Postprint of the Processing Time Course of Visual Symbolic Negation

Authors: He Dexian, Li Jinhui, Zhou Miao, Chen Yajue, Chen Yu, He Xianyou

Date: 2018-09-07T00:00:00+00:00

Abstract

Using a picture-word matching judgment task to investigate the processing mechanism of visual symbolic negation, three experiments were designed to explore the characteristics of mental simulation in visual symbolic negation at early (250 ms), middle (750 ms), and late (1500 ms) processing stages. The results revealed that at the early, middle, and late stages of visual symbolic negation processing, the reaction times for negation-related words matching the actual state were significantly faster than those for affirmation-related words matching the negated state. This finding indicates that the processing of visual symbolic negation is inconsistent with the two-step simulation hypothesis (two-step simulation hypothesis); participants simulated the actual state of the event from the beginning and maintained this representation throughout, consistent with the one-step simulation hypothesis; furthermore, the suppression/retention hypothesis (the suppression / retention hypothesis) for processing negated information was supported.

Full Text

The Processing of Visual Symbol Negation

He Dexian[1], Li Jinhui[1], Zhou Miao , Chen Yajue[1], Chen Yu[1], He Xianyou[1],[2],[3]

[1]Center for Studies of Psychological Application/School of Psychology, South China Normal University, Guangzhou 510631, China
[2]Key Research Institute of Humanities and Social Sciences in Universities –Center for Studies of Psychological Application, Ministry of Education, Guangzhou 510631, China
[3]Guangdong Key Laboratory of Mental Health and Cognitive Science, Guangzhou 510631, China
Guangzhou Financial Guarantee Center Co., Ltd, Guangzhou 510030, China

Abstract

This study employed a picture-word matching judgment task to investigate the processing mechanism of visual symbol negation. Three experiments were designed to examine the characteristics of mental simulation during early (250 ms), middle (750 ms), and late (1500 ms) stages of visual symbol negation processing. Results revealed that across all three stages, reaction times for negation-related words matching the actual state were significantly faster than those for affirmation-related words matching the negated state. These findings indicate that visual symbol negation processing is inconsistent with the two-step simulation hypothesis; participants simulated the actual state of events from the outset and maintained this representation throughout, supporting the one-step simulation hypothesis. Furthermore, the suppression/retention hypothesis for processing negated information was supported.

Keywords: visual symbol negation; visual negation marker; two-step simulation hypothesis; suppression/retention hypothesis

---

Introduction

Psycholinguistic research on negation processing mechanisms began in the 1960s and 1970s, focusing primarily on two aspects: the global effects of negation (its impact on processing entire sentences) and the local effects of negation (its impact on information within its scope). Early theoretical explanations for why negative sentences are more difficult to process than their affirmative counterparts included accounts based on sentence length, pragmatic hypothesis, Chomsky' s transformational grammar, word frequency, and sentence-related connotation (Wason, 1965; Kintsch & Dijk, 1978; Lüdtke & Kaup, 2006). However, these explanations failed to fully reveal the essence of negation processing. Consequently, psychologists proposed propositional theory and the experiential-simulations view to uncover the fundamental nature of negation processing.

Propositional theory (Kintsch & Dijk, 1978) posits that propositions constitute the building blocks of cognition. People represent information in language comprehension through propositional symbolic representations that form propositional networks, which are continuously updated through different operations or repeated operations. Understanding linguistic material involves constructing corresponding propositional representations. In this framework, negation is considered an explicit operator that incorporates the entire proposition into the scope of negation. For example, the negated proposition of the sentence "Sam is not wearing a hat" is "Sam is wearing a hat." Because negative sentences contain an additional propositional layer compared to their affirmative counterparts, constructing meaning representations for negative sentences is more complex and difficult, making them harder to process and comprehend. This additional propositional capsule also reduces the accessibility of negated information (e.g., "hat").

The experiential-simulations view, derived from perceptual symbol system theory (Barsalou, 1999), proposes that language understanding involves constructing mental models of situations described in sentences or discourse based on existing experience—a form of re-experiencing the described situation. This process is essentially experiential because it is grounded in perception and action, with negation being implicitly represented as a linguistic operator (Zwaan, Stanfield, & Yaxley, 2002; Zwaan & Taylor, 2006; Gao, Lu, & Ma, 2011). Building on this theory, Kaup and colleagues proposed the two-step simulation hypothesis (Kaup & Zwaan, 2003; Kaup, Zwaan, & Lüdtke, 2007), which posits that negation processing involves two stages: simulation of the negated state followed by simulation of the actual state. The negated state of an event is initially represented, then at some critical point this representation is suppressed, and only in the late processing stage is the actual state of the negative sentence represented. For instance, when processing the independent negative sentence "The door is not open," participants first mentally simulate "an open door," then at a certain key point begin simulating the actual state of the event, namely "a closed door." Experimental results using sentence-picture verification paradigms and picture naming tasks have supported this two-step simulation hypothesis (Kaup, Lüdtke, & Zwaan, 2005; Kaup, Lüdtke, & Zwaan, 2006).

However, some studies on Chinese negative sentence comprehension have yielded inconsistent results. Gao (2006) found that while negative declarative sentences followed the experiential-simulations view, negative imperative sentences consistently represented the negated state, with simulation of the event' s actual state occurring in either the initial or middle stage of comprehension. Gao et al. (2011) investigated Chinese simple negative sentences with independent predicates and found that the mental simulation process for this type of negative sentence did not conform to the two-step simulation hypothesis; instead, simulation of the event' s actual state was completed in the initial stage of comprehension. Relative to the two-step simulation hypothesis, this early completion of actual state simulation can be termed the one-step simulation view, wherein the actual state of an event is simulated early in negation comprehension, achieving access to the meaning of negative sentences without requiring a two-step process.

Regarding the late stage of negation processing, after participants have simulated the actual state of an event, researchers disagree on whether the negated state remains activated or becomes inhibited. This disagreement manifests as two opposing views: the suppression hypothesis and the suppression/retention hypothesis. The suppression hypothesis suggests that once the actual state of an event has been simulated, the negated state becomes unnecessary and is therefore discarded directly; that is, negation prompts comprehenders to suppress information within its scope (Hasson & Glucksberg, 2006; MacDonald & Just, 1989). In contrast, the suppression/retention hypothesis (Giora, Balaban, Fein, & Alkabets, 2005; Giora, 2006; Giora, Fein, Aschkenazi, & Alkabetszlozover, 2007) argues that suppression of negated concepts is not mandatory in the later stages of negation processing; rather, the decision to suppress or retain depends on the purpose of the context and the speaker' s intent.

In linguistic expression and communication, negation is often conveyed not only through negative adverbs but also through visual symbols (e.g., ×,) that we refer to as visual negation. Existing perspectives on visual communication suggest that visual and verbal communication differ in many respects, particularly in the substantial limitations of visual information for expressing negation. For example, pictures cannot express negation as flexibly as words (e.g., Chinese "不," "不是," "没有" or English "This is not a⋯" or "It is not the case that⋯can do") (Worth & Gross, 1981); visual images lack verbs or nouns and therefore cannot express "A is B" or "A is not B" (Kennedy & John, 2008; Sonesson & Series, 1989). Nevertheless, numerous real-world images can express negation through visual symbols that convey meanings like "prohibited" or "do not." For instance, placing an "×" on a picture constitutes what is known as a visual negation marker (Giora, Heruti, Metuk, & Fein, 2009).

One possible outcome of visual symbol negation is the retention of negated information, as illustrated by road traffic signs. Natural environment road traffic signs cannot be ambiguous and are highly constrained by context, making them ideal for testing the sensitivity of negation to situational information. When the situation requires avoiding replacement of negated information with its opposite, the suppressive effect of negation is impeded. However, visual negation in road signs does not absolutely prevent suppression; rather, this suppression occurs conditionally and may retain information within the scope of negation, similar to verbal negation. For example, both negative (Figures 1a [Figure 1: see original paper], 1b) and affirmative (Figure 1c) signs accurately convey their meanings without triggering complex inferential processes, much like verbal signs such as "No Entry." The "Do Not Enter" sign in Figure 1a does not necessarily activate its opposite concept "Exit," and the "No Right Turn" sign in Figure 1b does not necessarily evoke the concept "Left Turn," although this is its only possible opposite concept (going straight is an option but not the opposite of "left turn").

Giora et al. (2009) used a rating method to study pictures with negation markers. Participants were shown a picture with a visual negation marker (e.g., an open door with an "×"), followed by three interpretations of the picture' s meaning: a negation expression ("Don' t leave the door open!"), an affirmative expression ("Close the door!"), and a minimally related interpretation ("There is a strong lock in the door"). Participants rated the extent to which each interpretation reasonably explained the stimulus. Results showed that the negation expression received the highest rating, significantly different from the affirmative expression. This indicates that negation is sensitive to situational information and does not necessarily trigger suppression effects; under appropriate circumstances, negated information may be retained even when opposite information is available.

Most experimental evidence for the two-step simulation hypothesis comes from studies on independent negative sentence processing mechanisms. Does the processing of visual symbol negation also conform to this hypothesis? Based on previous research on negation sentence processing mechanisms (Kaup et al., 2006; Gao et al., 2011), we defined early, middle, and late stages of visual symbol negation comprehension as 250 ms, 750 ms, and 1500 ms, respectively, and designed three experiments to investigate the processing trajectory of visual symbol negation.

The fundamental logic of this study is as follows: If visual symbol negation processing follows the two-step simulation hypothesis, then the negated state should be simulated early and the actual state simulated late. For instance, in a visual symbol negation for "No Smoking," "smoking" represents the negated state. Therefore, in the early processing stage, affirmation-related words matching the negated state (smoking) should elicit significantly faster responses than negation-related words matching the actual state (no smoking). In the late processing stage, negation-related words matching the actual state (no smoking) should be significantly faster than affirmation-related words. Conversely, if visual symbol negation processing directly represents the actual state, then from the early stage onward, the visual symbol negation should be consistent with the actual state (no smoking), resulting in significantly shorter response times for negation-related words matching the actual state compared to affirmation verbs matching the negated state, with consistent results across early and late processing stages.

Experiment 1: Early Stage Processing (250 ms ISI)

2.1 Purpose

To investigate the characteristics of mental simulation during the early processing stage of visual symbol negation using a 250 ms interval.

2.2 Participants

Thirty undergraduate and graduate students from South China Normal University voluntarily participated in the experiment. All participants had normal or corrected-to-normal vision, no color blindness or color weakness, were native Chinese speakers, and had no reading or image recognition disabilities. None had participated in material evaluation or similar experiments, and they received compensation after the experiment.

2.3 Materials

Experimental Pictures: Seventy-two pairs of visual pictures depicting concrete actions and corresponding pictures with a red "×" negation marker, plus 72 pairs of filler visual pictures with the same red "×" marker. All pictures were processed using Photoshop CS6 software and measured 314 × 314 pixels.

Experimental Words: Seventy-two pairs of verbs corresponding to or opposite from the markers in the pictures (e.g., "smoking/no smoking"), which formed matching or non-matching relationships with the affirmative and negated states of the visual pictures. Filler words were verbs unrelated to the picture content (e.g., "injection"), with filler materials matching the formal materials in length and structure.

Sample experimental pictures and their corresponding probe words are shown in Table 1 .

Material Evaluation: Before the formal experiment, we conducted two evaluations of the experimental materials: (1) To ensure participants could accurately understand picture meanings, we first assessed picture familiarity using a 7-point scale (1 = completely unfamiliar, 7 = completely familiar, with 2–6 representing increasing familiarity). Pictures with mean ratings above 6 were selected, resulting in 72 pairs of concrete verb pictures (affirmative and corresponding negative pictures) as experimental materials. (2) To ensure that concrete action words (affirmative or negative) truly reflected the final meaning expressed by the visual pictures (affirmative or negative), we conducted a 2-point consistency rating (1 = consistent, 0 = inconsistent). Results confirmed that participants automatically processed "×" as carrying negation meaning.

2.4 Design

This experiment employed a 2 (picture type: affirmative vs. negative) × 2 (probe word type: affirmative verb vs. negative verb) within-subjects design. Dependent variables were reaction time and accuracy. A picture-word matching judgment task was used. Latin square balancing was applied to experimental materials and conditions, ensuring each experimental version contained only one condition of each material pair.

The experiment comprised 144 sets of materials (72 experimental and 72 filler sets). Each experimental set included one visual picture (affirmative or negative) and one probe word (matching or non-matching). Each filler set included one visual picture (affirmative or negative) and one verb completely unrelated to the picture meaning. Filler materials were included to balance "match" and "non-match" response ratios; filler data were not analyzed. Experimental sequence was randomized to control for practice and fatigue effects.

2.5 Procedure

The experiment used a picture-word matching paradigm. On each trial, participants first saw a red fixation cross "+" at the center of the screen for 500 ms, followed by a visual picture. The picture disappeared when participants pressed a key within 3000 ms. After picture offset, a blank screen appeared for 250 ms, followed by a verb phrase. Participants judged whether the word was consistent with the previous picture and responded by pressing "F/J" or "J/F" keys. The procedure is illustrated in Figure 2 [Figure 2: see original paper]. To balance hand dominance effects, half of the participants used "F" for "match" and "J" for "non-match," while the other half used the opposite mapping. The computer automatically recorded response times from word onset and judgment accuracy.

Participants placed their left index finger on the "F" key and right index finger on the "J" key at the start. They were instructed to examine each picture carefully and were informed that some pictures would be followed by content-related verbs, with their response times being recorded. They were asked to respond as quickly and accurately as possible. The entire experiment lasted approximately 15 minutes and included 18 practice trials before the formal experiment.

2.6 Results and Analysis

To ensure data reliability, we first analyzed accuracy and excluded participants with accuracy rates below 80%, resulting in the removal of 4 participants and leaving 26 valid participants. We then excluded incorrect responses and extreme data points beyond three standard deviations from the mean response time. Statistical analysis was performed using SPSS 16.0. Mean reaction times and accuracy rates for picture-word matching judgments are presented in Table 2 .

Repeated measures ANOVA on reaction times revealed significant main effects of picture type, $F1(1,25) = 47.34$, $p < 0.001$, $2 = 0.65$; $F2(1,35) = 35.43$, $p < 0.001$, $2 = 0.50$, and probe word type, $F1(1,25) = 17.72$, $p < 0.001$, $2 = 0.42$; $F2(1,35) = 20.15$, $p < 0.001$, $2 = 0.37$. The interaction between picture type and probe word type was also significant, $F1(1,25) = 94.10$, $p < 0.001$, $2 = 0.79$; $F2(1,35) = 79.85$, $p < 0.001$, $2 = 0.69$.

Simple effects analysis of the significant interaction showed that for affirmative pictures, responses to affirmative verbs were significantly faster than to negative verbs, $F1(1,25) = 86.67$, $p < 0.001$; $F2(1,35) = 95.00$, $p < 0.001$. For negative pictures, responses to negative verbs were significantly faster than to affirmative verbs, $F1(1,25) = 16.20$, $p < 0.001$; $F2(1,25) = 17.36$, $p < 0.001$.

Repeated measures ANOVA on accuracy revealed significant main effects of picture type, $F1(1,25) = 15.19$, $p = 0.001$, $2 = 0.38$; $F2(1,35) = 13.93$, $p = 0.001$, $2 = 0.29$, and probe word type, $F1(1,25) = 9.50$, $p = 0.005$, $2 = 0.28$; $F2(1,35) = 14.96$, $p < 0.001$, $2 = 0.30$. The interaction between picture type and probe word type was significant by participants but not by items, $F1(1,25) = 5.09$, $p = 0.033$, $2 = 0.17$; $F2(1,35) = 2.60$, $p = 0.116$, $2 = 0.07$.

Given the significant interaction by participants, simple effects analysis was conducted. Results showed that for affirmative pictures, accuracy for affirmative verbs was significantly higher than for negative verbs, $F1(1,25) = 25.40$, $p < 0.001$. For negative pictures, accuracy for negative verbs did not differ significantly from affirmative verbs, $F1(1,25) = 0.63$, $p = 0.435$.

According to the two-step simulation hypothesis (Kaup & Zwaan, 2003), comprehenders first represent the negated state of a sentence in early processing stages. However, our results showed that when picture type was negative, the difference in reaction times between affirmative and negative verbs was significant, with significantly faster responses to negative verbs than to affirmative verbs. This indicates that participants responded faster to the actual state of concrete actions, suggesting that early processing of pictures with negation markers may differ from that of verbal negation and does not conform to the two-step simulation hypothesis.

To further verify whether visual symbol negation processing follows the two-step simulation hypothesis, we designed Experiments 2 and 3 to examine mental simulation characteristics during middle (750 ms) and late (1500 ms) stages of visual symbol negation processing.

Experiment 2: Middle Stage Processing (750 ms ISI)

3.1 Purpose

To investigate the characteristics of mental simulation during the middle processing stage of visual symbol negation using a 750 ms interval.

3.2 Participants

Thirty-one undergraduate and graduate students from South China Normal University voluntarily participated. All had normal or corrected-to-normal vision, no color blindness or weakness, were native Chinese speakers, and had no reading or image recognition disabilities. None had participated in material evaluation or similar experiments.

3.3 Materials

Identical to Experiment 1.

3.4 Design

Identical to Experiment 1.

3.5 Procedure

Identical to Experiment 1, except that the interval after picture offset was extended from 250 ms to 750 ms.

3.6 Results and Analysis

To ensure data reliability, participants with picture-word matching accuracy below 80% were excluded, resulting in the removal of 3 participants and leaving 28 valid participants. Incorrect responses and extreme data points beyond three standard deviations were also excluded. Data were analyzed using the same method as Experiment 1. Mean reaction times and accuracy rates are presented in Table 3 .

Repeated measures ANOVA on reaction times revealed significant main effects of picture type, F1(1,27) = 24.68, $p < 0.001$, 2 = 0.48; F2(1,35) = 47.39, $p < 0.001$, 2 = 0.58, and probe word type, F1(1,27) = 14.85, p = 0.001, 2 = 0.36; F2(1,35) = 18.27, $p < 0.001$, 2 = 0.34. The interaction between picture type and probe word type was significant, F1 = 70.72, $p < 0.001$, 2 = 0.72; F2(1,35) = 108.53, $p < 0.001$, 2 = 0.76.

Simple effects analysis showed that for affirmative pictures, responses to affirmative verbs were significantly faster than to negative verbs, F1(1,27) = 60.51, $p < 0.001$; F2(1,35) = 95.53, $p < 0.001$. For negative pictures, responses to negative verbs were significantly faster than to affirmative verbs, F1(1,27) = 16.95, $p < 0.001$; F2(1,35) = 18.75, $p < 0.001$.

Repeated measures ANOVA on accuracy revealed no significant main effect of picture type, F1(1,27) = 1.08, p = 0.31, 2 = 0.04; F2(1,35) = 0.21, p = 0.65, 2 = 0.01. The main effect of probe word type was significant by both participants and items, F1(1,27) = 5.85, p = 0.023, 2 = 0.18; F2(1,35) = 5.29, p = 0.028, 2 = 0.13. The interaction between picture type and probe word type was not significant, F1(1,27) = 3.84, p = 0.06, 2 = 0.13; F2(1,35) = 1.75, p = 0.194, 2 = 0.05.

The data pattern obtained at 750 ms was almost identical to that at 250 ms, indicating that participants consistently simulated the actual state throughout the middle stage of visual symbol negation processing.

Experiment 3: Late Stage Processing (1500 ms ISI)

4.1 Purpose

To investigate the characteristics of mental simulation during the late processing stage of visual symbol negation using a 1500 ms interval.

4.2 Participants

Thirty-two undergraduate and graduate students from South China Normal University voluntarily participated. All had normal or corrected-to-normal vision, no color blindness or weakness, were native Chinese speakers, and had no reading or image recognition disabilities. None had participated in material evaluation or similar experiments, and they received compensation after the experiment.

4.3 Design

Identical to Experiment 1.

4.4 Materials

Identical to Experiment 1.

4.5 Procedure

Identical to Experiment 1, except that the blank screen interval after picture offset was increased from 250 ms to 1500 ms.

4.6 Results and Analysis

Using the same exclusion criteria, participants with accuracy below 80% were removed, resulting in the exclusion of 5 participants and leaving 27 valid participants. Incorrect responses and extreme data points beyond three standard deviations were excluded. Data were analyzed using identical methods. Mean reaction times and accuracy rates are presented in Table 4 .

Repeated measures ANOVA on reaction times revealed significant main effects of picture type, $F1(1,26) = 51.99$, $p < 0.001$, $2 = 0.67$; $F2(1,35) = 61.24$, $p < 0.001$, $2 = 0.64$, and probe word type, $F1(1,26) = 30.12$, $p < 0.001$, $2 = 0.54$; $F2(1,35) = 34.63$, $p < 0.001$, $2 = 0.50$. The interaction between picture type and probe word type was significant, $F1(1,26) = 52.25$, $p < 0.01$, $2 = 0.67$; $F2(1,35) = 58.57$, $p < 0.001$, $2 = 0.63$.

Simple effects analysis showed that for affirmative pictures, responses to affirmative verbs were significantly faster than to negative verbs, $F1(1,26) = 71.68$, $p < 0.05$; $F2(1,35) = 112.12$, $p < 0.001$. For negative pictures, responses to negative verbs were significantly faster than to affirmative verbs, $F1(1,26) = 7.40$, $p < 0.05$; $F2(1,35) = 7.34$, $p = 0.01$.

Repeated measures ANOVA on accuracy revealed no significant main effect of picture type, $F1(1,26) = 0.12$, $p > 0.05$; $F2 < 1$. The main effect of probe word type was not significant, $F1(1,26) = 1.67$, $p = 0.21$; $F2(1,35) = 1.39$, $p = 0.25$. The interaction between picture type and probe word type was significant, $F1(1,26) = 9.90$, $p < 0.01$; $F2(1,35) = 7.43$, $p = 0.01$, $2 = 0.18$.

Simple effects analysis of this significant interaction revealed that for affirmative pictures, accuracy for affirmative verbs was higher than for negative verbs, $F1(1,26) = 11.28$, $p < 0.05$; $F2(1,35) = 8.91$, $p < 0.01$. For negative pictures, accuracy did not differ significantly between affirmative and negative verbs, $F1(1,26) = 1.33$, $p > 0.05$; $F2(1,35) = 1.59$, $p > 0.05$.

The pattern of results in Experiment 3 replicated those of Experiments 1 and 2, demonstrating that participants continued to simulate the actual state of events during the late stage of visual symbol negation processing, contrary to the two-step simulation hypothesis.

General Discussion

To more clearly understand the processing trajectory of visual symbol negation, we conducted a comprehensive analysis combining results from all three experiments representing early (250 ms), middle (750 ms), and late (1500 ms) processing stages. First, a 2 (picture type) × 2 (probe word type) × 3 (time interval) repeated measures ANOVA on reaction times revealed significant main effects of picture type, F1(1,78) = 116.21, p < 0.001, 2 = 0.60; F2(1,105) = 136.03, p < 0.01, 2 = 0.56, and probe word type, F1(1,78) = 60.09, p < 0.001, 2 = 0.44; F2(1,105) = 69.60, p < 0.001, 2 = 0.40. The main effect of time interval was marginally significant by participants and significant by items, F1(2,78) = 3.04, p = 0.05, 2 = 0.435; F2(2,105) = 22.55, p < 0.001, 2 = 0.30. No significant interactions were found between picture type and time interval, F1(2,78) = 0.51, p = 0.60; F2(2,105) = 0.02, p = 0.98, or between probe word type and time interval, F1(2,78) = 0.36, p = 0.69; F2(2,105) = 0.32, p = 0.73. However, the interaction between picture type and probe word type was significant, F1(1,78) = 206.04, p < 0.001, 2 = 0.73; F2(1,105) = 235.83, p < 0.001, 2 = 0.69. The three-way interaction was not significant, F1(2,78) = 0.07; F2(2,105) = 0.16, p = 0.86.

Simple effects analysis of the significant picture type × probe word type interaction revealed that for affirmative pictures, responses to affirmative verbs were significantly faster than to negative verbs, F1(1,80) = 218.37, p < 0.001; F2(1,107) = 303.59, p < 0.001. For negative pictures, responses to negative verbs were significantly faster than to affirmative verbs, F1(1,80) = 39.27, p < 0.001; F2(1,107) = 40.81, p < 0.001. These results again demonstrate that across early, middle, and late stages of negative picture processing, participants responded significantly faster to negative verbs than to affirmative verbs, indicating that the final state of events was represented from the earliest processing stage.

A parallel analysis on accuracy revealed significant main effects of picture type, F1(1,78) = 10.98, p = 0.001, 2 = 0.12; F2(1,105) = 5.84, p = 0.017, 2 = 0.05, and probe word type, F1(1,78) = 16.19, p < 0.001, 2 = 0.17; F2(1,105) = 17.65, p < 0.001, 2 = 0.14. The main effect of time interval was not significant, F1(2,78) = 0.69, p = 0.51; F2(2,105) = 0.34, p = 0.72. The interaction between picture type and time interval was significant, F1(2,78) = 4.704, p = 0.01, 2 = 0.11; F2(2,105) = 4.55, p = 0.013, 2 = 0.08. The interaction between probe word type and time interval was not significant, F1(2,78) = 1.56, p = 0.21; F2(2,105) = 1.75, p = 0.18. The interaction between picture type and probe word type was significant, F1(1,78) = 18.22, p < 0.001, 2 = 0.19; F2(1,105) = 11.05, p = 0.001, 2 = 0.10. The three-way interaction was not significant, F1(2,78) = 0.47, p = 0.63; F2(2,105) = 0.80, p = 0.45.

Simple effects analysis of the significant picture type × time interval interaction revealed that at the 250 ms interval, accuracy for affirmative pictures was significantly higher than for negative pictures, F1(1,51) = 16.09, p < 0.001; F2(1,71)

= 10.93, p = 0.001. At both 750 ms and 1500 ms intervals, accuracy differences between affirmative and negative pictures were not significant (750 ms: F1(1,51) = 1.23, p = 0.27; F2(1,71) = 0.18, p = 0.68; 1500 ms: F1(1,51) = 0.10, p = 0.754; F2(1,71) = 0.01, p = 0.94).

Simple effects analysis of the significant picture type × probe word type interaction revealed that for negative pictures, the difference between affirmative and negative verbs was significant, with higher accuracy for affirmative verbs than negative verbs, $F1(1,80) = 43.64$, $p < 0.001$; $F2(1,107) = 37.14$, $p < 0.001$. For negative pictures, accuracy did not differ significantly between affirmative and negative verbs, $F1(1,80) = 0.01$, $p = 0.916$; $F2(1,107) = 0.04$, $p = 0.83$.

This study investigated mental simulation characteristics during early (250 ms), middle (750 ms), and late (1500 ms) stages of visual symbol negation processing to test whether the two-step simulation hypothesis, developed to explain verbal symbol negation, could also explain visual symbol negation processing, and to examine whether negated information in late processing stages follows the suppression hypothesis or the suppression/retention hypothesis.

According to the two-step simulation hypothesis, the negated state should be simulated first in the initial stage (250 ms), resulting in faster response times to affirmation-related words matching the negated state than to negation-related words matching the final state. In the middle stage (750 ms), a transition from simulating the negated state to simulating the actual state should occur, resulting in no significant difference between affirmation-related and negation-related words. In the late stage (1500 ms), the actual state should be simulated, resulting in faster responses to negation-related words than affirmation-related words. However, results from all three experiments showed that across 250 ms, 750 ms, and 1500 ms intervals, differences between affirmation-related and negation-related words were consistently significant, with negation-related words always eliciting faster responses. This indicates that participants consistently simulated the actual state of pictures—the final state of events—supporting the one-step simulation hypothesis. The two-step simulation hypothesis derived from verbal symbol negation research cannot explain visual symbol negation processing, suggesting that visual and verbal symbol negation involve different mechanisms.

Theoretical Explanation of Mental Simulation in Visual Symbol Negation

In psycholinguistics, numerous studies have demonstrated that negated concepts are accessed during early stages of negation processing (150–500 ms). For example, when processing "The window is not open," comprehenders initially simulate "The window is open." However, different perspectives exist regarding mental simulation in later stages of negation processing. The suppression hypothesis posits that suppression of negated information is inevitable and reduces activation of negated concepts below baseline levels (Hasson & Glucksberg, 2006;

Kaup et al., 2006). Therefore, when comprehenders process negative materials for longer durations (1500 ms), negated concepts are suppressed and replaced by their opposite concepts (Kaup et al., 2006; MacDonald & Just, 1989). For instance, in "The window is not open," "open" would be replaced by "closed."

In contrast, the suppression/retention hypothesis (Giora et al., 2005; Giora, 2006; Giora et al., 2007) argues that suppression of negated concepts is not obligatory but depends on contextual purpose and speaker intent. According to this view, negation involves not simple contrast but a series of contextual activation effects (Horn & Ward, 2006). When we say "Not X," we mean "Not X" rather than replacing "X" with its opposite "Y." In such cases, comprehenders retain concept "X" in mind rather than activating its opposite "Y." When relevant to prior or subsequent context, negated concepts are often not suppressed but rather preserved in consciousness and activated when appropriate (Giora et al., 2007).

Shuval (2006) used a visual world paradigm in which participants heard sentences while viewing four visual stimuli related to concepts in the sentence, with eye movements recorded. Results showed that fixation times on negated objects did not differ significantly from those on affirmed objects, with eye movement patterns showing participants shifting between the two objects. This suggests that negated objects were not suppressed but preserved in participants' minds.

ERP evidence also supports the suppression/retention hypothesis. Lüdtke, Friedrich, De, and Kaup (2008) found that when the time interval was 1500 ms, brain responses to probe pictures of "ghost" in sentences "In front of the tower there was / was no ghost" showed no differences, indicating that even without context, suppression effects for negated concepts did not occur and negated concepts remained as accessible as affirmed concepts.

Giora et al. (2009) used a rating method to study visual negation pictures and found that negation expressions ("Don' t leave the door open!") received the highest ratings, significantly different from affirmative expressions ("Close the door!"). This demonstrates that negation does not necessarily trigger suppression effects and that under appropriate circumstances, negated information may be retained even when opposite information is available.

Our results support the suppression/retention hypothesis. During visual symbol negation processing, the negated state was not suppressed despite increasing time intervals but persisted in participants' minds from the initial through the late processing stages.

General Discussion

Experimental results showed that across all three time intervals, when visual pictures were affirmative, responses to affirmative verbs were significantly faster than to negative verbs. However, when visual pictures were negative, responses to negative verbs were significantly faster than to affirmative verbs. This pattern reflects two issues: first, the difference between affirmative and negative sentence processing, consistent with previous research; second, the difference between visual symbol negation and verbal symbol negation processing. Previous research on verbal symbol negation has largely supported the two-step simulation hypothesis, with the first step simulating the negated state (faster responses to affirmative verbs) and the second step simulating the actual state (faster responses to negative verbs). In contrast, our three experiments consistently found that participants responded faster to negative verbs across all processing stages, indicating that visual symbol negation involves a processing mechanism different from that of verbal symbol negation.

The presence of the visual negation marker "×" influenced participants' picture-word matching judgments from the earliest processing stage, inhibiting access to the negated state while facilitating access to the actual (final) state. This may be determined by inherent characteristics of visual symbol negation pictures. Pictures are often more intuitive than sentence negation, making picture comprehension simpler and involving shallower processing levels. The visual negation marker "×" makes the actual state of events visually salient, enabling participants to more easily simulate this state. Moreover, because these visual negation markers are highly familiar and common in daily life, this highly experiential visual negation marker may form relatively stable associations with its intended meaning in an implicit manner. Upon encountering such markers, participants may automatically trigger established connections and directly simulate the actual state. If this explanation is valid, future research could further test this hypothesis from a developmental perspective or by examining how learning experiences alter associations between visual negation markers and actual event states.

Visual symbol negation is extremely important in both verbal and nonverbal communication, yet research in this area remains scarce with limited experimental evidence. This study empirically supplements and enriches research in this domain, validates the one-step simulation hypothesis, and provides preliminary exploration of whether theories of negation derived from verbal research can be extended to the visual domain. Our investigation of mental simulation across early, middle, and late stages of visual negation processing contributes significantly to understanding the universal mechanisms underlying human negation information processing.

It should be noted that existing theories of negation processing mechanisms are almost exclusively based on verbal symbol (sentence processing) research. While Giora et al. (2009) studied visual negation processing, they did not explore its underlying mechanisms, leaving our understanding of visual symbol negation processing mechanisms quite limited. Given that Chinese characters are themselves pictographic and share certain similarities with graphic processing, and in the absence of established theories to guide us, this study attempted to explore visual symbol negation processing mechanisms by adopting the same time points used in verbal symbol negation research to demarcate early, middle, and late processing stages. The appropriateness of this division requires further investigation.

Regarding experimental paradigm, we adapted the classic picture-word matching judgment task from negation processing research to reveal mental simulation characteristics in visual negation processing. In our experiments, participants viewed pictures at their own pace, pressing a key within 3000 ms of picture onset. After picture offset (or automatic disappearance after 3000 ms without response), a blank screen appeared for 250 ms, 750 ms, or 1500 ms before the verb phrase appeared, requiring participants to judge its consistency with the previous picture. While this procedure ensured careful picture processing, it also allowed participants potentially sufficient time to fully process visual pictures before keypress. We reviewed extensive literature and found that many classic studies on negation processing (Zwaan et al., 2002; Kaup et al., 2005; Kaup et al., 2006; Kaup et al., 2007; Gao, 2006; Gao et al., 2011) used self-paced reading paradigms with varying delays to examine how comprehenders represent event states at different stages. These studies and their results suggest that our experimental procedure is acceptable.

Furthermore, visual symbol negation includes two types: contrastive-state-determined visual symbol negation (e.g., only "smoking" vs. "no smoking" states) and contrastive-state-undetermined visual negation (e.g., "no left turn" allows both "left turn" and "straight" as possible states). This study only examined the former mechanism, and it remains unclear whether our conclusions apply to all types of visual negation or only to this specific type—an issue requiring further research.

Finally, as a behavioral experiment, the validity of our inferences requires caution. Future research should employ ERP and fMRI techniques to examine activation in relevant language and visual brain regions, providing more precise reflection of visual symbol negation processing trajectories at different time points.

Based on our results, we can draw the following preliminary conclusions:

1. During visual symbol negation processing, participants simulate the final state of events from the outset and maintain this representation through late processing stages. These results support the one-step simulation hypothesis and indicate that the two-step simulation hypothesis derived from verbal symbol negation research cannot explain visual symbol negation processing.

2. Regarding processing of negated information in visual symbol negation, our results support the suppression/retention hypothesis.

References

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences, 22*(4), 577-660.

Fischler, I., Bloom, P. A., Childers, D. G., Roucos, S. E., & Jr, N. W. P. (1983). Brain potentials related to stages of sentence verification. *Psychophysiology, 20*(4), 400-409.

Gao, Z. H. (2006). *Research on the Dynamic Perceptual Representation of Chinese Negative Sentence* (Unpublished Doctoral dissertation). Hebei Normal University.

Gao, Z. H., Lu, Z. Y., & Ma, H. X. (2011). The simulation process of Chinese simple negative declarative sentence. *Acta Psychologica Sinica, 43*(12), 1380-1387.

Giora, R. (2006). Anything negatives can do affirmatives can do just as well, except for some metaphors. *Journal of Pragmatics, 38*(7), 981-1014.

Giora, R., Balaban, N., Fein, O., & Alkabets, I. (2005). Explicit Negation as Positivity in Disguise. In H. L. Colston, & A. Katz (Eds.), *Figurative language comprehension: Social and cultural influences* (pp. 233-258). New York: Routledge.

Giora, R., Fein, O., Aschkenazi, K., & Alkabets-Zlozover, I. (2007). Negation in context: A functional approach to suppression. *Discourse Processes, 43*(2), 153-172.

Giora, R., Heruti, V., Metuki, N., & Fein, O. (2009). "When we say no, we mean no": Interpreting negation in vision and language. *Journal of Pragmatics, 41*(11), 2222-2239.

Hasson, U., & Glucksberg, S. (2006). Does understanding negation entail affirmation? An examination of negated metaphors. *Journal of Pragmatics, 38*(7), 1015-1032.

Horn, L., & Ward, G. (2006). *The handbook of pragmatics.* Blackwell publishing.

Kaup, B., Lüdtke, J., & Zwaan, R. A. (2005). Effects of negation, truth value, and delay on picture recognition after reading affirmative and negative sentences. *Proceedings of the Annual Meeting of the Cognitive Science Society, 27.* Retrieved June 6, 2018, from https://escholarship.org/uc/item/19s068vb

Kaup, B., Lüdtke, J., & Zwaan, R. A. (2006). Processing negated sentences with contradictory predicates: Is a door that is not open mentally closed? *Journal of Pragmatics, 38*(7), 1033-1050.

Kaup, B., & Zwaan, R. A. (2003). Effects of negation and situational presence on the accessibility of text information. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*(3), 439-446.

Kaup, B., Zwaan, R. A., & Lüdtke, J. (2007). The experiential view of language comprehension: How is negation represented? In F. Schmalhofer & C. A. Perfetti (Eds.), *Higher level language processes in the brain: Inference and comprehension processes* (pp. 255-288). Mahwah, NJ/London: Lawrence Erlbaum Associates.

Kennedy, John M. (2008). Metaphor and art. In W. R. Gibbs, Jr. (Ed.), *The Cambridge Handbook of Metaphor and Thought* (pp. 447-461). Cambridge University Press.

Kintsch, W., & Van Dijk, T. A. (1978). Toward a model of text comprehension and production. *Psychological Review, 85*(5), 363-394.

Lüdtke, J., Friedrich, C. K., De, F. M., & Kaup, B. (2008). Event-related potential correlates of negation in a sentence-picture verification paradigm. *Journal of Cognitive Neuroscience, 20*(8), 1355-1370.

Lüdtke, J., & Kaup, B. (2006). Context effects when reading negative and affirmative sentences. In R. Sun (Ed.), *Proceedings of the 28th Annual Conference of the Cognitive Science Society* (Vol. 27, pp. 1735-1740). Hillsdale, NJ: Lawrence Erlbaum Associates.

MacDonald, M. C., & Just, M. A. (1989). Changes in activation levels with negation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*(4), 633-642.

Shuval, N. (2006). *Processing and representation of negated constituents* (Unpublished master' s thesis). Provence University.

Sonesson, G., & Series, A. N. (1989). Pictorial concepts: inquiries into the semiotic heritage and its relevance for the interpretation of the visual world. *Journal of Cell Science, 76*(7), 35-51.

Wason, P. C. (1965). The contexts of plausible denial. *Journal of Verbal Learning and Verbal Behavior, 4*(1), 7-17.

Worth, S., & Gross, L. P. (1981). *Studying Visual Communication.* Philadelphia: University of Pennsylvania Press.

Zwaan, R. A., Stanfield, R. A., & Yaxley, R. H. (2002). Language comprehenders mentally represent the shapes of objects. *Psychological Science, 13*(2), 168-171.

Zwaan, R. A., & Taylor, L. J. (2006). Seeing, acting, understanding: Motor resonance in language comprehension. *Journal of Experimental Psychology: General, 135*(1), 1-11.

Note: Figure translations are in progress. See original paper for figures.