

# Comprehending Negated Sentences With Binary States and Locations

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## Abstract

Language theorists have argued that processing negated statements (“The eagle is not in the sky,”) differs from affirmative propositions. However, evidence for these claims comes from studies that did not control for the possibility of numerous states (e.g., the eagle is perched on a branch or on the ground). Here, we explore whether constraining this number of possibilities provides more information about processing negation. In Experiment 1, the stimuli described binary states. For example, a coin can be either heads up or tails up; if it is not heads up it is necessarily tails up. In Experiment 2, preceding contexts constrained the number of possible locations of a negated proposition. The results, consistent with earlier evidence for negation’s increased complexity, offer new data suggesting that perceptual simulation of negated proposition may be experimentally detected when the states or locations are sufficiently constrained, using binary states or contextual descriptions.

**Keywords:** Language Processing; Negation; Embodied Cognition; Perceptual Simulation

Negation is a fundamental part of everyday communication. Throughout the course of a typical day, people frequently have to report where things are *not* located, for instance, “Your keys are not on the table” or “My car is not in the garage.” They must also describe events that are *not* happening, such as, “The Patriots are not playing tonight” or “Your car will not start.” Despite the ubiquity of negated statements, surprisingly little is known about how they are processed and what their conceptual structure is.

One of the earliest and most reliable findings about negation is that people are slower to read negated sentences than they are to read affirmative sentences, due to their increased complexity (see Barres & Johnson, 2003; Carpenter & Just, 1975; Chase & Clark, 1972; Mayo, Schul, & Burnstein, 2004). Such findings have provided invaluable insights into sentence processing, but many important questions about processing negation remain. In particular, how do negated statements influence everyday cognition? Are negated sentences comprehended differently than affirmative sentences? The goal here is to further consider negation’s influence on sentence comprehension.

Negation has been of interest to philosophers and language theorists for centuries (for review, see Gilbert, 1991), but only recently has its processing received close attention. Early cognitive work on processing suggested that negated statements about spatial relations are processed differently from similar affirmative statements. For instance, participants

in Clark and Chase (1972) were presented with sentences followed by pictures and then asked whether the sentence was true or false of a corresponding picture. For example, a “true” trial might consist of the sentence, “The star is above the cross,” followed by a picture with a star above a cross, accurately depicting the relationship expressed by the sentence. Participants responded true or false more quickly to a picture following the sentence, “The star is above the cross,” than to the sentence, “The star is not above the cross.” These differences suggested that affirmative and negated statements are processed differently, but the nature of this difference was unclear. One possibility is that the increased processing time associated with negation is the result of evaluating the core proposition and then applying a negation marker to this proposition.

More recent evidence also supports the hypothesis that negating or affirming a statement involves subtly different processes. McKinstry, Dale, and Spivey (2008) presented participants with questions of varying truth-values and asked them to answer “yes” or “no” using a mouse to click on a corresponding, visually presented box on the computer screen. A sentence’s truth-value was defined as the proportion of participants who agreed the statement was true in an on-line survey. Therefore, the question, “Should you brush your teeth every day?” had a truth-value of 1.0, and the question, “Is murder sometimes justifiable?” had a truth value of .6. In addition to recording the end response and reaction time, the trajectory of the mouse as it moved across the computer screen to click on the appropriate answer was also recorded. These mouse-movement trajectories provide a continuous motor response that has been used to illustrate competition between alternatives in a number of cognitive tasks (Dale, Kehoe, & Spivey, 2007; Farmer, Anderson, & Spivey, 2007; Spivey, Grosjean, & Knoblich, 2005). McKinstry and colleagues’ findings were consistent with those of Clark & Chase (1972) in that participants had more difficulty in evaluating a false statement than a corresponding true statement. Participants were also slower to respond negatively to a statement, and the “no” response trajectories showed more competition than the “yes” response trajectories. Similar effects also arise in research exploring the influence of negation on memory (Fiedler, Walther, Armbruster, Fay, & Naumann, 1996), supporting a general cognitive bias towards affirmative propositions.

Similarly, negated and affirmative sentences seem to be handled differently in language comprehension (e.g., Hasson & Glucksberg, 2006; Kaup, 2001; MacDonald & Just, 1989), and this may be due to differences in their corresponding

perceptual simulations. Recent experimental evidence suggests that understanding a single word embedded in a sentence is associated with the way people would actually perceive the noun they are asked to identify. Zwaan, Stanfield, and Yaxley (2002) asked participants to read sentences and to decide whether or not a subsequent picture was mentioned in the sentence they had just read. When a sentence such as, “The eagle was in the sky,” was presented, participants were quicker to respond that a picture of an eagle with outstretched wings had been mentioned in the preceding sentence than when they saw a picture of an eagle with folded wings. These results support claims that participants construct an image to represent the sentences they read; this in turn makes that image more accessible, leading to faster subsequent responses to that image. Such images, constructed through the partial activation of the neurons used to actually perceive or interact with the objects, are called *perceptual simulations* (see Barsalou, 1999; Barsalou, Simmons, Barbey, & Wilson, 2003, for a more complete overview). When the test picture matched the image that had been mentally created, reaction times were faster than if the test picture did not match the state of the object described in the text. These data provide evidence that comprehending language may be grounded in perceptual representations.

Perceptual simulations seem able to explain the comprehension of affirmative sentences (Zwaan, Stanfield, and Yaxley, 2002), yet recent experimental results suggest that negated sentences are processed differently. Kaup, Yaxley, Madden, Zwaan, and Lüdtkke, (2006b) presented participants with sentences like, “The eagle was not in the sky,” and asked participants to judge whether a subsequently presented picture was mentioned in the sentence they had read. If participants perceptually simulate negation in the same way they simulate affirmative sentences, they should be quicker to respond “yes” to pictures that match the sentence (e.g., an eagle with its wings folded). The experimenters found that when participants read negated sentences, response times to a picture that matched the *affirmative* version of the proposition (eagle with wings spread) were faster than pictures that actually matched the negated sentence, suggesting that a perceptual simulation of the affirmative proposition was created in response to negated sentences. This suggested that negation is handled differently from other aspects of sentence processing, and specifically not through perceptual simulation.

Another possibility is that the experimental materials were not able to capture the perceptual simulation of the negation, similar to on-line research in verbal aspect. Madden and Zwaan (2003) examined potential differences produced by processing different verbal aspectual forms in narrative reading. In these experiments, participants were quicker to respond to pictures showing completed action after they had read a sentence containing a simple past verb than when they had read a sentence containing a past progressive verb, because simple past verbs emphasize the completion of a verb’s action. Conversely, no such latency differences were found when participants read sentences containing past

progressive verbs and then saw pictures of intermediate action. Like affirmative and negated sentences, these results suggest that perhaps one form of aspect is comprehended through perceptual simulations and that the other is comprehended via another mechanism.

However, the authors suggest that the past progressive’s lack of effect was due to readers representing the ongoing action at different stages of completion. Simple past verbs place emphasis on the end state of the action, which typically corresponds to only a single state, while past progressive verbs place emphasis on the ongoing nature of the verb. After reading narratives containing past progressive verbs, participants may simulate a number of locations. In other words, past progressive aspect produces a diffuse number of possible stages of intermediate action that are un-captured by the task. Therefore, even though past progressive verbs, like simple past verbs, may be comprehended via perceptual simulations, the static images used in the task simply do not match the particular point in the action they are simulating.

Similarly, it may be that when participants read a negated sentence, they do create a perceptual simulation of the negation, but the pictures they are asked to respond to do not capture the simulation. Whereas an affirmative sentence identifies a particular state or location for the noun that is responded to more quickly when presented visually, the negated sentences do not. For example, when “the eagle is in the air,” its wings are necessarily open to accommodate flying. However, when “the eagle is not in the air,” there are many states it could be in other than sitting with its wings folded. Thus, when hearing a negated sentence of this sort, participants may appear to simulate the eagle in the air not because perceptual simulations are incapable of negation but instead because the alternative simulations are too numerous and too diffuse. If this is the case, then constraining the possible simulations to only two for a given object, one corresponding to the affirmative proposition and one to the negated proposition, should further inform this research.

Here, we wanted to explore this in sentence comprehension by constraining the possible states and locations of the event. In general, we hypothesized that binary states would allow us to capture the simulation of negation in sentences. Similarly, we hypothesized that creating contexts to limit the possible locations to only two options would allow us to observe and further extend results on processing negated sentences.

### **Experiment 1: Binary States**

Evidence from recent research in sentence comprehension suggests that creating targets that themselves refer to binary states is promising for investigating the role of perceptual simulation in negation processing. Kaup, Lüdtkke, & Zwaan (2006a) investigated the way participants perceptually simulate sentences like those used in the earlier negation research (Kaup, et al., 2006b), but created materials that were binary, or had contradictory predicates. In Kaup, et al., (2006a), participants read binary sentences in the self-paced reading paradigm, and then after an SOA of either 750ms or

1500ms, they saw a picture of an object that they had to name as quickly as possible. At the 750ms SOA, responses to pictures that matched the non-negated state of affairs, even when the target sentence was negated, were significantly faster than pictures depicting the negated state of affairs. In other words, for the sentence “The door was not closed,” reaction times to a picture of a closed door (matching the proposition of the sentence) were significantly faster than to pictures of an open door. At the 1500ms SOA, when the target sentence was negated, responses to pictures matching the negated state of affairs were significantly faster than pictures depicting the proposition.

Here, we wanted to further expand these findings. In Experiment 1, we used the picture verification task used in the earlier negation (Kaup, et al., 2006b) and perceptual simulation (Zwaan, et al., 2002) research. We anticipated that this method might be more robust and allow for a full statistical interaction to emerge from the data. Additionally, we used an intermediate SOA of 1000ms, in order to provide data on processing at this intermediate point.

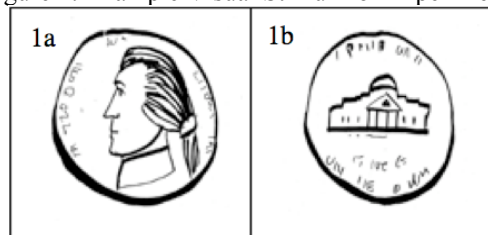
### Method

**Participants.** A total of 32 Cornell University undergraduates participated in the experiment for extra course credit. All participants were right-handed, born in the United States, and native English speakers.

**Materials.** Sixteen target sentence frames were constructed. These frames were manipulated in order to produce two versions of each: a negated (The coin is not heads up) and an affirmative (The coin is heads up) version. The sentences were created such that they described a proposition that was true only in one way and untrue only in one way, thereby making the materials binary. Sixteen filler sentences, half of which were affirmative and half of which were negated, were also constructed. The target sentences contained binary state objects similar to the examples provided above, while the filler sentences did not contain binary objects.

Two pictures were created for each target frame: a picture matching the proposition of the sentence, and a picture matching the negation of that proposition. For example, for the sentence frame, “The coin is (not) heads up,” the picture corresponding to the proposition would be a heads up coin (see Figure 1a) and the picture corresponding to the negation of the proposition would be a tails up coin (see Figure 1b). The correct response for either the negated or affirmative sentence and either picture is “yes,” because the sentence is about a coin and the picture depicts a coin. Filler sentences also had corresponding pictures, although these pictures did not match anything in the sentence. All of the images were black and white ink drawings, created by a senior art major, with as much simplicity and as few lines as possible; this was done in order to make sure all pictures were as similar as possible. All the pictures were scanned into the computer in the same size to control for discrepancies between the objects.

Figure 1: Example Visual Stimuli for Experiment 1



1a) Picture Matches Proposition  
1b) Picture Matches Negated Proposition

**Procedure.** Participants were seated at the computer and asked to make themselves comfortable. They read a page of instructions where they were informed that it was important for them to make decisions about the picture as quickly and accurately as possible. During the task, participants first read a sentence located in the center of the screen, pressing the spacebar when they had understood the sentence. A fixation cross appeared in the center of the screen for 1000ms and then a picture appeared. Participants indicated whether the pictured object had been mentioned in the previous sentence by pressing the f-key, covered with a “yes” sticker, or the j-key, covered with a “no” sticker. The correct response to all target trials was yes, and the correct response to all the filler trials was no. Half of the trials were followed by comprehension questions, in order to insure participants were paying attention. On these trials (half of the filler sentences, and half of the target sentences), a question regarding the sentence was presented next. Participants were asked to respond to the question as accurately as possible by clicking on the appropriate “yes” or “no” key. Participants were not given feedback on any of their responses. They were first given two practice trials before beginning the task (similar in construction to the filler items), and the task lasted approximately 10 minutes.

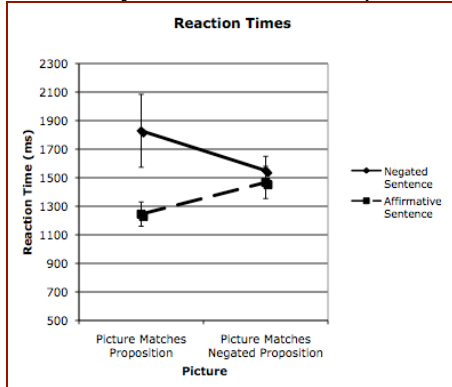
### Results and Discussion

Incorrect trials (trials on which a participant responded “no,” and the pictured object was not in the sentence they had just read) were removed before analyzing reaction time. Data from two participants were excluded from the analysis because they incorrectly answered one block of trials. In addition, the incorrect responses to 18 items from 9 different participants were discarded prior to the analysis.

There was a significant interaction of Sentence and Picture,  $F(1,29) = 4.308, p < .047$ . See Figure 2 below. Affirmative sentences that were followed by propositional pictures (“The coin was heads up” before a picture of a heads up coin) were responded to more quickly,  $M = 1245.12, SD = 84.98$ , than affirmative sentences that were followed by negated-propositional pictures (“The coin was heads up” before a picture of a tails up coin),  $M = 1467.02, SD = 113.05$ . These results are consistent with earlier perceptual simulation research (Zwaan, et al. 2002). Additionally, negated sentences followed by negated propositional pictures (“The coin is not heads up” followed by a picture of a tails up coin) were responded to more quickly,  $M = 1550.17, SD =$

99.81, than were negated sentences followed by propositional pictures (“The coin is not heads up” followed by a picture of a heads up coin),  $M = 1828.79$ ,  $SD = 255.49$ . These results moderately extend the results obtained in Kaup et al. (2006a) by providing support that perceptual simulation does seem to operate for comprehending negated sentences whenever the experimental conditions are sufficiently constrained to capture it at an intermediate SOA.

Figure 2: Binary states reaction times per condition



In examining the main effects, the affirmative sentences,  $M = 1467.02$ ,  $SD = 619.18$ , were responded to significantly faster,  $t(29) = 2.08$ ,  $p < .05$ , than negated sentences,  $M = 1245.12$ ,  $SD = 465.47$ . These results are consistent with earlier research, like that of Clark and Chase (1972) and McKinstry et al. (2008), suggesting that there is a bias in favor of affirmative sentences over negated sentences. Also, there was no main effect of picture type, implying that the type of picture did not impact comprehension.

Finally, in examining accuracy, there was a main effect of picture type within the affirmative sentences,  $F(1,29) = 6.916$ ,  $p < .014$ . When the sentence was affirmative, participants were less accurate when responding to pictures that did not match. Accuracy did not differ for the two picture conditions in the negative sentence condition. This implies that the effects that have been described so far are not to the result of a speed accuracy trade off in the negated sentence condition.

### Experiment 2: Binary Locations

Using the picture verification task of other perceptual simulation research (Kaup, et al., 2006b; Zwaan, et al., 2002), Experiment 1 converges with other negation research (Kaup, et al., 2006a): When the possible states of the items themselves are constrained to only two possibilities, perceptual simulations underlie the processing of these sentences at the intermediate 1000ms SOA. However, the materials that were used in Experiment 1 relied on binary *state* objects, leaving many questions regarding the processing of negation unanswered. Here, we sought to further extend these findings to investigate the role of context in the creation of binary *locations*. In Experiment 2, we again used the picture verification task was employed in the earlier

negation (Kaup, et al., 2006b) and perceptual simulation (Zwaan, et al., 2002) research as well as the intermediate 1000ms SOA. Rather than relying on binary states, context sentences describing two possible locations for an item were created.

### Method

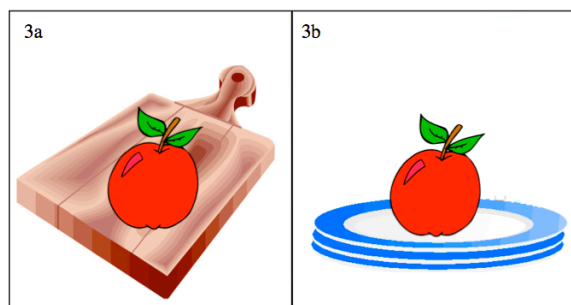
**Participants.** A total of 62 Cornell University undergraduates participated in the experiment for extra course credit. All participants were right-handed, born in the United States, and native English speakers.

**Materials.** Thirty-two target sentence frames were constructed. Each frame consisted of a context sentence, describing two possible locations for an item (i.e., The apple is either on the plate or on the cutting board), and a target sentence, identifying the location of the item. The context sentences were designed such that they limited the possible locations to only two; therefore, they could be true only in one way and untrue only in one way. The target sentences were manipulated in order to produce four versions of each: an affirmative version identifying the first location mentioned in the context sentence (The apple is on the plate); an affirmative version identifying the second location mentioned in the context sentence (The apple is on the cutting board); a negated version identifying the first location mentioned in the context sentence (The apple is not on the plate); and a negated version identifying the second location mentioned in the context sentence (The apple is not on the cutting board). Thirty-two filler sentences, one quarter of which corresponded to each of the four conditions described above, were also created.

Two pictures were created for each target frame: a picture matching the proposition of the sentence, and a picture matching the negation of that proposition. For example, for the target sentence frame, “The apple is (not) on the cutting board,” the picture corresponding to the proposition would show an apple on a cutting board (see Figure 3a) and the picture corresponding to the negation of the proposition would show an apple on a plate (see Figure 3b). Pictures were also constructed for the filler items, although these pictures did not match anything in the sentence. All of the images were taken from clip art. The target item (i.e., the apple) was spliced into the different locations to maintain similarity in the pictures.

Eight lists were constructed such that each participant would respond to all of the conditions but only one version of each sentence frame and picture. Conditions were created as follows: 1) affirmative target, identifying first location of context, picture matching proposition; 2) affirmative target, identifying first location, picture matching negated

Figure 3: Example Visual Stimuli for Experiment 2



3a) Picture matches proposition for “The apple is (not) on the cutting board.”

3b) Picture matches negated proposition for “The apple is (not) on the cutting board.”

Pictures match final prepositional phrase of target regardless of the target’s negation status.

proposition; 3) affirmative target, identifying the second location, picture matching proposition; 4) affirmative target, identifying the second location, picture matching negated proposition; 5) negated target, identifying the first location, picture matching proposition; 6) negated target, identifying first location, picture matching negated proposition; 7) negated target, identifying second location, picture matching proposition; and 8) negated target, identifying second location, picture matching negated proposition.

**Procedure.** The procedure of Experiment 2 was the same as that of Experiment 1, except it did not include comprehension questions and lasted 20 minutes.

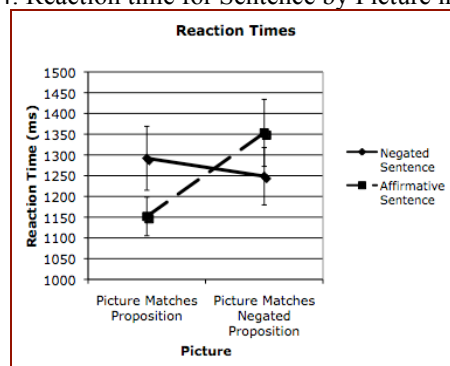
### Results and Discussion

Incorrect target trials (or trials on which a participant responded “no,” the pictured object was not in the sentence they had just read) were removed before analyzing reaction time. Two hundred fifty-four trials, 12% of the data, were excluded from the reaction time analysis, resulting in the loss of fourteen participants. Each participant had at least one trial excluded from the reaction time analysis due to these criteria.

There was no significant three-way interaction of Sentence, Picture, and Context,  $p > .28$ . Also, the main effect of context was not significant,  $p > .7$ . Therefore, the order of the items in the context sentence did not significantly impact the results. However, there was a significant interaction of Sentence and Picture,  $F(1,47) = 6.343, p < .015$ . See Figure 4. Affirmative sentences (“The apple is either on the plate or on the cutting board. The apple is on the plate”) followed by propositional pictures (a picture of the apple on the plate as in Figure 3b) were responded to faster,  $M = 1155.497, SD = 413.419$ , than affirmative sentences followed by negated propositional pictures (a picture of the apple on the cutting board as in Figure 3a),  $M = 1365.495, SD = 701.461$ . Similarly, negated sentences (“The apple is either on the plate or on the cutting board. The apple is not on the plate”) followed by propositional pictures (a picture of the apple on the plate as in Figure 3b) were responded to slower,  $M = 1335.8032, SD = 690.602$ , than negated sentences followed

by negated propositional pictures (a picture of the apple on the cutting board as in Figure 3a),  $M = 1258.295, SD = 539.869$ . These data further extend the results of Kaup et al. (2006a), providing support that perceptual simulations operate in comprehending negated sentences when contextual descriptions constrain possible locations to only two.

Figure 4: Reaction time for Sentence by Picture interaction



In examining the main effects, responses to negated sentences were not significantly slower than responses to affirmative sentences,  $p > .8$ . Also, there was a main effect of picture type,  $F(1,61) = 7.67, p < .01$ , such that pictures of the proposition were responded to faster,  $M = 1221.829, SD = 563.79$ , than pictures of the negated proposition,  $M = 1300.929, SD = 622.402$ . These results, combined with the percentage of incorrect responses, suggest that the complexity of the task may have caused problems or that some subjects employed strategies. For instance, it may have been possible to read the context sentence and respond to the pictures based on this information alone. Future work will further refine these preliminary data by using auditory files, rather than written text, in such a picture verification task. Such auditory presentation of the stimuli is less strategy prone than text presentation.

Finally, in examining accuracy, there was an interaction of negation and picture,  $F(1,61) = 17.8, p < .001$ . Participants responded more accurately when the target sentence matched the picture. Hence, participants responded more accurately to negated sentences when the picture matched the negated proposition than when the picture matched the proposition. Similarly, participants responded more accurately to affirmative sentences when the picture matched the proposition than when the picture matched the negated proposition. None of the other main effects were significant,  $p$ 's  $> .2$ . This implies the effects described so far are not due to a speed accuracy trade off in the either sentence condition.

### General Discussion

The materials of Experiment 1 were designed to reflect *binary state* propositions, such that affirmative and negated forms each referred to only one possibility. The interaction of picture and sentence types at the intermediate SOA of 1000 ms supports the hypothesis that appropriate perceptual simulations (of the negated proposition) may be used for

comprehending negated sentences. Further, Experiment 2 demonstrated that extrasentential context can constrain the possible perceptual simulations to reflect *binary locations*. Again, the interaction of picture and sentence types supports the hypothesis that perceptual simulations may be used in comprehending both affirmative and negated sentences. While the experiments here used the intermediate SOA of 1000 ms, future planned research, specifically in eye-tracking, will further investigate the time course of processing negated sentences.

The results reported here are promising, but future research is needed to further explore the mechanisms of negation. The exact mechanism underlying perceptual simulations in negation has not been thoroughly explored, and its explication is likely to require computational modeling. To this end, we have begun some preliminary explorations with a simple recurrent network (Elman, 1990). In addition to the word-prediction relation between 91 input word-nodes to 91 output word-nodes, this model includes 63 perceptual features on the output layer that are prominent properties of the relevant perceptual simulations (see also, Howell, Jankowicz, & Becker, 2005). Thus, combined with its learning to predict the next word in a sentence, this network also learns to activate the appropriate set of features for the perceptual simulation associated with the sentence (Anderson, Huette, Matlock, & Spivey, in press). In this network model, the only difference between an affirmative sentence and a negated sentence is that the input from the negated sentence has the word “not” immediately preceding its critical adjective (e.g., flying, not flying, heads-up, not heads-up). Thus, without a specialized logical operation of negation, this network can nonetheless reverse its perceptual simulation as a result of the presence or absence of the word “not” in the sentence. Current extensions of this model are exploring ways to include some temporal dynamics that may simulate the experimental results with different SOAs.

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