Journal of Visualized Experiments

Dissociation of the confounding influences of expectancy and integrative difficulty residing in anomalous sentences in Event-related potential studies

--Manuscript Draft--

Article Type:	Invited Methods Article - JoVE Produced Video
Manuscript Number:	JoVE59436R3
Full Title:	Dissociation of the confounding influences of expectancy and integrative difficulty residing in anomalous sentences in Event-related potential studies
Keywords:	dynamic method; multiple repetitions; enhancing expectancy; retaining integrative difficulty; N400; ERP
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Additional Information:	
Question	**Response**
Please indicate whether this article will be Standard Access or Open Access.	Standard Access (US$2,400)
Please indicate the **city, state/province, and country** where this article will be **filmed**. Please do not use abbreviations.	Tsinghua University, Beijing, China

TITLE:

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

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KEYWORDS:

dynamic method, multiple repetitions, enhancing expectancy, retaining integrative difficulty, N400, ERP

SUMMARY:

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.

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[6-8] 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) (see **Figure 2**).

NOTE: This isuseful 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]

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]

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 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 & TABLE LEGENDS:

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.

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.

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[15-19], some other later higher-level processing such as syntactic reanalysis[5,20-22], 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 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.

ACKNOWLEDGMENTS:

This work was supported by the National Natural Science Foundation of China [61433015], National Social Science Major Fund of China[14ZDB154; 15ZDB017], and the MOE (Ministry of Education in China) Project of Humanities and Social Sciences [14YJC740104]. We express great gratitude to the two anonymous reviewers for their valuable suggestions.

DISCLOSURES:

There are no competing financial interests.

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Fig. 1


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Table 1

(a) Example of semantically enriched complete anomalou

	Repeated Core Structure
Control	
Repetition Group	* Component is participled…
Non-repetition Group	* Component is differenced…

(b) Example of the simplified core stru

	Implausible Expressions
For Repetition Group	* Component is participled…
For Non-repetition Group	* Component is differenced…

s sentences and their preceding core structures

Semantically Enriched Complete Sentence
These two components were separated by a centrifugal device.
* These two components were participled by a centrifugal device.
* These two components were semicoloned by a centrifugal device.

ctures in the repetition part

Plausible Expressions
Component is mixed…
Component is discovered…

Table 2

(a) Exam

	Implausible Expressions
Repeated Group	* 数据/被人/记者 * **Data** *were* **reportered** *by someone*
Unrepeated Group	* 数据/被人/记性 * **Data** *were* **memoryed** *by someone*

(b) Example of seman

	Repeated Core Structure
Control	
Repeated Group	* 数据/被人/记者 * **Data** *were* **reportered** *by someone*
Unrepeated Group	* 数据/被人/记性 * **Data** *were* **memoryed** *by someone*

ıple of the simplified core structures in the repetition part

Plausible Expressions
数据/被人/**泄露** **Data** *were* **leaked** *by someone*
数据/被人/**分析** **Data** *were* **analyzed** *by someone*

tically enriched complete sentences and their preceding core structures

Semantically Enriched Complete Sentence
飞行/**数据**/是由/专门/设备/**记录**/的。 The flying **data** were **recorded** by special devices.
* 飞行/**数据**/是由/专门/设备/**记者**/的。 * The flying **data** were **reportered** by special devices.
* 飞行/**数据**/是由/专门/设备/**记号**/的。 * The flying **data** were **markered** by special devices.

Name of Material/ Equipment	Company	Catalog Number	Comments/Description
BrainAmp DC amplifier system (Brain Products GmbH)	Brain Products, Gilching, Germany		BrainAmp S/N AMP13061964DC Input 5.6DC=150mA Operation 7mA Standby
Easycap (Brain Products GmbH)	Brain Products, Gilching, Germany		62 Ag/AgCl electrodes with a configuration of the international 10–20 system of electrode

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Following the received the feedback and suggestions, we've made careful reflections and revisions on the contents and the writing of that article. After all the changes and improvements, we now resubmit it to you for your review of this article. Thanks!

Please find the following attached for our detailed responses.

(All the changes are indicated by red font or correction tracking tools in the attached file at the end of the letter)

Sincerely
Minghu Jiang (Prof. Ph.D.)
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Editorial comments:

Reply: Great appreciation for your patiently reading through our manuscript and kindly point out all the locations need to be improved, we have made the revisions accordingly. The revisions are marked by tracking tools and could be found in the independent attached file at the end of the letter.

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Reply: The Summary section has been added accordingly, Thanks!

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Reply: We have rechecked the protocol and made improvements and simplifications to the steps included in the protocol accordingly, and added sub-steps for the Impedance Reduction step.

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Reviewer Comments:

Reviewer #1

Manuscript Summary:

This manuscript proposes a method of teasing apart the roles of expectancy and semantic integration difficulty in N400 effects. It proposes that by repeating the core structure of an anomalous sentence, the resulting N400 attenuations can be informative as to whether expectancy or semantic integration elicit N400s. While I think this is a fascinating proposition, I don't follow how the authors' proposed method definitively distinguishes between semantic integration and expectancy. As this is the main claim of this methodology, more description is

needed to clarify this argument.

Reply:

Great appreciation for your patiently reading through our manuscript and kindly point out the necessity for more clarification about the way the method distinguishes the semantic integration and expectancy. After receiving the feedback information, we've added the following illustrations into the Introduction part of the manuscript and added corresponding explanations into the Discussion part accordingly (the added information are marked by red fonts):

Introduction Part:

Importantly, multiple repetitions do not change the stimulus itself, therefore the semantically anomalous information itself remains unchanged (i.e., the critical word could not be successfully integrated into context as before).

However, the brain might give up integration after learning that the anomalous information could not be successfully integrated into 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, then uses the complete anomalous sentence, which contains the identical anomalous information, as a semantically enriched version of this core anomalous information, to initiated 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 together, 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 the semantic integration processing during repetitions). Hence, we assume the factor of semantic integration difficulty in the semantically enriched complete anomalous sentences remains unchanged after repetitions as compared with its first presentation in a much more simplified core structure, but the factor of expectancy is greatly enhanced.

Based on all the above assumptions, we then compare the N400 effect elicited by the semantically enriched complete anomalous sentences containing the repeated core anomalous information with another group of newly met complete anomalous sentences to investigate the major contributor of this elicited ERP effects. The working hypotheses are as follows: according to previous studies, N400 effect would be significantly attenuated by repetition(s). On the basis of the attenuated N400, if the newly initiated semantic integration of the same anomalous information would cause a recovery of the attenuated N400 effect to a similar level as those elicited by the same type of anomalous information contained in the other group of newly met anomalous sentences without repetitions, then it would support that the semantic integration difficulty is the dominant contributor of the elicited N400 effect, otherwise it would speak for the other way round.

Discussion Part:

The complete anomalous sentences in the repeated and unrepeated groups shared the same type of semantic anomaly (i.e., the critical words in both

anomalous groups could not be integrated into the context successfully to generate a plausible message). Repetitions could enhance the expectancy for anomalous information in the repetition group, but might also cause the participants 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 first, then used the complete anomalous sentence containing the same anomalous information to reinitiate semantic integration processing. Comparing with the anomalous core structures in the repetition part, the complete anomalous sentences were much more enriched in semantic (i.e., new semantic information were added in). The newly added information in the semantically enriched complete anomalous sentences were used to initiate new semantic integration processing. To process the new information together with the old information, the participants will have to start new semantic integration process to integrate all the word-by-word information input and form a message level interpretation. In the present experiment, we suppose that the P600 effect could provide further evidence for that the participants did not give up later higher level information processing of the critical anomalous word. The P600 effect has been proposed as an indicator of semantic integration, and some other later higher level processes such as syntactic reanalysis, or relationship establishment. These much later and much higher level processing like structural reanalysis and relationship establishment also include the earlier efforts for semantic integration processing. Therefore, we suggest the elicited P600 effect in the semantically enriched new complete sentence indicates that the participants do not give up higher level processing (including semantic integration) while meeting the same anomalous information in a new enriched sentential context.

As analyzed in the introduction part, 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 together, we can infer that the semantic integration difficulty triggered by the complete anomalous sentence should be almost the same as that triggered by the core anomalous structure during its first presentation in the present protocol (i.e., almost unchanged by multiple repetitions). As a result, the initiated new semantic integration processing helps to re-trigger the same degree of semantic integration difficulty after applying multiple repetitions to enhance the participant's expectancy for this anomalous information.

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

Major Concerns:

1) The Introduction would benefit from an example of an anomalous sentence, so that readers are better able to understand the theory and logic behind the arguments. The authors do provide an example, but not until the Methods section. It would also be useful to have the "base" control sentence in the example ("These two components were separated by a centrifugal device") presented first in the text, so that it is clear how the target word is changed

in each condition. Rewording the phrasing in section 2.1.1 should address this issue.

Reply: Thanks a lot for the valuable advice, we've added anomalous sentences as examples in the Introduction part and reordered the presentation of the control sentence and the anomalous sentence accordingly for an improvement of the Introduction part following your kind advice.

2) I do not follow the argument presented in the Discussion section claiming that this method shows that the N400 reflects expectancy rather than semantic integration. As the authors state in the first paragraph of the discussion, multiple repetitions may have enhanced expectancy for the anomalous expression, and/or may have made semantic integration easier by familiarizing the participants with the anomalous expressions. Thus it remains unclear whether the N400 is reflective of expectancy and/or semantic integration. As written, the second paragraph of the discussion seems to clarify this issue by presenting results from the complete sentence part, but this is just yet another repetition of the anomalous sentence, so I do not see how it provides an answer to the question. As this is the main claim of this methodology, this is an important issue to resolve. Could the authors please elaborate on this logic or clarify the argument?

Reply:
Thanks for your important question. we have rewritten the discussion part about the results of the complete sentences to provide more explanations of the experimental results. The text are provided in the first Reply together with those illustrations added for the introduction part for your convenience, Thanks!

Minor Concerns:
1) It might be clearer to combine sections 2.1.1 and 2.1.2 and just say "construct >80 anomalous sentences and then allocate half for the repetition group and allocate half for the non-repetition group". As currently written I was unclear as to whether the sentences in these two steps were fundamentally different or not.
Reply: Thanks for the suggestion! We have revised the text following your suggestions.

2) Section 2.1.4: What is meant by the phrase "Ensure that the selected stimuli are statistically valid"?
Reply: Thanks for helping us pointing out the misuse of language, we have revised the sentence as "Ensure that there is no statistical difference between the scores of the selected stimuli in the two anomalous sentence groups."

3) The description of the EEG protocol is specific to the EEG system being used. It might be worth adding a note somewhere that this protocol was written for a specific system and the steps may differ for other recording systems.
Reply: Thanks for the advice. We have added necessary notes accordingly into the protocol in the revised manuscript.

4) The discussion of the P600 effect feels very post-hoc, but should be included in the results section.
Reply: Thanks for the remind and suggestion, we have moved the results of P600 effect to the results part and added corresponding discussion of the effect in the second and thid paragraph of the Discussion part.

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Reviewer #2
Manuscript Summary:
The authors describe a new experimental approach that the authors have recently argued (Huang et al 2018, Neuroreport) dissociates expectedness from semantic integration. The value of the approach as motivated in the introduction (and abstract) is that it separates these two processes and thus advances understanding of the underlying cognitive processes that generate the N400 (and potentially the P600).

Major Concerns:
I am a bit confused by the presentation of the methods in that it seems that these are the methods that were followed in the Huang et al report, but they are described prospectively here. Many of these methods concern general use of EEG/ERGs to study cognition. In that sense, as a general account of how one set up an EEG experiment I think there is real value. My concern/confusion is whether focusing on the methods for development of the items and materials for this specific theoretical question will be of broad interest.
The value of the methods for selecting materials etc depends entirely on whether a reader is persuaded that the proposed experimental approach succeeds in separating unexpectedness from semantic integration processes. I am not an expert on this literature but my concern (from 10,000 feet) is that the authors argument essentially comes down to assuming that the 'brain gives up' on trying to integrate the semantics of the anomalous sentences (or their repeated constituent cores), so that when the full sentence comes one is purely measuring the effect of expectedness. It seems that this assumption may be challenged on several levels (e.g., how do the authors know that the brain 'is giving up' rather than it has found a fast solution? how do the authors know that semantic integration processes are the same for the sentence cores as for the whole sentences?).
My point is not to argue one or the other about the theoretical efficacy of the experimental approach--presumably that is the domain of the prior publication (Huang et al)--the point is whether a visualized experiment should be based on an approach that might be challenged. It seems to me that the impact or significance of this work could be broadened if the authors should take a wider view--and say: using EEG to study the N400 and P600 offers a window in semantic and syntactic processes. There many experimental approaches for doing this. Here are 3, and included in those 3 (as one example) is the current approach. Then the value of the visualized experiment is 'bigger' than the perceived value of the authors argument about being able to separate expectedness from semantic processing (which i think is going to be inherently difficult, since the recognition of anomaly is probably dependent on failure of semantic

integration processes!).

Reply:

Great appreciation for your patiently reading through our manuscript and kindly point out related questions and important suggestions. The present protocol provides a dynamic method to dissociate the unexpectedness and semantic integration difficulty in anomalous sentences. These two intertwining factors naturally reside in any anomalous sentences, and the anomalous sentences are widely used to study languages, a method to dissociate them from each other would be helpful to future related studies, and we believe the present method could be broadened to other experimental linguistic studies using ERP and fMRI techniques. For example, the protocol could be used to conduct multiple repetitions to complete sentences as well (normally, in an experiment, the time cost is quite limited, but to conduct multiple repetitions to complete sentences require great time cost, this is the reason why there are no studies which have conducted repetitions to complete sentences over three times to our knowledge in ERP studies, the present protocol provides a way to meet this end) .

For your kind worry about the brain might actually find a fast solution instead of giving up the integration in the representative experiment, we think this is less likely to be true due to that in both of the repetition and non-repetition conditions, the complete anomalous sentence was preceded by a repeated anomalous core structure (together with a similar but correct filler) as the following:

	Anomalous core structure	**Correct filler structure**	**Complete anomalous sentence**
Repetition condition	Data were reportered…	Data were leaked…	The flying data were reportered by…
Non-repetition condition	Data were memoryed…	Data were analyzed…	The flying data were markered by…

Before presenting the complete anomalous sentence in both groups, the participants would have the same amount of time to work out a solution, and all the short structures begin with the same framework “Data were…by someone”, if the participants would work out a fast correct solution, we suppose both conditions should be the same, which would cause the same results in both conditions. So we think this possibility is not a thing to worry about in the present representative experiment.

For the question about how would we know that the semantic integration processes are the same for the sentence cores as for the whole sentences, we’ve added a detailed explanation into the discussion part follow your query as the following (the newly added explanation is marked by red font for your convenience to review):

> The complete anomalous sentences in the repeated and unrepeated groups shared the same type of semantic anomaly (i.e., the critical words in both anomalous groups could not be integrated into the context successfully to generate a plausible message). Repetitions could enhance the expectancy for anomalous information in the repetition group, but might also cause the participants 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 first, then used the complete anomalous sentence containing the same anomalous information to reinitiate

semantic integration processing. Comparing with the anomalous core structures in the repetition part, the complete anomalous sentences were much more enriched in semantic (i.e., new semantic information were added in). The newly added information in the semantically enriched complete anomalous sentences were used to initiate new semantic integration processing. To process the new information together with the old information, the participants will have to start new semantic integration process to integrate all the word-by-word information input and form a message level interpretation. In the present experiment, we suppose that the P600 effect could provide further evidence for that the participants did not give up later higher level information processing of the critical anomalous word. The P600 effect has been proposed as an indicator of semantic integration, and some other later higher level processes such as syntactic reanalysis, or relationship establishment. These much later and much higher level processing like structural reanalysis and relationship establishment also include the earlier efforts for semantic integration processing. Therefore, we suggest the elicited P600 effect in the semantically enriched new complete sentence indicates that the participants do not give up higher level processing (including semantic integration) while meeting the same anomalous information in a new enriched sentential context.

As analyzed in the introduction part, 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 together, we can infer that the semantic integration difficulty triggered by the complete anomalous sentence should be almost the same as that triggered by the core anomalous structure during its first presentation in the present protocol (i.e., almost unchanged by multiple repetitions). As a result, the initiated new semantic integration processing helps to re-trigger the same degree of semantic integration difficulty after applying multiple repetitions to enhance the participant's expectancy for this anomalous information.

For the worry about "the recognition of anomaly is probably dependent on failure of semantic integration processes, which might cause great difficulties to separate expectedness from semantic processing", we think that during sentence comprehension, there is also another possibility that the participants might actively predict the incoming word as comprehending the continuously input information, when the word input does not match with the prediction, the anomaly could be detected at earlier stage as well. But exactly as you worried, the recognition of anomaly, especially higher level or more complicated anomalies, should be more dependent on failure of semantic integration.

Lastly, thanks for the valuable advice for broadening possible applications of the present protocol, we think broadening new possible applications of the contents of the present protocol is quite important, therefore, we've added an extra part to discuss the possible applications of the present protocol at the end of the manuscript.

Minor Concerns:

My understanding is that some of the new EEG systems out there don't require gel; in which case it may be worth considering whether to broaden the methods. e.g., if your system requires gel, then do this; otherwise, do this.

Reply: Thanks for the advice. We have added necessary notes accordingly into the protocol in the revised manuscript.

A dynamic method to dissociate the confounding influences of expectancy and integrative difficulty residing in the anomalous sentences in ERP studies

Summary:

Here, we present a protocol to dissociate the intertwining factors of the integrative difficulty and unexpectedness in semantically anomalous sentences by applying multiple repetitions to enhance participant's expectancy for the anomalous sentences. The dissociation helps to investigate the major contributor of the elicited ERP effects like N400 in language studies.

Abstract: The confounding factors of the unexpectedness and semantic integration difficulty naturally residing in the anomalous sentences in language studies have caused confusion for researchers 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 the participants' expectancy for rarely-met anomalous sentences by multiple repetitions while maintaining their semantic integration difficulties at the same time. To address the challenge of time cost increase brought by multiple repetitions, this protocol proposes to repeat the strictly simplified core structure extracted from the anomalous sentence first, and then immediately present this semantically enriched, much more informative complete anomalous sentence containing this anomalous information just repeated, to reinitiate the semantic integration processing. The complete anomalous sentence elicited a P600 effect. We suppose that the P600 effect indicates that the participant did not give up processing the anomalous information after repetitions, or that the same type of semantic integration difficulty has been successfully reinitiated. Importantly, the representative experimental results reveal that the greatly attenuated N400 effect caused by multiple repetitions has not been recovered by the follow-up reinitiated semantic integration difficulty. Therefore, we suggest that the reason for the attenuated N400 effect should be mainly attributed to the enhancement of expectancy for anomalous information by multiple repetitions. The experimental results also prove that this method can effectively enhance the participants' expectancy for anomalous sentences while retaining the ~~same type of~~ semantic integration difficulty at the same time.

Keywords: dynamic method; multiple repetitions; enhancing expectancy; retaining integrative difficulty; N400; ERP

Introduction

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

However, although anomalous sentences often cause great difficulties for the semantic integration processing during comprehension, they also contain confounding factors such as unexpectedness (i.e., any anomalous expression is naturally an unexpected expression). These intertwining factors have posed great difficulty for researchers, making it difficult for them to determine the true cognitive process underlies the observed effect elicited by anomalous sentences. For example, if the N400 effect is elicited by an anomalous sentence, it may still be difficult for researchers to judge whether it is caused by unexpectedness[6-8] or

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integrative difficulty[1,9,10].

To figure out whether it is expectancy or semantic integration difficulty that really contributes to the elicited electrophysiological effect, we need to dissociate these two different 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 or low scores in expectancy to form the expected or the unexpected groups respectively. This method has provided an effective way to manipulate expectancy, and it has produced abundant insightful results.

However, as a static approach to manipulate expectancy, it has one limitation: if we manipulate the factor of expectancy with this method, the factor of semantic integration difficulty would be hard to maintain strictly the same between the expected and the unexpected groups. Under this manipulation, the stimuli selected for the expected and unexpected groups have to be different ones (i.e., the semantic integration difficulty has to be altered when we manipulate expectancy by using different stimuli with different expectancy values or cloze probabilities). While we could still find many unexpected but reasonable expressions (i.e., expressions which are unexpected but their words could be successfully integrated into a reasonable message), it might be possible that the integrative efforts required by these unexpected but reasonable expressions are quite different from those required by the normal ones. If the differences are not well controlled, one could expect that it might possibly cause significant differences in brain responses, as there are clear evidences demonstrating that the integrative processing of unexpected but reasonable new metaphorical expressions would trigger quite different brain responses comparing with those triggered by old metaphors[11,12].

To address this issue, we propose a new method in the present protocol to dynamically enhance the participants' expectancy for an anomalous sentence while trying to maintain the semantic integration difficulty the same. The way we introduced here to dynamically enhance the participants' expectancy for an anomalous sentence is by adopting multiple repetitions. During multiple repetitions, the unfamiliar anomalous sentence could be familiarized quickly by the participants, so it could be used to enhance the participants' expectancy. Importantly, multiple repetitions do not change the stimulus itself, therefore ~~it could be assumed that~~ the semantically anomalous information itself remains unchanged (i.e., the critical word could not be successfully integrated into context as before). ~~integration difficulty of the same anomalous sentence should be the same.~~

However, the brain might give up integration after learning that the anomalous information could not be successfully integrated into 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, then uses the complete anomalous sentence, which contains the identical anomalous information, as a semantically enriched version of this core anomalous information, to initiated 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 together, 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 the semantic integration processing during repetitions). Hence, we assume the factor of semantic integration difficulty in the semantically enriched complete anomalous sentences remains unchanged after repetitions as compared with its first presentation in a much more simplified core structure, but the factor of expectancy is greatly enhanced.

Based on all the above assumptions, we then compare the N400 effect elicited by the

semantically enriched complete anomalous sentences containing the repeated core anomalous information with another group of newly met complete anomalous sentences to investigate the major contributor of this elicited ERP effects. The working hypotheses are as follows: according to previous studies, N400 effect would be significantly attenuated by repetition(s). On the basis of the attenuated N400, if the newly initiated semantic integration of the same anomalous information would cause a recovery of the attenuated N400 effect to a similar level as those elicited by the same type of anomalous information contained in the other group of newly met anomalous sentences without repetitions, then it would support that the semantic integration difficulty is the dominant contributor of the elicited N400 effect, otherwise it would speak for the other way round.
The present protocol was approved by the Institutional Review Board of our University.

Protocol

~~The protocol was approved by the Institutional Review Board at the Department of Psychology, Tsinghua University.~~

1. ~~Participants and preparation~~

~~1.~~1.1 ~~Recruit participants who are native speakers with normal or corrected-to-normal vision and with the same handedness (the Edinburgh handedness test could be used to select the participants). The participants should be free of neurological or psychiatric disorders, and not taking any medications affecting the central nervous system.~~

~~2.~~1.2 ~~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.~~

~~2.~~1. Stimuli construction

~~1.2.1~~**1.1 Construct critical anomalous sentences for the repetition and non-repetition group**

1.1.1 Prepare 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 the best to use only emotion free sentences.

~~1. Construct adequate number of anomalous sentences which cause semantic integration difficulties (no less than 40). For example: “These two components were **participled** by a centrifugal device” (The correct form of this anomalous sentence should be “These two components were separated by a centrifugal device”). All of these anomalous sentences are prepared for the repetition group.~~

1.1.2 Construct anomalous sentences based on the correct sentences and then allocate half for the repetition group and allocate half for the non-repetition group. For example, “These two components were **participled** by a centrifugal device” for the repetition group and “These two components were **semicoloned** by a centrifugal device” for the non-repetition group. Ensure that these two groups of anomalous sentences are similar enough in plausibility, violation type and length etc.

~~2. Construct the same number of similar anomalous sentences with semantic integration difficulties, based on those anomalous sentences just created (see step 2.1.1). For example: “These two components were **semicoloned** by a centrifugal device”. All of the anomalous sentences constructed here are prepared for the non-repetition group. Ensure that these two groups of anomalous sentences are similar enough in plausibility, violation type and length etc.~~

~~3.~~1.1.3 Mix all of these 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. Invite another group of native speakers (no less than 30 ones) to score the acceptability of these anomalous sentences using a 1-7 point scale, with the highest

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value representing the highest acceptability.

~~4.~~1.1.4 Select enough pairs of appropriate anomalous sentences (no less than 35) to be used as stimuli according to the scores of acceptability. Anomalous sentences should be rated as low as possible in acceptability (e.g., with scores lower than 2). Ensure that there is no statistical difference between the scores of the selected stimuli in the two anomalous sentence groups~~are statistically valid~~.

~~5. Try the best to use only emotion free sentences.~~

~~1.2.2~~1.2 Prepare corresponding stimuli for these critical anomalous sentences for the use of repetition

~~1.3.1~~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 the study of N400 effect, extract the core elements causing semantic incongruity). Ensure that only the most simplified core anomalous elements were kept (i.e., remove any unnecessary information that is unrelated to the elicitation of the interested effect ~~we are interested in~~). 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".

~~1.3.2~~1.2.2 For the non-repetition group, further change the core structure extracted from the complete anomalous sentence to another different one 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). 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, further replace the key word "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 in the non-repetition group).

~~1.3.3~~1.2.3 Optional minor modifications. Make minor modifications to the extracted core structure in some minor aspects (e.g., tense or singular/plural forms), but ensure that the new one could still elicit the same interested effect ~~we are interested in~~ as its corresponding complete anomalous sentence would. For example, the past tense and plural form in the anomalous core structure could be further changed to its corresponding present tense and singular form: such as changing "components were participled" to "component is participled…". **NOTE:** The minor modification step is optional. If the extracted anomalous core structure to be used for repetition has exactly the same form and order as it appears in the anomalous complete sentence, it is then highly recommended. The purpose of doing this is to prevent the participant from memorizing the core structure as an entire unit, and thus ensuring that the follow-up presentation of the anomalous complete sentence could better reinitiate the semantic integration. (This protocol chooses to apply minor modification.)

~~1.3.4~~1.2.4 Construct a filler short expression for each of the extracted (and modified) core structures in both the repetition and non-repetition group. 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. 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:** Two purposes for the introduction of filler short expressions are: 1) to balance the correctness of the anomalous core structures, 2) to serve as the baseline to observe the 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 might also be influenced by multiple repetitions.

Table 1. Examples of stimuli: Complete sentences and simplified core structures

(a) Example of semantically enriched complete anomalous sentences and their preceding core structures

	Repeated Core Structure	Semantically Enriched Complete Sentence
Control		These two components were separated by a centrifugal device.
Repetition Group	* Component is participled…	* These two components were participled by a centrifugal device.
Non-repetition Group	* Component is differenced…	* These two components were semicoloned by a centrifugal device.

(b) Example of the simplified core structures for the repetition part

	Implausible Expressions	Plausible Expressions
For Repetition Group	* Component is participled…	Component is mixed…
For Non-repetition Group	* Component is differenced…	Component is discovered…

~~1.2.3~~1.3 Construct filler sentences

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~~2.~~1.3.1 Prepare enough filler sentences to enrich the types of sentences and also to make sure that the number of all the normal and anomalous sentences are well-balanced.

~~3.~~1.3.2 Select ~~equal~~ a number of correct filler sentences from the filler sentences (based on the number of all the critical anomalous sentences in the repetition group), and create a repetition part for each of these selected filler ~~them by performing the same operations to these selected filler sentences~~ sentences in a same way as the creation of repetition parts for ~~we did to all~~ 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**: The purpose of introducing a repetition part to these correct filler sentences is to avoid exposure of the critical anomalous sentences (which also have a repetition part prior to them) to participants. After this, there would be two types of complete sentences: sentences with a preceding repetition part (including all the critical sentences and the selected filler sentences to be preceded by a repetition part) and sentences without a preceding repetition part (other sentences).

~~3.~~2. Stimuli presentation

~~**NOTE**: The present protocol achieves the goal of conducting multiple repetitions to a complete sentence by adopting the following method: 1) repeat the core structure (together with its corresponding filler short expression) first, and then present the corresponding complete sentence immediately after the repetition part.~~

~~a)~~2.1 Presentation of the repetition part. Present the extracted core structure and its correct filler expression (see Table 1b) together for certain times (e.g., 7 times) in a random manner (see the repetition part in Fig. 1).

~~b)~~2.2 Presentation of the semantic reinitiating complete sentence. Present the complete anomalous sentence right after its corresponding repetition part (see Fig. 1). (Different colors for the repetition part and complete sentence proves to be helpful for the participants to distinguish these two different parts, for example, dark blue vs. dark green)

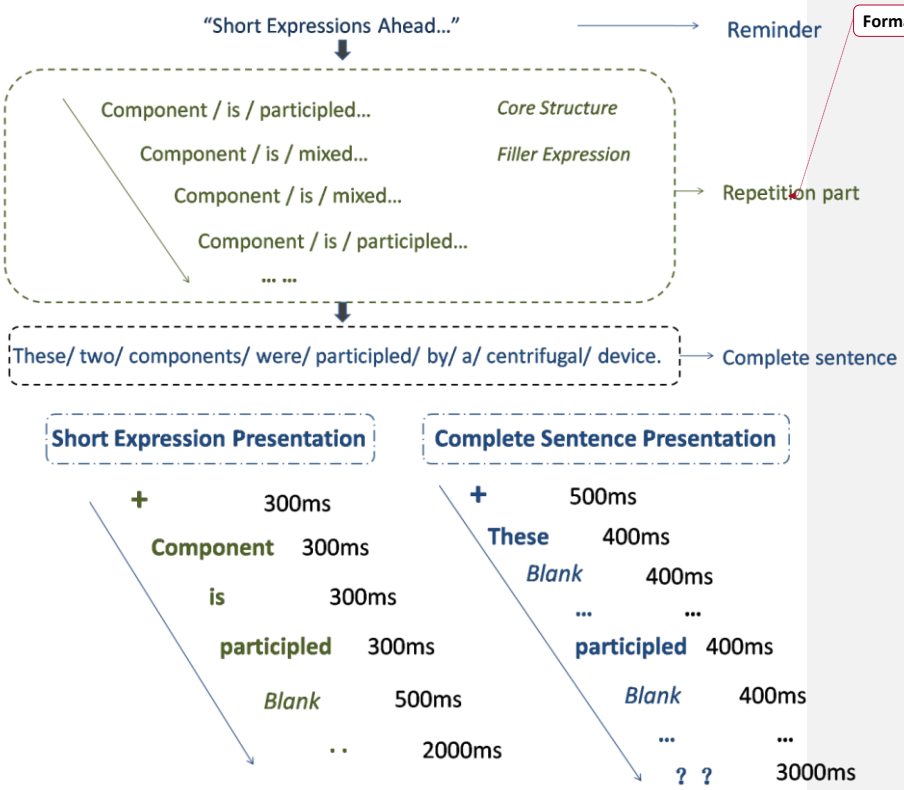

Fig. 1 Schematic illustration of the stimulus presentation

NOTE: Optional modifications. If the experiment only concerns the results of the complete sentence part, then the short expressions could be presented as an entire unit to save time.

~~c)~~2.3 Set tasks for the repetition part and the complete sentence part. Give a task for each core structure in the repetition part to keep participants focused, for example, a plausibility judging task (or other related task which requires the participants to respond differently to different core structures, e.g., judging whether it is a previously given expression or not) . Set the task for the complete sentence part to be the same as the tasks widely used in previous related studies (e.g., plausibility judging) in order to compare the results with previous studies.

~~d)~~2.4 Overall stimuli organization. Present each repetition part (along with its corresponding subsequent complete sentence) only after the incorrect anomalous sentences, so that the presentation of all the stimuli followed the following pattern: an incorrect anomalous sentence would be followed by a repetition part (along with its corresponding subsequent complete sentence), while a correct normal sentence would be followed by another complete sentence (being either correct or incorrect) (see Fig. 2). **NOTE:** This would be helpful in two ways: 1) ~~for you~~ to give the participant a reasonable explanation about why some sentences are preceded by a repetition part but others are not (e.g., by explaining that "only incorrect sentence will be followed by a repetition part, a correct sentence will have the power to bypass the repetition part and jump directly to another complete sentence"); 2) to make the experiment more interesting (avoid the feeling of monotony), and accordingly, make the participant more focused.

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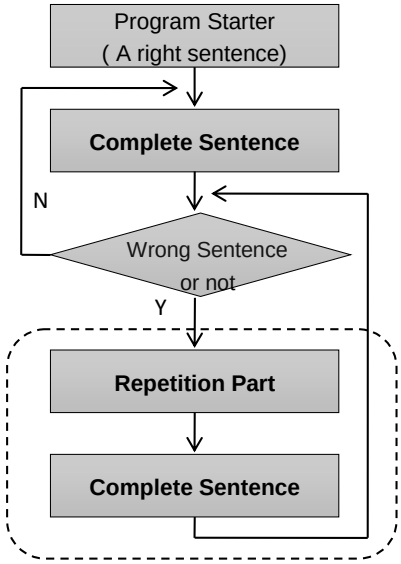

Fig. 2. The organizing method of stimuli in each block [From Huang et al., 2018[21]]

3. Experiment Preparation and Electrophysiological Recording

~~4. Participants and preparation~~

3.1 Recruit participants who are native speakers with normal or corrected-to-normal vision and with the same handedness (the Edinburgh handedness test could be used to select the participants). The participants should be free of neurological or psychiatric disorders, and not taking any medications affecting the central nervous system.

~~3.~~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.

~~1.~~3.3 Inform the participant to have enough sleep and rest before the experiment. Ensure the participant is in a healthy state (having no cough, fever, headache etc.) when attending the experiment

~~2.~~3.4 After the participant arrives at the lab, introduce the equipments 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) to the participant first, in order to help the participant ~~him/her~~ to have a basic knowledge about the overall procedure and eliminate unnecessary worries.

~~3.~~3.5 ~~Give~~ Ask the participant to fill in the Edinburgh Handedness Query Form ~~to the participant~~ if ~~he/she~~the participant has no further questions or worries about the experiment and agrees to participate in the experiment~~, and tell him/her to fill it~~. Confirm whether the participant meets the handedness requirement of the experiment.

~~4.~~3.6 Give the informed consent form to the participant and ask the participant to read it carefully. Make necessary explanations if the participant ~~If the participant have~~ has questions about the content~~, please give him/her clear explanations~~. After ~~he/she~~the participant understands and agrees to all the contents, ask ~~him/her~~the participant to sign the form at the designated place, and proceed to the next step.

~~5.~~3.7 Instruct the participant to clean ~~his/her~~ the head ~~in the laboratory~~ and has the hair dried properly in the laboratory. While waiting for the participant, ~~had~~ get all the needed

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experimental materials ready.~~cap, the cotton swab, the adhesive tape, the conductive gel, sterile syringe with blunt tip needle and tissues ready.~~ **NOTE**: The preparation of experimental materials depends on the requirement of specific recording system.

~~6.~~3.8 Invite the participant to sit comfortably in the chair of the chamber where the experiment will be conducted and then start to prepare the electrodes.

~~7.~~3.9 Before wearing on the cap with electrodes, clean the skin for corresponding electrode(s) on the forehead (e.g., for the electrodes Fpz, Fp1, Fp2, Af7, Af8), ~~the skin~~ under the left eye (e.g., for the VEOG electrode), ~~the skin~~ near the outer canthus of the right eye (e.g., for the HEOG electrode), and ~~the skin~~ around the left and right mastoid bone (e.g., for the electrodes of Tp9, Tp10 which will be used as offline new references) with facial scrub and cotton swab. Be sure to scrub the skin gently and do not make the participant feel uncomfortable, but also ensure that the dead skin cells or other substances such as cosmetics are removed. **NOTE**: The distribution of the electrodes might be different depending on the caps used, in that case 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 the skin cleaning.

3.10 Wear the elastic cap with electrodes on it for the participant. Ensure that the electrode Cz on the cap 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, place the electrodes following 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 have them fixed by adhesive tape. ~~Then f~~**NOTE**: if the system does not require conductive gel, neglect the gel-filling step.

~~8.~~3.12 Fasten the strap under the chin to prevent the adjacent electrodes from moving during the experiment~~(~~. T~~t~~he strap should not be too tight or too loose~~)~~. Connect the cap/electrodes to the recording system.

3.13 Reduce the impedances of all the electrodes to a level below the widely applied impedance threshold for ERP studies (typically below 5kΩ or 10kΩ). To do this~~,~~:

3.13.1 ~~switch~~ Switch the recording software ~~(we use Brain Recorder 2.0)~~ to the impedance monitoring interface;

3.13.2 ~~start~~ Start with the Ground (GND) and Reference (Ref) electrodes first~~,~~;

3.13.3 ~~p~~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 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 (Be careful not to inject too much of it in case that the superfluous gel connects the electrodes with adjacent ones); **NOTE**: if the system does not require conductive gel, neglect this step, but act according to the requirements of the specific system.

3.13.4 ~~c~~Check the real-time impedance level displayed in different colors on the monitor until the impedance become lower than the threshold value. **NOTE:** If the impedance decreases very slow, it is often helpful to speed up the process by using a cotton swab (or the blunt needle tip) to gently press the gel so that the gel could have a better contact with the skin or by making some circles of the cotton swab (or the syringe) but without moving its tip on the scalp~~.~~;

~~9.~~ 3.13.5 After the Ground and Reference electrodes are prepared, deal with the rest of the electrodes with the same method. **NOTE**: Always keep in mind that the impedance reduction process should never make the participant feel uncomfortable. It is also helpful to start and maintain a conversation with the participant while preparing the electrodes.

~~10.~~3.14 Ask the participant to get ready for the experiment. Tell the participant to relax but

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also try ~~their best~~ to avoid excessive eye blinks and body movements during the experiment.

~~11.~~3.15 Inform the participant about the tasks in the repetition part and the main sentence part and ask ~~him/her~~the participant to respond accordingly ~~based on his/her understanding of the stimuli~~. Inform the participant explicitly that an incorrect sentence would be followed by a repetition part and a correct sentence by another complete sentence (could be either correct or incorrect) before the experiment started. **NOTE**: This helps to direct participants' attention to the relationship between the repetition part and the sentence before it rather than its subsequent complete sentence.

~~12.~~3.16 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.

~~13.~~3.17 Start the formal experiment session and record the electrophysiological signals. Divide all the stimuli into different blocks so that the participant could take a break for about 10 minutes between each block.

~~14.~~3.18 Monitor the recording system during recording, if any problem arises, pause the experiment and recording until the problem is solved properly.

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

~~15.~~3.20 Provide the participant with the ~~promised~~ reward and thank the participant~~him/her~~ for the participation.

Representative Results

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

Table 2. Examples of stimuli: Complete sentences and simplified core structures [From Huang et al., 2018[14]]

(a) Example of the simplified core structures in the repetition part

	Implausible Expressions	Plausible Expressions
Repeated Group	* 数据/被人/记者	数据/被人/泄露
	* **Data** *were* **reportered** *by someone*	**Data** *were* **leaked** *by someone*
Unrepeated Group	* 数据/被人/记性	数据/被人/分析
	* **Data** *were* **memoryed** *by someone*	**Data** *were* **analyzed** *by someone*

(b) Example of semantically enriched complete sentences and their preceding core structures

	Repeated Core Structure	Semantically Enriched Complete Sentence
Control		飞行/**数据**/是由/专门/设备/**记录**/的。 The flying **data** were **recorded** by special devices.
Repeated Group	* **数据**/被人/**记者** * **Data** *were* **reportered** *by someone*	* 飞行/**数据**/是由/专门/设备/**记者**/的。 * The flying **data** were **reportered** by special devices.
Unrepeated Group	* **数据**/被人/**记性** * **Data** *were* **memoryed** *by someone*	* 飞行/**数据**/是由/专门/设备/**记号**/的。 * The flying **data** were **markered** by special devices.

The two hypotheses in that study were: 1) N400 effect elicited by semantically anomalous information will be significantly attenuated by multiple repetitions at the first stage; and 2) the follow-up reinitiated semantic integration difficulty (by the same repeated anomalous

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information) will cause a recovery of the already 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 Fig. 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, $F < 1$. ~~The results demonstrated that the N400 effect after the onset of the stimuli became smaller and smaller until almost non-existent.~~

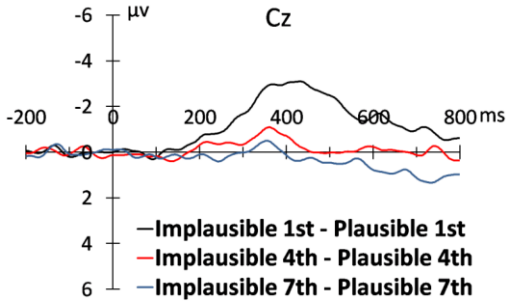

Fig. 3 Differential waves (implausible–plausible) of the first, fourth, and seventh presentation of the core structures in the repetition part at the representative electrode of Cz (black: the first presentation; red: the fourth presentation; blue: the seventh presentation) [From Huang et al., 2018[14]]

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 there is a significant effect of condition, $F(2, 42) = 8.872$, $p = .001$. The follow-up separate ANOVAs indicated that there is a significant effect of semantic anomaly between the control group and the unrepeated anomalous sentence group, $F(1, 21) = 21.580$, $p < .001$. ERPs in the unrepeated anomalous sentence group were more negative than those in the control group. Between the repeated anomalous and unrepeated anomalous group, a significant effect of repetition was revealed, $F(1, 21) = 7.780$, $p = .011$. 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, $F(1, 21) = 1.39$, $p = .252$. The ERPs of the complete sentence part at the representative electrode of Cz were displayed in Fig. 4.

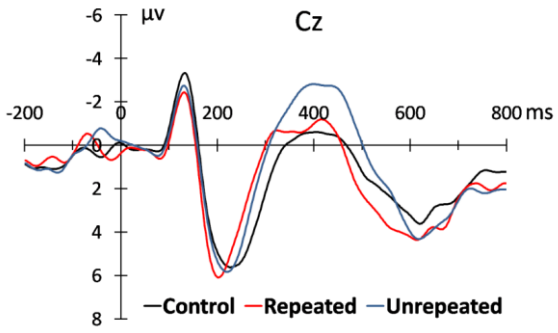

Fig. 4 Event-related potential (ERP) waveforms of the semantically enriched complete sentences in the repeated, unrepeated, and control conditions at the representative electrode of Cz (black:

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control condition; red: repeated sentences; blue: unrepeated sentences) [From Huang et al., 2018[14]]

P600 effects in the complete sentence part

Besides the N400 effect in the repeated complete sentence group, further analysis revealed that there was a marginally significant P600 effect followed the N400 effect in the 500-800ms time window between the repetition and control condition across all the nine ROIs on the scalp ($F(1, 21) = 3.266$, $p = .085$), with the ERPs in the repetition condition more positive, and if we consider only the central-posterior six ROIs, where the P600 effect often reaches its greatest value, the P600 effect would be significant ($F(1, 21) = 8.112$, $p = .010$)

Discussion

The experimental results and significance

In the repetition part, ~~T~~the results demonstrated that the N400 effect ~~after the onset of the stimuli~~ became smaller and smaller until almost non-existent.~~the~~ The greatly attenuated N400 effect proved that multiple repetitions did significantly modulate the amplitude of N400. However, although the N400 effect had been greatly attenuated by multiple repetitions, the results were still not sufficient enough to tell whether N400 was actually affected by the change of expectancy or semantic integration. The attenuated N400 effect could still be explained differently: 1) multiple repetitions enhanced the participants' expectancy for the anomalous expression, thus, it was expectancy which contributed to the attenuation of N400 (supporting that N400 index expectancy rather than semantic integration difficulty); 2) after familiarized with anomalous expressions, the brain realized that the words in the expression simply could not be successfully integrated into a plausible message. Therefore, the brain gave up further attempts to integrate this information (supporting that N400 index semantic integration).

In the complete sentence part, the ERP results reveal that there is no N400 effect in the repetition condition but significant N400 effect in the non-repetition condition. Comparing with the N400 effect elicited by the anomalous sentences in the non-repetition condition, the N400 effect in the repetition condition seems to be almost non-existent. The almost disappeared N400 effect is consistent with the attenuated N400 effect in the repetition part. We suggest that the almost disappeared N400 effects in the repetition condition is caused by multiple repetitions. Besides the N400 effect, the complete anomalous sentences also elicited significant P600 effect. We suggest that the P600 effect reflects later higher level processing to form the message level interpretation.

The complete anomalous sentences in the repeated and unrepeated groups shared the same type of semantic anomaly (i.e., the critical words in both anomalous groups could not be integrated into the context successfully to generate a plausible message). Repetitions could enhance the expectancy for anomalous information in the repetition group, but might also cause the participants 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 first, then used the complete anomalous sentence containing the same anomalous information to reinitiate semantic integration processing. Comparing with the anomalous core structures in the repetition part, the complete anomalous sentences were much more enriched in semantic (i.e., new semantic information were added in). The newly added information in the semantically enriched complete anomalous sentences were used to initiate new semantic integration processing. To process the new information together with the old information, the participants will have to start new semantic integration process to integrate all the word-by-word information input and form a message level interpretation. In the present experiment, we suppose that the P600 effect could provide further evidence for that the participants did not give up later higher level information processing of the critical anomalous word. The P600 effect has been proposed as an indicator of semantic integration[15-19], and some other later higher level processes such as syntactic reanalysis[5,20-22], or relationship establishment[23]. These much later

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and much higher level processing like structural reanalysis and relationship establishment also include the earlier efforts for semantic integration processing. Therefore, we suggest the elicited P600 effect in the semantically enriched new complete sentence indicates that the participants do not give up higher level processing (including semantic integration) while meeting the same anomalous information in a new enriched sentential context. As analyzed in the introduction part, 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 together, we can infer that the semantic integration difficulty triggered by the complete anomalous sentence should be almost the same as that triggered by the core anomalous structure during its first presentation in the present protocol (i.e., almost unchanged by multiple repetitions). As a result, the initiated new semantic integration processing helps to re-trigger the same degree of semantic integration difficulty after applying multiple repetitions to enhance the participant's expectancy for this anomalous information.

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

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The Effectiveness of the Method

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The most important goal of the present protocol is to provide a dynamic way to continuously enhance the participants' expectancy for an anomalous sentence while maintaining the integration difficulty of the sentence (i.e., to prevent the participants from giving up the integration attempts after they have learnt that there is no possibility to integrate the anomalous information into a plausible message 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.

The first thing to evaluate the effectiveness of this protocol is whether the participant's 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 will be[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 and demonstrate that N400 effect has been greatly attenuated by multiple repetitions. Following previous proposals, we suggest that the greatly attenuated N400 effect in the experiment might actually indicate the participants' expectancy for anomalous sentences has been significantly enhanced by multiple repetitions (see Fig. 3).

The second question is whether the follow-up semantically enriched complete anomalous sentence can successfully reinitiate the semantic integration difficulty. For this concern, our experimental results have demonstrated that there is also a ~~marginally~~ significant P600 effect followed the N400 effect in the 500-800ms time window in the repetition condition (see Fig. 4) ~~(F(1, 21) = 3.266, p = .085), and if we only consider the central posterior six ROIs, where the P600 effect often reaches its greatest value, the P600 effect will be significant (F(1, 21) = 8.112, p = .010~~). As discussed above, the elicited P600 effect in the complete anomalous sentence, which reflects later higher level of information processing, indicates that the follow-up more informative sentences have successfully reinitiated the semantic integration

processing of the same anomalous information in an enriched sentential context. Additionally, as the repeated core structures share the same anomalous information with the follow-up complete sentences, we further suggest that the degree of the reinitiated semantic integration difficulty in the complete anomalous sentence is (almost) the same as that before repetition (i.e., the critical word still cannot be integrated into prior context to generate a successful message as before).

Taken together, the present method has been proven to be effective in enhancing the participants' expectancy for anomalous sentences in a dynamic manner while still maintaining the semantic integration difficulty. Therefore, the present method could provide a useful way to dissociate the expectancy elicited effect and the integration elicited effect while processing anomalous sentences. ~~Besides, the present method could also provide insights to future studies with intention to conduct multiple repetitions to the context-rich complete 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 other considerations like time cost, the protocol needs to repeat only the core anomalous information instead of the whole sentence. 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 while constructing the core anomalous structures for the use of repetition, it will increase the total time cost. Therefore, to save time and eliminate any unnecessary information (lay a better foundation for subsequent integration initiation), the core anomalous structure should be as simplified 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 would be useful to conduct a pre-test to exam whether the extracted core structure could elicit the same N400 effect as the complete anomalous sentence before the formal experiment. Besides, if the extracted anomalous core structure to be used for repetition has exactly the same form and order as it appears in the anomalous complete sentence, it is then highly recommended to conduct some minor modifications to the structure as indicated by Step 1.2.3. Otherwise, the participant might memorize the core structure as an entire unit, and therefore block the initiation of the semantic integration by adding new information.

~~Besides, t~~The present method could also provide insights to future studies with intention to conduct multiple repetitions to the context-rich complete sentences.

Figure Legends

Table 1. Examples of stimuli: Complete sentences and simplified core structures

Fig. 1. Schematic illustration of the stimulus presentation

Fig. 2. The organizing method of stimuli in each block [This figure has been modified from Huang et al., 2018[14]]

Table 2. Examples of stimuli: Complete sentences and simplified core structures [This table has been modified from Huang et al., 2018[14]]

Fig. 3. Differential waves (implausible–plausible) of the first, fourth, and seventh presentation of the core structures in the repetition part at the representative electrode of Cz (black: the first presentation; red: the fourth presentation; blue: the seventh presentation) [This figure has been modified from Huang et al., 2018[14]]

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Acknowledgements

This work was supported by the National Natural Science Foundation of China [61433015], National Social Science Major Fund of China [14ZDB154; 15ZDB017], and the MOE (Ministry of Education in China) Project of Humanities and Social Sciences [14YJC740104].

We express our great gratitude to the two anonymous reviewers for their valuable advices.

Disclosures

There are no competing financial interests.

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Licensed Content Date	Nov 7, 2018
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Figures/tables/illustrations used	Fig. 1; Fig. 2; Fig. 3; Table 1
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Expected publication date	Feb 2019
Estimated size of content (pages)	6
Requestor Location	Dr. Yunlong Huang 306, Wenbei Building,Tsinghua University Beijing, Beijing 100084 China Attn: Dr. Yunlong Huang
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