2.1.1. Ensure that only the most simplified core anomalous elements are kept (i.e., remove any information that is unrelated to elicitation of the effect to be studied). For example, extract only the semantically anomalous core structure “components were participled…” from the complete anomalous sentence “These two components were participled by a centrifugal device.”

1.2.2. For the non-repetition group, change the core structure so that it is different from the one extracted from the complete anomalous sentence, to prevent repetition of the anomalous core structure contained in the complete anomalous sentence (i.e., to prepare a different core structure for the use of repetition).

1.2.2.1. For example, after extracting the core structure “components were semicoloned…”from the critical anomalous sentence “These two components were semicoloned by a centrifugal device” in the non-repetition group, replace the keyword “semicoloned” in the extracted core structure with another word such as “differenced” (i.e., use “components were differenced…” instead of “components were semicoloned…” for repetition with the non-repetition group).

1.2.3. (Optional minor modifications) Make minor modifications to the extracted core structure (e.g., tense or singular/plural forms), but ensure that the new one can still elicit the same effect as the corresponding complete anomalous sentence.

1.2.3.1. For example, the past tense and the plural form in the anomalous core structure can be further changed to the present tense and the singular form: “component is participled…” instead of “components were participled.”

NOTE: The minor modification step is optional. It is highly recommended that the extracted anomalous core structure to be used for repetition have the same form and order as the core structure in the anomalous complete sentence. The purpose of the minor modification is to prevent the participant from memorizing the core structure as an entire unit, so that the follow-up presentation of the anomalous complete sentence can better reinitiate the semantic integration. This protocol chooses to apply minor modification.

1.2.4. Construct a filler short expression for each of the extracted (and modified) core structures in both the repetition and non-repetition groups. For example, coin and introduce a correct but similar filler expression “component is mixed…” for the anomalous core structure “component is participled…” in the repetition group.

1.2.5. Similarly, coin and introduce another correct but similar filler expression "component is discovered…" for the anomalous core structure "component is differenced…" in the non-repetition group.

NOTE: The filler short expressions are introduced for two purposes: (i) to balance the correctness of the anomalous core structures, and (ii) to serve as the baseline for observing possible elicited effects at different repetition stages (e.g., N400 effect at the first-time, the fifth-time or the tenth-time of repetition), because even the correct stimuli may be influenced by multiple repetitions.

[Place Table 1 here]

1.3. Construct filler sentences

1.3.1. Prepare enough filler sentences to enrich the sentence type and to make sure that the normal and anomalous sentences are well-balanced in number.

1.3.2. Select a number of correct filler sentences from the filler sentences (based on the number of all critical anomalous sentences in the repetition group), and create a repetition part for each of the selected filler sentences in the same way as creating the repetition parts for the critical anomalous sentences: extract the core structure from each correct filler sentence and coin a corresponding short filler expression for this core structure.

NOTE: A repetition part is introduced before each correct filler sentence to avoid exposure of the critical anomalous sentences (which also have a repetition part prior to them). After this step, there are two types of complete sentences: sentences with a preceding repetition part (including all critical sentences and the selected filler sentences preceded by a repetition part) and sentences without a preceding repetition part.

2. Stimuli presentation

2.1. Presentation of the repetition part

2.2.1. Present the extracted core structure and its correct filler expression (see **Table 1b**) together for a specific number of times (e.g., seven times) in a random manner (see the repetition part in **Figure 1**).

2.2. Presentation of the semantic reinitiating complete sentence

2.2.1. Present the complete anomalous sentence right after its corresponding repetition part (see **Figure 1**).

NOTE: Different colors for the repetition part and the complete sentence (e.g., dark blue versus dark green) prove helpful for the participants to distinguish these two parts.

[Place Figure 1 here]

2.2.2. (Optional modifications) If the researcher is concerned only about results of the complete sentence part, then the short expressions can be presented as an entire unit to save time.

2.3. Task setting for the repetition part and the complete sentence part

2.3.1. Give a task for each core structure in the repetition part to keep participants focused, for example, a plausibility judging task (or a similar task which requires the participants to respond differently to different core structures, e.g., judging whether an expression has previously been given).

2.3.2. Choose task for the complete sentence part that are widely used in previous related studies (e.g., plausibility judging) so that the results can be compared with results of previous studies.

2.4. Overall stimuli organization

2.4.1. Present each repetition part (along with its corresponding subsequent complete sentence) only after an anomalous sentence, and present after a normal sentence another complete sentence (whether it is normal or ~~anormalous~~ anomalous) (see **Figure 2**).

NOTE: This ~~isuseful~~ is useful in two ways: (i) providing the participant a reasonable explanation about why some sentences are preceded by a repetition part but others are not (e.g., a researcher may explain that only an incorrect sentence will be followed by a repetition part while a correct sentence will have the power to bypass the repetition part and jump directly to another complete sentence); (ii) making the experiment more interesting by avoiding monotony and thus helping the participant remain focused.

[Place **Figure 2** here]

3. Experiment preparation and electrophysiological recording

3.1. Recruit native speakers with normal or corrected-to-normal vision and with the same handedness (the Edinburgh handedness test can be used to select the participants[13]). The participants should be free of neurological or psychiatric

disorders, and should not be taking any medications affecting the central nervous system.

3.2. Ensure that participants have no perm or hair dyeing history within two months before the test. Ensure a balanced number of male and female participants in the required age range.

3.3. Inform participants to have enough sleep and rest before the experiment. Ensure they are in a healthy state (with no cough, fever, headache, etc.) while participating in the experiment.

3.4. After a participant arrives at the lab, introduce to the participant the equipment and materials that will be used in the experiment, the procedure of the experiment, the tasks and time cost of the experiment, and also the requirements (such as movement and eye blink restriction), in order to help the participant to have basic knowledge about the overall procedure and to eliminate unnecessary concerns.

3.5. Ask the participant to fill in the Edinburgh Handedness Query Form if the participant has no further questions or worries about the experiment and agrees to participate in the experiment. Confirm that all participants have the same handedness.

3.6. Give the informed consent form to the participant and ask the participant to read it carefully. Provide necessary explanations if the participant has questions about the content. After the participant understands and agrees to all the contents, ask the participant to sign the form at the designated place, and proceed to the next step.

3.7. Instruct the participant to clean their head and dry hair properly in the laboratory. While waiting for the participant, keep all the experimental materials ready.

NOTE: Preparation of experimental materials depends on requirements of the specific recording system.

3.8. Invite the participant to sit comfortably in the chair of the chamber where the experiment will be conducted.

3.9. Clean the participant's skin for corresponding electrode(s) on the forehead (e.g., for the electrodes Fpz, Fp1, Fp2, Af7, Af8), under the left eye (e.g., for the vertical electrooculography [VEOG] electrode), near the outer canthus of the right eye (e.g., for the horizontal electrooculography [HEOG] electrode), and around the left and right mastoid bone (e.g., for the electrodes of Tp9 and Tp10, which will be used as new references offline) with facial scrub and cotton swab.

3.9.1. Scrub the skin gently and do not make the participant feel uncomfortable, but also ensure that the dead skin cells and other substances such as cosmetics are removed.

NOTE: The distribution of the electrodes might be different depending on the caps used. Please follow the distribution of the electrodes on the cap in use or the guidance of the international 10-20 system of electrode placement to find corresponding locations in the abovementioned areas for skin cleaning.

3.10. Place the elastic cap with electrodes on the participant's head. Ensure that the electrode Cz on the cap is located at the vertex of the head and the cap has a left-right symmetry, with midline electrodes placed over the midline of the head.

NOTE: If the electrodes are not fixed on a cap, follow the international 10-20 system of electrode placement on the scalp of the participant

3.11. Have the electrode(s) recording eye movements placed well and fixed. Fill the two separate HEOG and VEOG electrodes with conductive gel, place them at the outer canthus of the right eye and below the left eye, respectively and fix using adhesive tape.

NOTE: If the system does not require conductive gel, skip the gel-filling step.

3.12. Fasten the strap under the chin to prevent the adjacent electrodes from moving during the experiment. The strap should not be too tight or too loose. Connect the cap/electrodes to the recording system.

3.13. Reduce the impedance of all electrodes to a level below the widely applied impedance threshold for ERP studies (typically below 5 kΩ; or 10 kΩ;). This can be done as follows.

3.13.1. Switch the recording software to the impedance monitoring interface.

3.13.2. Start with the Ground (GND) and Reference (Ref) electrodes.

3.13.3. Pass the blunt tip needle of the syringe containing conductive gel through the eyelets of the electrodes and hairs until it reaches the skin of the scalp, push the syringe plunger to inject a small dose of the conducting gel onto the skin until the gel connects the metal circle on the electrode and the skin.

NOTE: Be careful not to inject too much gel in case that superfluous gel connects adjacent electrodes); if the system does not require conductive gel, skip this step, but act according to the requirements of the system.

3.13.4. Check the real-time impedance level displayed in different colors on the monitor until the impedance decreases to below the threshold value.

NOTE: If the impedance decreases very slowly, the process can be sped up by gently pressing the gel with a cotton swab (or the blunt needle tip) so that the gel can have better contact with the skin or by making circles with the cotton swab (or the syringe) without moving its tip on the scalp.

3.13.5. After the Ground and Reference electrodes are prepared, treat the other electrodes with the same method.

NOTE: Keep in mind that the impedance reduction process should never make the participant feel uncomfortable. It is helpful to start and maintain a conversation with the participant while preparing the electrodes.

3.14. Ask the participant to get ready for the experiment. Tell the participant to relax but also try to avoid excessive eye blinks and body movements during the experiment.

3.15. Inform the participant about the tasks in the repetition part (i.e., to judge the plausibility of the core structure upon seeing the cue ".." following each core structure) and tasks in the main sentence part (i.e., to judge the plausibility of the complete anomalous sentence upon seeing the cue "? ?" following each sentence), and ask the participant to respond accordingly in the experiment.

3.16. Before the experiment starts, inform the participant explicitly that an incorrect sentence will be followed by a repetition part and a correct sentence by another complete sentence (which may be correct or incorrect).

NOTE: This helps to direct participants' attention to the relationship between the repetition part and the sentence before it rather than the subsequent complete sentence.

3.17. Start the stimuli presentation program and let the participant practice with the practicing section.

NOTE: Ensure that all types of stimuli included in the experiment appear in this practice session.

3.18. Start the formal experiment session and record the electrophysiological signals. Divide all the stimuli into different blocks so that the participant can take a break for about 10 min between each block.

3.19. Monitor the recording system during recording. If any problem arises, pause the experiment and recording until the problem is solved properly.

3.20. Save the recorded electrophysiological data and help the participant take off the cap. Instruct the participant to wash away the conductive gel on the skin and hair.

3.21. Provide the participant with the reward and thank the participant for their participation.

REPRESENTATIVE RESULTS:

The present protocol was used in one of our recent studies to investigate whether the N400 effect reflects semantic integration processing[14]. The stimuli used in that study were in Chinese, as shown in **Table 2**.

[Place Table 2 here]

The two hypotheses in that study were that (i) the N400 effect elicited by semantically anomalous information will be significantly attenuated by multiple repetitions at the first stage; and (ii) the follow-up reinitiated semantic integration difficulty (by the same repeated anomalous information) will cause recovery of the attenuated N400 effect.

N400 effect in the repetition part

The ERPs of the first-time, the fourth-time and the seventh-time presentation of the anomalous core structures revealed that the N400 effect in the 300–500 ms time window disappeared gradually (see **Figure 3**). Repeated measures analysis of variance (repeated measures ANOVA) results provided support for the attenuating and disappearing N400 effect: for the first-time, $F(1, 21) = 37.690$, $P < 0.001$; for the fourth-time, $F(1, 21) = 2.770$, $P = 0.111$; and for the seventh-time, $F < 1$.

[Place Figure 3 here]

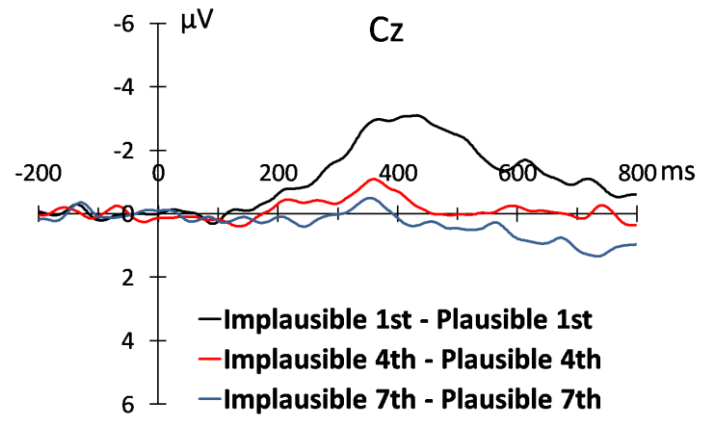

Figure 3: Differential waves (implausible–plausible) of the first, fourth, and seventh presentation of core structures in the repetition part at the representative electrode of Cz. This figure displays the N400 attenuation effect in the repetition part by using differential waves at different presenting stages (black: the first presentation; red: the fourth presentation; blue: the seventh presentation). This figure was adopted from Huang et al.[14] with permission.

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N400 effect in the complete sentence part

Within the planned time window of 300–500 ms, omnibus ANOVA results across all the regions of interest (ROIs) indicated a significant effect of condition, $F(2, 42) = 8.872$, $p = 0.001$. The follow-up separate ANOVAs indicated a significant effect of semantic anomaly between the control group and the unrepeated anomalous sentence group, $F(1, 21) = 21.580$, $p < 0.001$. ERPs in the unrepeated anomalous sentence group were more negative than those in the control group. Between the repeated anomalous and unrepeated anomalous groups, a significant effect of repetition was revealed, $F(1, 21) = 7.780$, $p = 0.011$. ERPs in the repeated group were more positive than those in the unrepeated group. Separate comparison between the control group and the repeated anomalous group revealed no significant effect, $F(1, 21) = 1.39$, $p = 0.252$. The ERPs of the complete sentence part at the representative electrode of Cz are displayed in **Figure 4**.

[Place Figure 4 here]

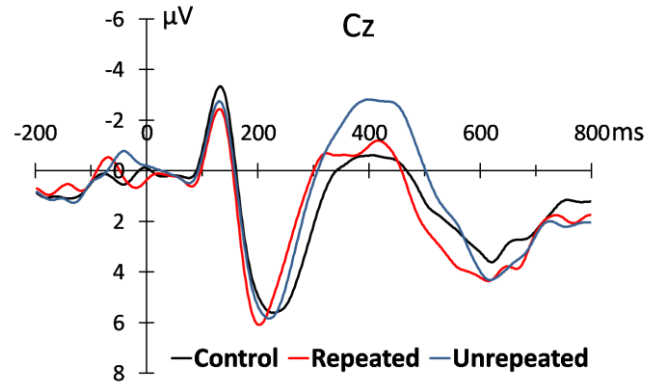

Figure 4: Event-related potential (ERP) waveforms of semantically enriched complete sentences in the repeated, unrepeated, and control conditions at the representative electrode of Cz. This figure displays different waveforms in three different conditions (black: control condition; red: repeated sentences; blue: unrepeated sentences). This figure is adopted from Huang et al.[14] with permission.

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P600 effects in the complete sentence part

Besides the N400 effect in the repeated complete sentence group, further analysis revealed that a marginally significant P600 effect followed the N400 effect in the 500–800 ms time window between the repetition and control ~~conditionsacross~~

conditions across all the nine ROIs on the scalp ($F(1, 21) = 3.266$, $p = 0.085$), with the ERPs in the repetition condition more positive. If we consider only the central-posterior six ROIs, where the P600 effect often reaches its peak value, the P600 effect was significant, $F(1, 21) = 8.112$, $p = 0.010$.

Figure 1: Schematic illustration of the stimulus presentation. The upper half of the figure displays the flowchart of presenting the repetition part and its corresponding follow-up complete anomalous sentence, the left side of the lower half displays the detailed manner of presenting each short expression, and the right side of the lower half displays the detailed manner of presenting each complete sentence.

Figure 2: The organization of stimuli in each block. This figure displays the overall flowchart of programming for all anomalous complete sentences (with their corresponding repetition parts) and the correct, complete filler sentences (without any preceding repetition part) in each block. This figure is adopted from Huang et al.[14] with permission.

Figure 3: Differential waves (implausible–plausible) of the first, fourth, and seventh presentation of core structures in the repetition part at the representative electrode of Cz. This figure displays the N400 attenuation effect in the repetition part by using differential waves at different presenting stages (black: the first presentation; red: the fourth presentation; blue: the seventh presentation). This figure was adopted from Huang et al.[14] with permission.

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Table 1: Examples of stimuli: Complete sentences and simplified core structures. The upper half of the table displays examples of complete sentences (in the control group, the repeated anomalous sentence group,and the unrepeated anomalous sentence group, respectively) in the complete sentence part and their corresponding anomalous core structures to be used in the repetition part; the lower half of the table displays the anomalous core structures and their plausible filler short expressions in the repetition part.

Table 2: Examples of stimuli: Complete sentences and simplified core structures. This table displays examples of complete sentences, their corresponding anomalous core structures, and plausible filler short expressions for the anomalous core structures. This table was adopted from Huang et al.[14] with permission.

DISCUSSION:

Experimental results and significance

In the repetition part, the results demonstrated that the N400 effect became smaller and smaller until almost non-existent. The greatly attenuated N400 effect proved that multiple repetitions did significantly modulate the amplitude of N400. However, the results in this part cannot show whether N400 was actually affected by the change of expectancy or semantic integration. The attenuated N400 effect can still be explained differently. One explanation is that expectancy contributed to the attenuation of N400 in that multiple repetitions enhanced participants' expectancy for anomalous expressions. This would suggest that N400 indexes expectancy rather than semantic integration difficulty. Another explanation is that after getting familiarized with anomalous expressions, the brain realized that the words in the expressions simply could not be successfully integrated into a plausible message and therefore gave up further attempts to integrate the information. This explanation would suggest that N400 indexes semantic integration.

In the complete sentence part, the ERP results reveal no N400 effect in the repetition condition but significant N400 effect in the non-repetition condition. Compared with the N400 effect elicited by anomalous sentences in the non-repetition condition, the N400 effect was almost non-existent in the repetition condition. This is consistent with the attenuated N400 effect in the repetition part. We hold that the N400 effect almost disappeared in the repetition condition because of the multiple repetitions. Besides the N400 effect, the complete anomalous sentences also elicited a significant P600 effect. We suggest that the P600 effect reflects a higher level of processing later to form the message level interpretation.

The complete anomalous sentences in the repeated and unrepeated groups share the same type of semantic anomaly (i.e., the critical words in both anomalous groups cannot be successfully integrated into the context to generate a plausible message). Repetitions can enhance the expectancy for anomalous information in the repetition group, but may also cause the participant to give up semantic integration. To prevent the participants from giving up integration after repetitions, we repeated only the core anomalous information extracted from the anomalous sentence and then used the complete anomalous sentence containing the same anomalous information to reinitiate semantic integration processing. Compared with the anomalous core structures in the repetition part, the complete anomalous sentences were semantically much more enriched, with new semantic information added. The new information was used to initiate new semantic integration processing. To process the new information together with the old information, participants had to start new semantic integration processing to integrate all the word-by-word information input and form a message level interpretation. In the present experiment, we hold that the P600 effect provided evidence that participants did not give up higher-level information processing of the critical anomalous word. The P600 effect has been proposed as an indicator of semantic integration[15,16,17,18,19], some other later higher-level processing such as syntactic reanalysis[5,20,21,22], or relationship establishment[23].

The much later, higher-level processing like structural reanalysis and relationship establishment also includes the earlier efforts for semantic integration processing. Therefore, the elicited P600 effect in the semantically enriched new complete sentence suggests that participants did not give up higher level processing (including semantic integration) when meeting the same anomalous information in a new, enriched sentential context. With the identical anomalous information before and after repetitions and the newly initiated cognitive efforts after repetitions to integrate the old information with new information, we can infer that the semantic integration difficulty triggered by the complete anomalous sentence was almost the same as that triggered by the core anomalous structure during its first presentation in the present protocol. As a result, the initiated new semantic integration processing helped to re-trigger the same degree of semantic integration difficulty after multiple repetitions were applied to enhance participants' expectancy for the anomalous information.

Taken together, the present results demonstrate that the semantic integration difficulty in the repetition group did not cause recovery of the significantly attenuated N400 effect resulting from multiple repetitions, to a level similar to the N400 effect elicited by unrepeated anomalous sentences. Therefore, the results suggest that semantic integration difficulty does not contribute significantly to the N400 amplitude and provide support for the proposal that N400 does not reflect semantic integration processing.

Effectiveness of the method

The most important goal of the present protocol is to provide a dynamic way to continuously enhance participants' expectancy for an anomalous sentence while maintaining the integration difficulty of the sentence (by preventing the participants from giving up attempts to integrate the repeated anomalous information after they have learned that there is no possibility to get a plausible message from it after multiple repetitions). In this protocol, the repetition part is designed to achieve multiple repetitions of the less informative anomalous core structures contained in the complete anomalous sentence, and the follow-up, much more informative complete anomalous sentence containing the same anomalous information is designed to reinitiate the semantic integration of the same anomalous information.

To evaluate the effectiveness of this protocol, we need first to examine whether participants' expectancy for anomalous sentences is enhanced by multiple repetitions. Many previous studies have proposed that the N400 amplitude is actually an inverse function of the expectedness or prediction of the input semantic information, i.e., the less the input semantic information is expected, the larger the N400 amplitude[6,8]. Accordingly, the greatly attenuated N400 amplitude after repetitions suggests that the expectancy has been greatly enhanced. The present experimental results corroborate these previous studies by demonstrating that the N400 effect ~~wasgreatly~~ was greatly attenuated by multiple repetitions. Following

previous proposals, we maintain that the greatly attenuated N400 effect in the experiment indicates that participants' expectancy for anomalous sentences was significantly enhanced by multiple repetitions (see **Figure 3**).

The second concern is whether the follow-up, semantically enriched complete anomalous sentences can successfully reinitiate the semantic integration difficulty. Our experimental results demonstrate that a significant P600 effect followed the N400 effect in the 500–800 ms time window in the repetition condition (see **Figure 4**). As discussed above, the elicited P600 effect in the complete anomalous sentence, which reflects the later higher-level information processing, indicates that the follow-up, more informative sentences successfully reinitiated the semantic integration processing of the same anomalous information in the enriched sentential context. Additionally, since the repeated core structures share the same anomalous information as the follow-up complete sentences, this further suggests that the reinitiated semantic integration is (almost) as difficult in the complete anomalous sentences as before repetition (i.e., the critical word still cannot be integrated into the context to generate a successful message).

Taken together, the present method has proved to be effective in dynamically enhancing participants' expectancy for anomalous sentences while maintaining the semantic integration difficulty. Therefore, the present method is a useful way to dissociate the expectancy elicited effect and the integration elicited effect in processing of anomalous sentences.

Further explanations and possible other applications

The present protocol provides an effective dynamic method to dissociate the intertwining factors of unexpectedness and semantic integration difficulty in anomalous sentences by multiple repetitions. To achieve this goal and for considerations like time cost control, the protocol repeats only the core anomalous information, instead of the whole sentence. Therefore, the core anomalous structure construction process (step 1.2) is critical in this protocol. It should be noted that if unnecessary information is included in the core structure, it will increase the total time cost. Therefore, to save time and eliminate any unnecessary information (to lay a better foundation for subsequent integration initiation), the core anomalous structure should be as simplified as much as possible. On the other hand, all the necessary elements should be included to represent the anomalous information and to ensure the efficacy of multiple repetitions. It is useful to conduct a pre-test to examine whether the extracted core structure can elicit the same N400 effect as the complete anomalous sentence. Besides, minor modifications are recommended such that the extracted anomalous core structures used in repetitions differ in form and order from the core structures in the anomalous complete sentences, as indicated by step 1.2.3. Otherwise, participants might memorize a core structure as an entire unit, which will block the initiation of the semantic integration when new information is added.

The present method can provide insight for future studies that intend to conduct multiple repetitions of context-rich complete sentences. Multiple repetitions are widely used to investigate memory-related cognitive processing, for example, the roles of memory in word comprehension. However, multiple repetitions of context-rich sentences will greatly increase the experimental time cost and make an experiment impossible. The present protocol provides a way to control the time cost of repeating sentence level information in an experiment.

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There are no competing financial interests.

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