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The contents of predictions in sentence comprehension: Activation of the shape of objects before they are referred to

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ABSTRACT

When comprehending concrete words, listeners and readers can activate specific visual information such as the shape of the words' referents. In two experiments we examined whether such information can be activated in an anticipatory fashion. In Experiment 1, listeners' eye movements were tracked while they were listening to sentences that were predictive of a specific critical word (e.g., "moon" in "In 1969 Neil Armstrong was the first man to set foot on the moon"). 500 ms before the acoustic onset of the critical word, participants were shown four-object displays featuring three unrelated distractor objects and a critical object, which was either the target object (e.g., moon), an object with a similar shape (e.g., tomato), or an unrelated control object (e.g., rice). In a time window before shape information from the spoken target word could be retrieved, participants already tended to fixate both the target and the shape competitors more often than they fixated the control objects, indicating that they had anticipatorily activated the shape of the upcoming word's referent. This was confirmed in Experiment 2, which was an ERP experiment without picture displays. Participants listened to the same lead-in sentences as in Experiment 1. The sentence-final words corresponded to the predictable target, the shape competitor, or the unrelated control object (yielding, for instance, "In 1969 Neil Armstrong was the first man to set foot on the moon/tomato/rice"). N400 amplitude in response to the final words was significantly attenuated in the shape-related compared to the unrelated condition. Taken together, these results suggest that listeners can activate perceptual attributes of objects before they are referred to in an utterance.

1. Introduction

In sentence comprehension, readers and listeners often anticipate upcoming information (Altmann & Kamide, 1999; DeLong, Urbach, & Kutas, 2005; Federmeier & Kutas, 1999; van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005; Wicha, Moreno, & Kutas, 2004). For instance, when a word is highly predictable, differential event-related brain potential (ERP) effects can be observed when a preceding adjective matches or mismatches with the expected word in grammatical gender (van Berkum et al., 2005; Wicha et al., 2004) or in phonological form (DeLong et al., 2005). Anticipation plays an important role in current views of sentence comprehension (Altmann & Mirkovic, 2009; Federmeier, 2007; Gibson, 1998; Kamide, 2008; Levy, 2008; Pickering & Garrod, 2007). Current theories focus on the underlying cognitive processes, with a prominent view being that predictions in comprehension are generated by the language production system (Pickering & Garrod, 2007).

An issue that has not received much attention concerns the kinds of information that listeners or readers pre-activate when they anticipate upcoming words. For understanding the mechanisms underlying prediction it is important to determine what listeners and readers do, or do not, predict. So far, studies have focused on functional semantic features or categories. Evidence for the involvement of this kind of information in predictions comes from anticipatory eye movements observed in the visual world paradigm, where participants listen to sentences and look at displays with multiple objects (Cooper, 1974; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995; for review see Huettig, Rommers, & Meyer, 2011). For instance, in a seminal study by Altmann and Kamide (1999), participants heard sentences such as "The boy will eat the cake" or "The boy will move the cake" while viewing a display featuring several objects of which a cake was the only edible object. The authors found that,

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before the cake had been referred to, participants were more likely to initiate eye movements towards the cake when the verb was "eat" than when it was "move". This demonstrates that they predicted which object would be referred to on the basis of functional attributes (e.g., edibility) implied by the verb.

Other evidence for the involvement of functional semantic information in predictions comes from ERP studies. The component of interest is the N400, a centroparietally distributed component of negative polarity that peaks around 400 ms after onset of a content word and is considered a sensitive index of semantic processing (Kutas & Federmeier, 2000, 2011; Kutas & Hillyard, 1980). Federmeier and Kutas (1999) presented participants with contexts such as "They wanted to make the hotel look more like a tropical resort. So along the driveway, they planted rows of…", which were followed by a predictable word (e.g., "palms"), or an unexpected word from the same semantic category (e.g., "pines"), or an unexpected word from a different category (e.g., "tulips"). N400 amplitude to the unexpected words was reduced when the word was related to the expected word (e.g., "pines") compared to when it was unrelated (e.g., "tulips"), even though in both of these conditions the predictable word was never presented. This suggests that semantic category information had been activated based on the context.

In the present study we were specifically interested in another kind of information that can be activated when words are processed, namely perceptual information—that is, physical attributes of objects. We focused on shape information. There is evidence from several sources that information about object shape can be activated *after* the relevant word has been processed. For instance, in sentence-picture verification experiments, Zwaan, Stanfield, and Yaxley (2002) observed congruency effects between a shape implied in a sentence and a shape shown in a picture. Furthermore, several studies have observed perceptual priming in lexical decision, where a response to a target word (e.g., "coin") is faster when a preceding prime word has a referent with a shape similar to the target word's referent (e.g., "pizza") than when the prime word has a referent with a different shape (e.g., "table"; Moss, McCormick, & Tyler, 1997; Schreuder, Flores d'Arcais, & Glazenborg, 1984; but see Pecher, Zeelenberg, & Raaijmakers, 1998). Kellenbach, Wijers, and Mulder (2000) showed that at the neurophysiological level this shape priming was reflected in the N400, with N400 amplitude being smaller when prime and target had similarly shaped referents than when these were different. Finally, several visual world experiments showed that upon hearing a word such as "snake", listeners were more likely to move their eyes to objects with a shape similar to the referent (e.g., a cable) than to objects with a different shape (Dahan & Tanenhaus, 2005; Huettig & Altmann, 2007).

In sum, there is strong evidence that shape information can be activated when words are processed. However, it is unknown whether this type of information already becomes activated when words are anticipated. For instance, do listeners expecting to hear about a moon activate visual representations of the object before they actually hear "moon"? As mentioned above, there is evidence for a high degree of specificity of predicted lexical information, since specific words can be anticipated (DeLong et al., 2005; van Berkum et al., 2005; Wicha et al., 2004). Listeners thus seem to prepare in advance for the input they might receive. Whether this degree of specificity extends to the level of perceptual attributes is unknown. One might, for instance, speculate that in many contexts shape information is not crucial for understanding the meaning of an utterance and would therefore be activated late or not at all. Alternatively, it could be the case that anticipation of a specific word entails some activation of all associated information, regardless of its relevance for understanding the current utterance.

A second issue we explored in the present study concerns the influence of the participants' task on the activation of shape information. Although previous studies have shown that shape representations can be activated in language comprehension, it is not known to what extent the reported shape effects depend on the participants' tasks. For lexical decision (Schreuder et al., 1984), it is conceivable that the activation of shape information stems from task properties, as being able to activate a mental image for a stimulus is a cue that distinguishes words from nonwords. For sentence–picture verification (Zwaan et al., 2002), one could argue that the instruction to compare sentences to pictures encourages readers or listeners to create mental images corresponding to the sentence content. In the present study, participants were simply asked to listen attentively to spoken sentences. No additional task was given. Two online techniques were used to measure pre-activation of visual representations of upcoming words' referents: Eye-tracking during a visual world task, and recording of event-related potentials during a passive listening task. We asked whether participants, in anticipation of specific critical words, would activate the shape of the referents.

In Experiment 1, we used the target-absent version of the visual world paradigm in which a fully matching target word referent is excluded from the visual display on some trials (cf. Huettig & Altmann, 2005; Huettig et al., 2011, for detailed discussion). Participants listened to sentences that were predictive of a specific word (e.g., "moon" in "In 1969 Neil Armstrong was the first man to set foot on the moon"). Five-hundred ms before the acoustic onset of the critical word (i.e. "moon"), participants were shown displays of four objects. These were three unrelated distractor objects and one critical object. Depending on the condition, the critical object was either the target object (e.g., a moon), or a shape competitor of the target object (e.g. a tomato), or a control object with a different shape than the target (e.g. rice). The participants' eye movements were recorded. We expected to observe anticipatory eye movements to the target object (e.g., the moon) before it was referred to. More importantly, if specific object shape representations form part of the contents of predictions for upcoming words, the expectation of the target concept (e.g., the moon) should also lead to anticipatory eye movements to a shape competitor (e.g., to a tomato).

We indeed observed such anticipatory eye movements. However, the visual world experiment involved the presentation of pictorial stimuli, which may encourage the activation of information concerning the physical properties of the referent objects' shape (for discussion, see Huettig et al., 2011; Mitchell, 2004; for experimental evidence, see Huettig & McQueen, 2011). To determine whether shape information is also preactivated in the absence of pictorial information, a second experiment was conducted. This was an ERP experiment similar to Federmeier and Kutas's (1999) study. The participants listened to the same lead-in sentences as in Experiment 1. The final word of the sentence was either a highly predictable word (e.g., "moon"), or a word referring to an object with a similar shape (e.g., "tomato"), or an unrelated word (e.g., "rice"). We examined whether the N400 component in response to these words would reflect the semantic anomaly and, more importantly, would be sensitive to the referents' shape as well.

2. Experiment 1

2.1. Participants

Forty-five participants (34 women, mean age 21 years, range 18–29 years) from the Radboud University Nijmegen and the HAN University of Applied Sciences gave informed consent and were paid to take part in the experiment. All were native speakers of