How does sentence context affect activation of homophone and cohort competitors? Evidence from language-mediated eye movements.

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Abstract

This study used eyetracking to measure the effects of sentence context on the unfolding process of spoken word identification. It is unclear from previous research whether sentence context affects the processing of spoken words and whether the effect is immediate or delayed. Huettig and Altmann (2004) presented sentences containing a homophone (e.g. pen). Participants tended to look at objects corresponding to both meanings of the homograph (writing pen, pig pen), even when the sentence context was biased towards one interpretation. This suggests that both meanings of a homophone are activated, regardless of context. However, other studies show that on hearing a target word (e.g. button) the tendency to look at a cohort competitor (e.g. butter) disappears if the competitor does not fit the sentence context (Brock & Nation, 2009; Dahan & Tanenhaus, 2004). The discrepancy between these findings may reflect differences in the way homophones are processed compared with other words, or may simply reflect differences in sentence context used across studies. In the present study, we directly compare the effect of the same sentence context on eye-movements directed at homophone and cohort competitors. Participants hear sentences such as "When Mark coughed he felt a pain in his chest so he decided to call the doctor" while viewing a display containing either a homophone competitor (e.g. a treasure chest) or a cohort competitor (e.g. a cheque). Results will shed light on the process of spoken word identification in typical populations and will provide reference for future studies investigating developmental disorders such as autism that are associated with difficulties processing language in context.

Keywords: homophones; context; eye tracking; language processing.

Introduction

The comprehension of words and sentences in spoken language is an ongoing process that has been the subject of research for over three decades. For much of this time, theories of spoken language comprehension have been based almost exclusively on behavioural experiments that involve spoken or manual responses. However, a limitation of these methodologies is that the underlying cognitive processes involved in comprehension have to be inferred indirectly from the accuracy or reaction time of responses made after the linguistic stimuli have been presented.

More recently, researchers have made use of eye-tracking as a tool for investigating comprehension of words and sentences as they unfold. Cooper (1974) showed that people tend to look at objects that directly correspond to the word they are currently hearing or are semantically related (see also Huettig & Altmann, 2004). Altmann and Kamide (1999) reported anticipatory eye-movements, whereby participants fixate on objects that they expect to be mentioned next in the sentence. On hearing *The boy will eat the cake*, looks towards a cake were greater than looks towards inedible objects even before the word *cake* was spoken (see also Boland, 2005). These authors further showed that eye-movements were sensitive to verb tense (Altmann & Kamide, 2007). Participants were more likely to look towards an empty wine glass after hearing *The man has drunk the wine* compared with *The man will drink the wine*. Again, this effect could be observed before the onset of the referring expression.

In the current study, we used eyetracking to reexamine an old question in psycholinguistic research: How does sentence context affect the perception of spoken words? Researchers using traditional behavioural paradigms such as cross-modal semantic priming have concluded that context only has a relatively late effect and that initial stages of lexical access are context free. However, the results of eyetracking studies are equivocal. While one study is consistent with the priming research (Huettig & Altmann, 2004), three further studies indicate a very early effect of context (Barr, 2008; Brock & Nation, in preparation, Dahan & Tanenhaus, 2004). Our aim in this study is to reconcile these eyetracking findings with each other and with previous literature.

According to Marslen-Wilson's influential model of spoken word processing, word identification typically has two stages; access and selection (Marslen-Wilson, 1987; 1989). Access triggers potential lexical candidates based on acoustic input. For example, upon hearing the sound /kæm/ the words *camera*, *camper* and *camel* will each be activated and will remain activated until further acoustic evidence excludes them as candidates. Selection is the process of deciding on the best possible match between the input and potential candidates. At issue is whether the context in which a word is heard can affect the initial

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access stage or whether access is based entirely on the acoustic input with context only affecting the selection process.

Much of the evidence relevant to this question comes from studies looking at the processing of homophones. These are words with different meanings that sound the same (e.g., bank, bug, night/knight). Within the access / selection framework, homophones have a special status because the correct meaning cannot be determined on the basis of bottom-up acoustic information alone. If access is context independent then all the potential meanings of a homophone should be accessed regardless of the context.

Swinney (1979) used a cross-modal semantic priming task to investigate the effect of sentence context on the processing of homophones. Participants heard a homophone embedded in a story context. Shortly after the homophone was heard, a written text string was presented and participants made a lexical decision, indicating whether the text string was a word or a nonword. Responses to written words were accelerated if they were semantically related to either meaning of the homophone. This semantic priming effect remained even when the story context pointed towards the unrelated meaning of the homophone. For example, the homophone *bugs* led to faster lexical decisions to the word *ant*, even when the word *bugs* was heard in the context of spying. Similar results were reported in several other studies (e.g., Tanenhaus, Leiman & Seidenberg, 1979; Seidenberg et al., 1982), leading these researchers to conclude that context does not restrict lexical access.

Huettig and Altmann (2004) reported analogous results from a study using language-mediated eye-movements. Participants were presented with four objects on a computer screen. The images included the dominant meaning of a target homophone (e.g. writing *pen*), the subordinate meaning (e.g. pig *pen*) and two unrelated distractor objects. Sentence context was biased towards the subordinate meaning of a homophone (e.g. *The welder locked up carefully, but then he checked the* ***pen*** *and suspected that it was damaged*). By the offset of the target homophone, participants were looking at the dominant (but contextually incongruent) meaning of the target word significantly more than they looked to either of the distractor objects. Huettig and Altmann (2004) concluded, therefore, that the dominant meaning of a homophone is activated, regardless of the context.

However, a very different pattern of results has been found in studies looking at the effect of context on eye-movements directed at cohort competitors – words that have the same phonological onset. Allopenna, Magnuson & Tannenhaus (1998) reported that, when participants heard a word in a neutral context, they showed an increased tendency to look at objects corresponding to cohort competitors. For example, on hearing *beaker*, participants were more likely to look at a beetle than an unrelated object, pram. Moreover, the time-course of fixations on the cohort competitor fitted well with predictions derived from models of the access stage of speech perception. Fixations on the competitor increased rapidly following the onset of the target word and then receded as more of the word was heard and participants were able to rule that word out as a candidate. Importantly, however, three subsequent studies have now shown that this 'cohort effect' is wiped out if participants hear the target word in a context that does not support the cohort competitor. For example, on hearing *Joe stroked the hamster carefully,* participants do *not* look at a hammer any more than they look at unrelated objects (Barr, 2008; Brock & Nation, in preparation; Dahan & Tanenhaus, 2004; see also Brock et al., 2008). In contrast to the studies reported above, these results suggest that context can affect the very earliest moments of spoken word perception.

The aim of the current study is to try and reconcile these conflicting findings. The most obvious difference between the studies providing evidence for and against early effects of context is the nature of the target word. Evidence for early contextual influence comes from studies looking at cohort competitor effects on processing of unambiguous words, whereas evidence for context-independent access comes from studies of homophone processing. However, homophones are effectively special cases of cohort competitors in which the ambiguity remains unresolved even after the whole word has been presented. If context affects access of cohort competitors, there is no reason why it shouldn't also have a similar effect on homophones.

An alternative explanation is that context effects are a function of the type of context. In the three studies showing early context effects, the context was provided by the immediately preceding verb, which restricted the number of plausible referents. By contrast, in studies using homophones, the context made one interpretation of the homophone less likely but still plausible. For example, a welder might be more likely to check a pig pen than would, say, a journalist, but it is not implausible that they might also check a writing pen.

In the current study, therefore, we investigated the effect of the same sentence context on eye-movements to homophone competitors of a target word and cohort-competitors of the same words. Participants heard sentences containing a homophone (e.g., night) while viewing a display containing either a homophone competitor (knight) or cohort competitor (knife). In the neutral condition, the sentence context left all four objects as plausible referents and so eye-movements were driven primarily by the phonological match between the spoken sentence and each object. Thus, on hearing the word "night" in the neutral sentence, "The man chose the night over the other possibilities", one would expect an early increase in fixations on both the homophone competitor (knight) and cohort competitor (knife). Fixations on the cohort competitor should recede rapidly once sufficient acoustic information had been received to eliminate it as a

candidate word. By contrast, participants were expected to remain fixated on the homophone competitor because it is essentially the 'correct' object – it is compatible with the context and matches the target word phonologically (even though it does not necessarily match it orthographically).

In the constraining condition, the sentence context was biased towards the alternative meaning of the homophone, with both the homophone competitor and the cohort competitor being unlikely referents (e.g., "The owl flew in the night over the fields"). Given that the onset of the homophone and the competitor are phonologically identical and both competitors are contextually incongruent, there should be a similar effect of context on eye-movements to both competitors. However, previous findings lead to different predictions depending on the type of competitor – participants should look at the homophone competitor even when it is contextually incongruent (cf. Huettig & Altmann, 2004) but should avoid fixating on incongruent cohort competitors (cf. Barr, 2008; Brock & Nation, in preparation; Dahan & Tanenhaus, 2004).

Method

Participants

In these proceedings, we present preliminary data from the first 8 participants. All participants were adults studying at Macquarie University, aged 22 to 30 years. All had normal vision or wore contact lenses that corrected their vision to normal.

Stimuli

A list of 30 target words was generated consisting of homophones that also had a cohort competitor (e.g. stake/steak/stain; Table 1). Two sentences were generated for each of the target words; a contextually constraining sentence biased towards the lower frequency meaning of the homophone (e.g. *The witch was burned at the stake while the villagers looked on*) and a contextually neutral sentence (e.g. *Peter should consider the stake while the option is available)*. To control for coarticulation effects on the pronunciation of the target word and the possibility that eye-movements might be driven by the surrounding words rather than the target word itself, the word preceding the target word and the following two words were the same in both sentences in the pair. Sentences were recorded by a female native Australian speaker using natural intonation but with small pauses between each word. Visual stimuli were photo-quality pictures on a grey background taken primarily from Hemera Photo-Objects Collection. Three stimuli were photo-quality pictures found on the internet. Pictures were presented on a screen with a grey background (see Figure 1). Each picture occupied the centre of one quadrant of the screen.

In the homophone condition the display included the homophone image and three unrelated objects. In the equivalent trial of the cohort competitor condition, the display was identical except for the fact that the homophone competitor was replaced with the corresponding cohort competitor. The location of the critical object was counterbalanced across trials.

Eye-tracking

Participants were seated at a table, approximately 70 cm from a computer screen. Eye movements were recorded using an Eyelink 1000 desktop infra-red camera located below the screen. Participants were required to wear a target sticker on their forehead so the camera could locate them. The eye tracker tolerated some degree of movement so the participants did not need to be physically restrained. The right eye was tracked for every participant. The eye tracker was calibrated using a nine-point calibration and validation routine at the start of the experiment and once at the halfway point.

Figure 1: Example scenes. The two versions of the scene for target word 'night' shown here. Upper panel corresponds to the 'homophone competitor' condition and lower panel corresponds to the 'cohort competitor' condition.

Table 1: Homophone and cohort competitor pairs.

Spoken Target	Homophone Competitor	Cohort Competitor
Band *music*	Band *rubber*	Bat
Bat *cricket*	Bat *animal*	Bag
Bow *ribbon*	Bow *arrow*	Boat
Bulb *plant*	Bulb *light*	Bug
Chest *body*	Chest *treasure*	Cheque
Chord	Cord	Corn
Deck *ship*	Deck *cards*	Desk
Drum *container*	Drum *music*	Drug
Fan *admirer*	Fan *cool*	Fang
File *nail*	File *cabinet*	Fire
Flour	Flower	Flag
Horn *animal*	Horn *car*	Horse
Jam *stuck*	Jam *toast*	Jack
Match *sport*	Match *fire*	Map
Mouse *computer*	Mouse *animal*	Mouth
Night	Knight	Knife
Note *music*	Note *letter*	Nose
Nut *food*	Nut *bolt*	Nun
Pair	Pear	Pen
Pen *pig*	Pen *writing*	Peg
Plane *tool*	Plane *airplane*	Plate
Plug *sink*	Plug *electrical*	Plum
Sale	Sail	Safe
Scales *fish*	Scales *weight*	Skates
Seal *close*	Seal *animal*	Seed
Son	Sun	Sub
Stake	Steak	Stain
Tank *fish*	Tank *military*	Tap
Trunk *tree*	Trunk *elephant*	Truck
Waist	Waste	Whale

** Italics denote meaning*

Procedure

Stimuli were presented using the SR Research Experiment Builder program. Participants heard sentences through Sennheiser headphones and were instructed to listen carefully and look freely about the screen. Free viewing is widely used in experiments of this nature and it has been demonstrated that the presence or absence of an explicit task has little effect on the pattern of language-mediated eye-movements (Altmann & Kamide, 1999; see Altmann, 2004; Kamide, Altmann, & Haywood, 2003, for discussion).

Two practice trials were completed and no feedback was given. Each trial began with a fixation cross in the centre of the screen. Once the participant was looking at the cross, the stimulus display was presented and subsequently the auditory sentence was presented. There were four conditions resulting from the crossing of sentence context with competitor type (homophone or cohort). Participants heard each of the 60 sentences once, with 15 sentences in each of the four conditions. Counterbalancing ensured that, for each sentence pair, half the participants heard the constraining sentence with a homophone competitor in the display and the corresponding neutral sentence with the cohort competitor displayed, while the remaining participants received the reversed pairings. Sentences were presented in two blocks of 30 in a fixed pseudo-random order, ensuring that constraining and neutral sentences for the same target word were not presented sequentially.

Analysis

Areas of interest were ovals, centered on each of the four stimuli. They were 250 pixels high and 300 pixels wide. An interest period was defined from the onset of the target word and for 6000 msec after the onset word. Raw data were exported from EyeLink Data Viewer and analysed using Microsoft Excel to determine whether, for each 20msec segment, the participant was looking at the critical image (homophone or cohort competitor) or a distractor. Proportion of gazes towards the homophone or the cohort competitor image were collapsed across conditions and averaged across participants.

Results

Homophone Condition

The upper panel of Figure 2 shows the proportion of trials on which participants were gazing at the homophone competitor as a function of time since the onset of the target word. In neutral trials there was an increase of fixations on the homophone competitor shortly after the onset of the target word. Of course, in the absence of context the homophone competitor is one of two plausible interpretations of the target word. In constraining sentences, there was also an increase in fixations on the homophone competitor. This increase was slightly less than in the neutral condition. However, consistent with the data reported by Huettig and Altmann (2004), by the end of the target word, the participants were looking at the contextually inappropriate homophone competitor considerably more than chance.

Cohort Competitor Condition

The lower panel of Figure 2 demonstrates the proportion of trials on which participants were gazing at the cohort competitor image as a function of time since the onset of the target word. When sentences were neutral, there were increased fixations on the competitor object, which declined soon after the offset of the word once the competitor object was no longer considered a candidate. In the constraining sentence condition, looks towards the cohort competitor did not differ from chance level throughout the interest period. Again, this is broadly consistent with previous studies looking at the effect of sentence context on eye-movements to cohort competitors (Barr, 2008; Brock & Nation, in preparation; Dahan & Tanenhaus, 2004).

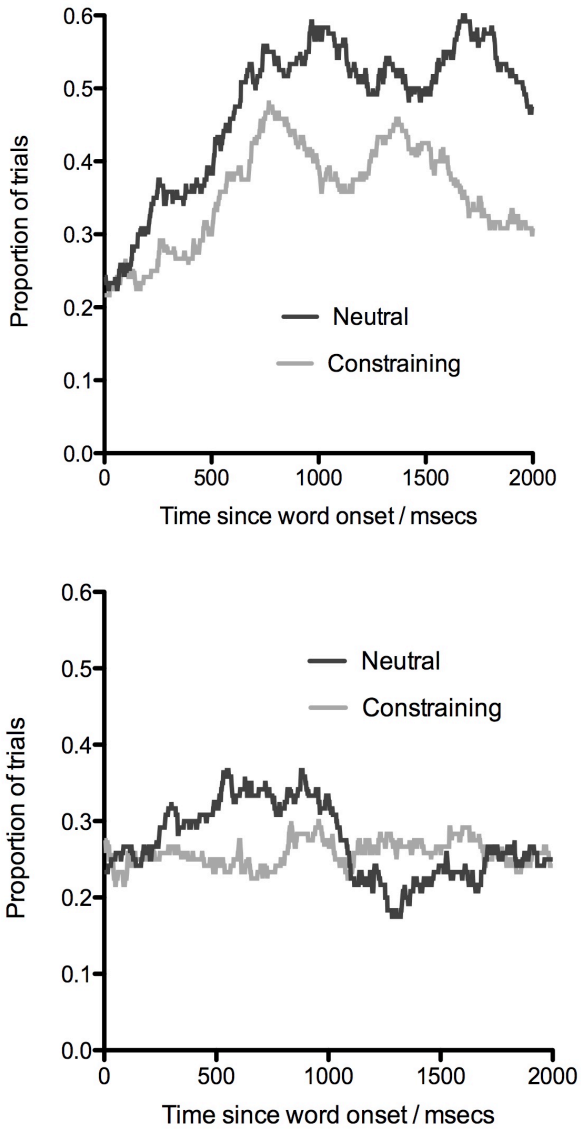

Figure 2: Proportion of trials on which participants were looking at competitor objects in neutral and constraining sentence conditions. Upper panel shows data for homophone competitors. Lower panel shows cohort competitors.

Preliminary statistical analysis

The results and analyses presented here are essentially pilot data and, while they are encouraging, more data is required before a meaningful analysis of the time-course of eye-movements can be conducted. Nevertheless, it is possible to conduct a preliminary analysis by looking at the probability of fixating on the competitor averaged across a particular window.

Visual inspection of Figure 2 (lower panel) shows that the effect of context on fixations on the cohort competitor was apparent between approximately 200 and 800 msecs after the onset of the target word. We therefore calculated the mean probability of fixation during this time window for each participant in each condition. If the effect of context is present only for cohort competitors then we should expect a significant interaction between competitor type and sentence context, particularly as we have chosen a time window to maximize the context effect in the cohort competitor condition.

A 2 (competitor) x 2 (context) repeated measures ANOVA revealed a significant effect of competitor item $F(1, 7) = 16.58$, $p < .01$. Figure 3 demonstrates that subjects were more likely to gaze at the cohort competitors than the homophone competitor objects. There was a marginally significant effect of context, $F(1, 7) = 5.13$, $p = .06$ where subjects were more likely to gaze at the target items when sentence context was neutral (Figure 3). However, there was no interaction effect $F(1, 7) = .10$, $p = .76$. Thus, the effect of sentence context on this particular measure was similar for both competitor types.

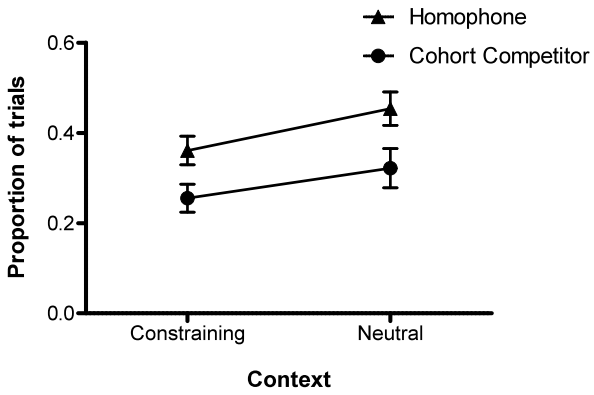

Figure 3: Average proportion of trials where participants were looking at the homophone or cohort competitor objects in constraining or neutral sentences.

Discussion

The present study used eye tracking to examine language mediated eye movements with respect to language processing. In particular we examined how sentence context impacts the identification of a word. Data reported here are only from a limited number of participants, and any conclusions are preliminary. Nevertheless, even with a small initial sample, we can already see some clear patterns emerging in the eye-tracking data.

Consistent with previous reports (Barr, 2008; Brock & Nation, in preparation; Dahan & Tanenhaus, 2004), we found that sentence context eliminated the cohort competitor effect on eye-movements. On hearing the target word in a neutral context, participants looked at a cohort competitor at above-chance levels for a brief period of around 800 msecs (in other words, until they had heard sufficient information to discount it as a

potential candidate). However, when the same words were heard in a constraining context that made the competitor an unlikely referent, the proportion of fixations on the cohort competitor never rose above chance levels. Assuming a link between eye-movements and lexical access, these findings indicate an immediate or at least very early effect of context on lexical access.

In contrast, participants tended to look at the picture corresponding to the homophone competitor, even if the context of the sentence pointed towards the alternative interpretation of the homophone. These findings are broadly consistent with the eye-tracking data reported by Huettig and Altmann (2004) as well as the semantic priming data reported by Swinney (1979) and others. If we again assume a link between eye-movements and lexical access, these findings indicate that both meanings of the homophone are accessed, regardless of the sentence context. Importantly, however, there was still an effect of sentence context. Indeed, preliminary analyses showed that the effect of sentence context on fixations on the cohort and homophone competitors was similar in magnitude, as indicated by the absence of a significant interaction term. In this respect, findings from the two competitor conditions are in agreement and reconcile the contradictory findings from previous research.

Thus, it can plausibly be argued that context has a similar immediate effect on lexical access for both homophones and cohort competitors. The difference is that, in the case of cohort competitors, the effect is sufficient to eliminate the competitor effect, whereas it only reduces the homophone competitor effect.

We must then address the question of why the homophone competitor effect is so much stronger than the cohort competitor effect. Phonologically, the onset of the cohort competitor is identical to the target word (and, of course, the homophone) so the pattern of early eye-movements should be very similar (cf. Allopenna, Magnuson & Tanenhaus, 1998). However, listeners may be sensitive to sub-phonological coarticulation cues (see e.g., Dahan & Tanenhaus, 2004, Experiment 2). The fact that later phonemes in the cohort competitor are different may alter the acoustic realization of the onset, sufficient to reduce fixations on the cohort competitor relative to the homophone.

As noted above, the results are preliminary at this stage and more data is needed to increase statistical power and reliability. It will then be possible to conduct a fine-grained analysis of the time-course of context effects for cohort and homophone competitors. Intuitively, early context effects should be the same because the homophone and competitor have phonologically identical onsets. However, as noted above, there may be some fine-grained sub-phonological differences that affect the evolution of eye-movements and context effects. Differences in fixation patterns should emerge later on once sufficient phonological information has been received to enable the cohort competitor to be eliminated as a candidate word.

Future analyses will also address the potential concern that contextual constraints may be stronger in one competitor condition than another. Although the same sentence frames were employed across the two conditions, it could still be argued that, for a given sentence frame, the homophone competitor was a more plausible referent than the corresponding cohort competitor (or vice versa). If there were any systematic differences here then we would expect differences in fixation patterns at the onset of the target word as participants anticipate the subsequent referent (Altmann & Kamide, 1999). The current data do not support this contention. At the onset of the target word, fixations on the homophone and cohort competitor were both around chance levels (25%) and there was certainly no evidence for increased gaze on the homophone competitor within the first 150 msecs or so after the target word onset.

Our results will also provide a reference for future studies that will investigate sentence context effects in developmental disorders such as autism. There is an inconsistency in the literature on autism which thus far remains unresolved. Some past research suggests that individuals with autism have impaired contextual integration such that they do not use information from sentence context when reading fully ambiguous words (Lopez & Leekam, 2003). In contrast, other research has found no group differences between typically developing and autistic children when examining the effect of context on language mediated eye-movements directed at cohort competitors (Brock, et al, 2008). Using the paradigm in this study, our future research will focus on children with autism and examine the effects of context in atypical language processing.

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