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## The world is too much: Effects of array size on the link between language comprehension and eye movements

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The visual world paradigm (VWP; e.g., Cooper, 1974; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995) is a methodology in which eye movements (relative to a display) are used to infer underlying language processing. This paradigm arguably allows for precise measurement (if relevant eye movements are closely time-locked to concurrent language) while using tasks that more closely reflect everyday language use (Tanenhaus et al., 1995). However, VWP displays (usually arrays of objects or images) differ from the everyday visual world (Henderson & Ferreira, 2004) in that (among other things) they limit object array size. Currently, little is known about how array size affects eye movements in the VWP. If changes in array size affect eye movement patterns in response to the same verbal stimulus, then the direct, time-locked link between eye movements and language may, in fact, be mediated by other cognitive processes.

### EXPERIMENT 1

In order to examine the effects of array size on eye movements, we chose to replicate and extend a robust VWP finding. Huettig and Altmann (2005) found that a given noun elicited more immediate saccades to a target object (a referent of the noun) or a semantic competitor object (from the same

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category as the noun), than to nonsemantically related distractors. These object images were displayed in  $2 \times 2$  arrays. The current study examined whether the same patterns were present in  $3 \times 3$  and  $4 \times 4$  arrays. Two display types were selected from the Huettig and Altmann (2005) study. The target-present display contained both a target and competitor, along with distractors; the target-absent display contained only a competitor in addition to distractors. For each of 30 nouns, we constructed six displays, corresponding to the two display types and three array sizes. Each noun was recorded in a neutral utterance (material prior to the noun did not bias participants' eye movements).

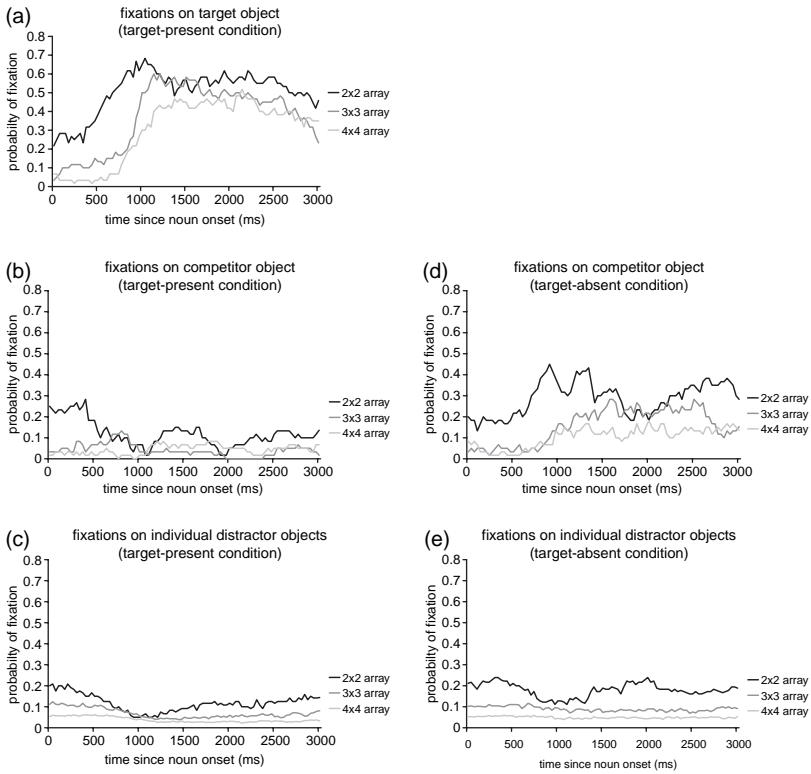
Twelve participants listened to the 30 sentences while viewing accompanying displays on a computer screen. Each participant saw only one of the six display conditions for each sentence, but saw an equal number of each display condition overall. Participants were told to look wherever they wanted, as long as they were viewing the screen; no other task was given. Displays appeared one second prior to utterance onset; each display was visible for 8 s. Eye position data relative to the screen was sampled at 30 Hz. Analyses of immediate saccades to objects were conducted, relative to the noun, on a trial by trial basis.

Because the current VWP approach assumes that eye movement patterns are not affected by array size (sizes are chosen arbitrarily), we should not expect a main effect of array size. However, as in Huettig and Altmann (2005), we should expect to find more immediate saccades to the target or competitor than to distractors.

Our results replicated the expected semantic effects for the  $2 \times 2$  array: participants made more saccades during the noun to the target (41.7% of trials) and competitor (26.7% of trials) in the target-present display than to individual distractors (17.5%). Likewise, in the target-absent display, participants made more saccades to the competitor (33.3%) than to individual distractors (17.5%). This pattern did not hold for the  $3 \times 3$  and  $4 \times 4$  arrays. As array size increased, differences between the target or competitor and individual distractors were reduced; in the  $4 \times 4$  array, as many saccades were launched during the noun to the target or competitor as to individual distractors. However, the target and competitor were overall more likely to be fixated in the 3–4 s following the noun (until the offset of the display) than were distractors; thus, as array size increased, the expected overall patterns were obtained, but were less closely time-locked to language processing (Figure 1).

## EXPERIMENT 2

The above array size effect may be due to participants' failure to fixate targets in the larger arrays prior to noun onset, thus precluding those objects



**Figure 1.** (a–e) These graphs show the probability of fixation on objects over time in Experiment 1, starting with critical noun onset. Note that additional objects in the  $3 \times 3$  and  $4 \times 4$  arrays lead to delayed responses to the critical noun and a weaker eye movement-language processing link in (a) and (d).

from being present in memory. Thus, in this experiment, we increased preview prior to utterance onset from 1 to 16 s for all three array sizes. Twelve participants took part in this experiment, which was otherwise identical to Experiment 1.

While the target was generally fixated during preview (even in the  $4 \times 4$  array), neither target nor competitor effects were found for the  $2 \times 2$  and  $4 \times 4$  arrays. The  $3 \times 3$  array elicited more immediate saccades to the target than to either the competitor or individual distractors. Again, participants fixated both targets and competitors more overall than distractors during the 3–4 s following the noun. It seems, then, that although targets were in long-term memory, some additional mediating process was necessary to drive eye movements.

### EXPERIMENT 3

In order to control for array size, we ran a variation of Experiment 2 with 12 participants, in which 1 s of preview time was given per object (i.e., each array size was seen for a different length of time). Results were similar to Experiment 1, although competitor effects were not present in any target-present condition. Again, participants fixated the target and competitor more often overall relative to individual distractors. As in Experiment 2, this implicates a mediating factor in the language-eye movement link.

### DISCUSSION

This study suggests that the VWP may be affected by the properties of displays. Specifically, increases in array size and preview time serve to decouple the strong, immediate link between language processing and eye movements. One possible mediator of the link may be short-term or working memory; larger arrays may result in the representation of the target object decaying or being dropped from short-term storage, thus requiring a visual search to take place. The lack of preview benefit is consistent with such an account. This study, then, suggests that in order to properly interpret VWP studies, models of cognition are needed that fully describe the link between language processing and eye movements.

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