Concurrent memory load attenuates the link between eye movements and language comprehension in the visual world paradigm.

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PROBLEM

THE VISUAL WORLD PARADIGM

• The Visual World Paradigm (VWP; Cooper, 1974; Tanenhaus, et al., 1995) is a methodology that uses eye movement patterns as an online and continuous measurement of the effects of spoken language production and comprehension.

• Most VWP studies use the timing of looks to and the probability of fixation on particular regions of interest to infer the nature of underlying language processes.

• VWP studies rely on two tacit assumptions about the link between eye movements and language processing:

[A] The time-locking between eye movements and language processing is tight and consistent.

Evidence: Researchers consistently (across many studies) delay their analysis of eye movements by 200 ms following events of interest, assuming that eye movements related to language comprehension begin at that point. (but cf. Altmann & Kamide, 2004)

[B] The selection of target objects from among distractors is cost-free and independent of the number of objects in the display.

Evidence: Researchers are surprisingly inconsistent across and within studies in the number and types of objects used in visual worlds (Henderson & Ferreira, 2004)

LINKING VISION AND LANGUAGE

Attention

Cooper (1974) identified three modes of eye movement behavior relative to language processing: visual-aural interaction, point fixation, and free scanning. He suggested that shifts between these models might be related to how attention was distributed between the processing of the visual and aural stimuli.

Other work suggests that programming eye movements does, in fact, incur a limited, but measurable attentional cost (e.g. Kowler, Anderson, Dosher, & Blaser, 1995).

Short-term Memory Capacity

Cooper (1974) also noted that language-related eye movements were not always context sensitive; eye movements to visual objects were often driven by whatever concepts were currently active at a given time.

Conceptual short-term memory (Potter, 2003) or some other type of capacity-limited short-term memory (e.g. Knoeferle & Crocker, 2007) that limits the concepts (from both language and visual stimuli) that are immediately available at a given time may account for this pattern.

CURRENT EXPERIMENT

What, then, is the effect of increasing cognitive load on the link between eye movements and language comprehension in the visual world paradigm?

- We varied cognitive loads on subjects by using different types of disfluencies and a memory span-like task.
- We measured both where people looked relative to concurrent language, as well as the overall likelihood of generating new eye movements.

METHODS

- 13 subjects
- listening span-like task: subjects were required to recall the last noun from each of six utterances at the end of each of 12 blocks of utterances
- order of blocks was pseudo-randomized
- eye movements were recorded at 30 Hz using a Arrington Viewpoint table-mounted eye tracker.

CURRENT EXPERIMENT

MATERIALS

Visual World

- 9 Snodgrass & Vanderwart-like images (Roisson & Pourtois, 2004) selected from three unrelated categories were placed in a 3x3 array
- a target object (❶) and a competitor object (❷) corresponding to the nouns used in the repair disfluencies (see box below) were identified
- each image subtended 6° of visual angle

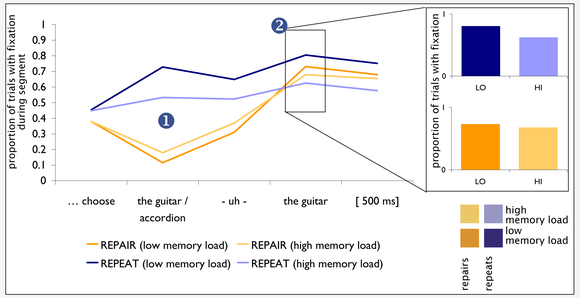
Utterances

[1] Repeat Disfluency: Jessica knew that she would choose / the guitar / uh / the guitar. / {500 ms}

[2] Repair Disfluency: Jessica knew that she would choose / the guitar / uh / the piano. / {500 ms}

- 12 blocks of 6 utterances each
- 2 target disfluent utterances per block occurred in the 2nd (low memory load) and 5th (high memory load) serial position in each block; 1 repair [1] and 1 repetition [2] disfluency per block
- eye movements were analyzed relative to utterance segments as in [1-2]
- 4 filler utterances per block (one disfluent)

RESULTS

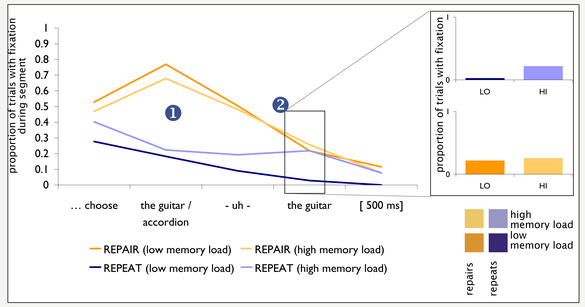


The pattern of eye movements in response to repeat and repair disfluencies replicates the pattern seen in previous studies (Bailey & Christianson, 2007): eye movements early on (❶) are driven by the reparandum nouns (guitar or accordion). Later eye movements (❷) are due to looks to the target driven by the repair noun.

However:

- a high memory load attenuates the link between eye movements and language in repeats; fewer eye movements are made to the target in the high memory load-repeat disfluency condition (see detail at ❷).
- this attenuation does not occur in response to repair disfluencies - possibly due to the high cognitive load "capping" eye movements to the target in both conditions

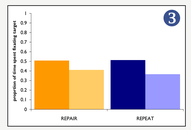
CURRENT EXPERIMENT

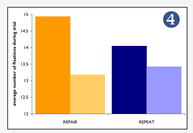


Again, early fixations (❶) are driven by the reparandum (guitar or accordion), while later patterns (❷) are due to looks away from the competitor during the repair noun.

However:

- perseveration on the competitor occurs in the high memory load and repair disfluency conditions; again, the effects of cognitive loads imposed by the memory span task and disfluency processing are not additive.

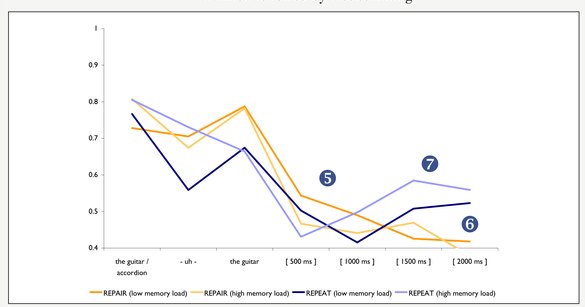




High cognitive load slightly decreases the time spent looking at target after utterance (❸) and the number of overall fixations (❹); this may indicate that cognitive load reduces visual-aural interaction.

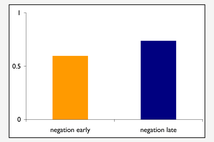
However:

- the probability of launching *any* saccade changes over the course of the trial: there is an overall decrease in saccades launched following the utterance (❺)
- this decrement lasts longer in the repair conditions (❻); in the repeat conditions, there is an rebound in the number of eye movement about 1.5 seconds after the end of the utterance (❼). This may indicate a cycle of point fixation followed by free scanning.



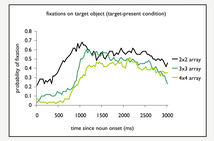
CONVERGING EVIDENCE

INCREASED COGNITIVE LOAD



Bailey & Christianson (2007) found a similar decrease in the probability of launching a saccade in utterances that involved negation. However, they found the decrease at the point of greatest difficulty (at the point of the negation), not after utterance offset as in the current experiment. One possible reason for this difference may be the lower perceptual load imposed by displays in the earlier study compared to the current study.

INCREASED PERCEPTUAL LOAD



Sorensen & Bailey (2007) held the utterance type constant, while increasing the number of irrelevant distractors in the display (using 2x2, 3x3 [as in the current experiment], and 4x4 image arrays). As the number of distractors increased, a corresponding delay and attenuation of fixations on the target object occurred.

IMPLICATIONS

The current experiment and other evidence from our lab indicates that the link between eye movements and language processing may be attenuated or delayed by two factors - short-term memory capacity and attention - leading subjects to shift between the aural-visual interaction mode and cycles of point fixation and free scanning. The proposed relationship between cognitive factors and modes of eye movements behavior in the Visual World Paradigm is as follows:

	Short-term memory capacity limits lead to delays in eye movements to objects that are referenced by concurrent language - as perceptual load increases, the likelihood that the correct object is currently in short-term memory decreases	
Limits on attention lead to increasing interference from distractors as cognitive load increases (Lavie, 2005) - more difficult tasks or structures may lead to point fixation and free scanning as the attentional system tries to compensate for interference or confusion (Engelhardt, Bailey, & Ferreira, 2006)	low perceptual load	high perceptual load
low cognitive load	visual-aural interaction	attenuated and delayed visual-aural interaction
high cognitive load	increased numbers of cycles of point fixation and free scanning	increased numbers and lengthened cycles of point fixation and free scanning

This study also suggests that attentuation and perseveration effects may be additional measures that can be used to examine spoken language using the Visual World Paradigm.

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