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Effect of repetition proportion on language-driven anticipatory eye movements

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ABSTRACT

Previous masked priming research in word recognition has demonstrated that repetition priming is influenced by experiment-wise information structure, such as proportion of target repetition. Research using naturalistic tasks and eye-tracking has shown that people use linguistic knowledge to anticipate upcoming words. We examined whether the proportion of target repetition within an experiment can have a similar effect on anticipatory eye movements. We used a word-to-picture matching task (i.e., the visual world paradigm) with target repetition proportion carefully controlled. Participants' eye movements were tracked starting when the pictures appeared, one second prior to the onset of the target word. Targets repeated from the previous trial were fixated more than other items during this preview period when target repetition proportion was high and less than other items when target repetition proportion was low. These results indicate that linguistic anticipation can be driven by short-term within-experiment trial structure, with implications for the generalization of priming effects, the bases of anticipatory eye movements, and experiment design.

1. Introduction

Learning regularities in the environment is a critical aspect of perception and cognition, especially in the domain of language processing. Studies on this topic have typically examined either participants' long-term knowledge of the regularities in their language and in the world more generally, or participants' learning of experimentally-constructed regularities within a controlled laboratory setting. Together, these lines of research have revealed that regularities are learned quickly and play an important role in online language processing. In this report we first briefly review these two lines of research and related findings on how within-experiment regularities affect priming. We then present an eye-tracking study that used an implicit measure (eye fixations) in a naturalistic task (word-to-picture matching, i.e., the “visual world paradigm” (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995) applied to spoken word recognition (Allopenna, Magnuson, & Tanenhaus, 1998)) to examine how within-experiment regularities influence the dynamics of spoken word comprehension. The results demonstrated that within-experiment regularities produce the same kind of anticipatory effects that arise from regularities in language and the world at large.

1.1. Knowledge of regularities in language and the world

Anticipation is a crucial aspect of spoken language processing (for a review see Altmann & Mirković, 2009) and knowledge of regularities serves as a basis for anticipation. Eye-tracking provides a useful method for studying anticipation based on semantic, syntactic, and pragmatic factors. For example, Altmann and Kamide (1999) showed that listeners were more likely to look at a picture of a cake than at a non-food item after hearing the verb “eat” (in phrases such as “the boy will eat…”), suggesting that they anticipated the word “cake” based on the selectional requirements of the verb “eat” (see also Kukona, Fang, Aicher, Chen, & Magnuson, 2011). Furthermore, when there is more than one item that would be a plausible patient for the verb, listeners anticipate the most appropriate one based on the agent (Kamide, Altmann, & Haywood, 2003). Similarly, Dahan and Tanenhaus (2004) found that, when a preceding verb context established thematic constraints, fixations to items in an array were limited to the referent that maximally matched both thematic and phonetic constraints. Such anticipation is the result of experience with both language and the real-life events to which it refers. Eye tracking provides an elegant way to demonstrate this knowledge because it provides an implicit, online measure that participants need not be consciously aware of.

Eye tracking has also been used to demonstrate implicit knowledge of lexical probabilities (McDonald & Shillcock, 2003). While reading sentences, participants' initial-fixation durations—a measure of processing effort—were shorter for verb–noun combinations

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with high transitional probabilities than for pairs with low transitional probabilities. Presumably, skilled readers are able to form online predictions about upcoming words based on their knowledge about word-to-word contingencies.

When listeners encounter temporary syntactic ambiguities, they construct situation-specific evaluations of the utterance, based on perceptual and action-based knowledge (Chambers, Tanenhaus, & Magnuson, 2004). For example, when listeners heard the phrase "pour the egg in the bowl over the flour," their eye movements indicated that they expected "in the bowl" to be a modifier when the scene contained two eggs in liquid form. However, they expected "in the bowl" to specify the goal when there was only one egg in liquid form.

Listeners also use pragmatic constraints such as the knowledge of the speaker to anticipate upcoming referents (e.g., Barr, 2008; Hanna, Tanenhaus, & Trueswell, 2003). Participants engaged in a task with a confederate were able to track which items were in common ground (known to both participants) and which were in privileged ground (known only to the participant and not to the confederate). When there were two identical items that differed only in whether they were in common or privileged ground, participants used common ground as a contextual constraint and were more likely to look at the item also known to the confederate.

1.2. Learning regularities within an experiment

In addition to using information built up over a lifetime of experiences to make predictions and facilitate processing, participants in experiments can quickly exploit information gleaned from a relatively small number of instances within an experimental setting. Even infants demonstrate this kind of implicit learning: when presented with a steam of syllables, eight-month-olds were later able to discriminate "words" (recurring trisyllabic sequences that always occur in sequence) from "part-words" (recurring trisyllabic sequences with lower transitional probability because they span a "word" boundary) based on transitional probabilities (Saffran, Aslin, & Newport, 1996). Further, this kind of statistical learning facilitates later referential word learning (Graf Estes, Evans, Alibali, & Saffran, 2007; Mirman, Graf Estes, & Magnuson, 2010; Mirman, Magnuson, Graf Estes, & Dixon, 2008).

Similarly, people are able to learn regularities in a stream of visual images. Infants as young as two months showed a reliable preference for novel sequences after they were familiarized with a series of images whose ordering followed a statistically predictable pattern (e.g., Fiser & Aslin, 2001, 2002; Kirkham, Slemmer, & Johnson, 2002). Evidence for learning of visual regularities by adults was shown through faster reaction times on a categorical response task for the second item in pairs of trials that always appeared together, compared to unpaired trials (Turke-Browne, Scholl, Johnson, & Chun, 2010). Functional neuroimaging also revealed that the right anterior hippocampus responded more strongly to the first item in a pair, suggesting that the hippocampus might mediate a form of implicit perceptual anticipation. Although no participants reported being aware of the trial structure and pairs were repeated only six times, behavioral and neural results showed that learning had taken place. Participants also find targets more quickly in a visual search task when they appear in repeated configurations of distractors, compared to inconsistent locations (Chun & Jiang, 1998).

1.3. Effect of learned regularities on priming

Sensitivity to repetition proportion in priming is another type of implicit regularity learning and is particularly relevant to the present study. Bodner and Masson (2001) manipulated the proportion of masked repetition primes in a lexical decision task. Groups received 60-ms repetition primes on either 20% or 80% of trials, with unrelated primes preceding targets for the remaining trials. Both groups showed repetition priming, but the priming effect was exaggerated when the repetition priming trials made up a higher proportion of trials. The authors proposed that this repetition proportion effect stemmed from participants' ability to tune into regularities in priming stimuli and exhibit sensitivity to the validity of primes as a source of information concerning the target. Similar results were demonstrated with different tasks, such as reading aloud (Bodner & Masson, 2004).

The proportion of related primes has also been shown to influence semantic priming (e.g., de Groot, 1984; den Heyer, 1985; den Heyer, Briand, & Danenbring, 1983; Stolz & Neely, 1995). A greater proportion of related word pairs, relative to unrelated pairs, led to a greater amount of facilitation in lexical decision. In some cases, this effect is only seen with at least several hundred milliseconds between the onset of the prime and the target (e.g., Hutchinson, Neely, & Johnson, 2001; Perea & Rosa, 2002; Stolz & Neely, 1995). However, Bodner and Masson (2003) replicated the effect of relatedness proportion on semantic priming using 45-ms masked primes, suggesting that conscious awareness of primes was not necessary in order for prime validity to influence processing.

1.4. The current study

The current study aimed to bridge several gaps in the existing literature. First, we examined whether repetition priming effects and their modulation by repetition proportion generalize to a more naturalistic task (spoken word-to-picture matching) that does not require meta-linguistic judgments (e.g., lexical decision). This design used a "continuous" or "single-presentation" priming paradigm (e.g., McNamara & Altarriba, 1988; Shelton & Martin, 1992) in which the previous trial is considered the prime for the present trial and participants respond to each stimulus. The more common two-stimulus priming paradigm, in which participants are presented with two stimuli (the prime and the target) and only respond to the second, makes the pairing explicit and therefore encourages strategic processing (for discussion see McNamara & Altarriba, 1988; Shelton & Martin, 1992) even if conscious recognition of the prime is made difficult by brief presentation and visual masking (neither of which can be easily adapted for spoken word processing).

Second, the current study used eye-tracking to examine repetition priming and repetition proportion effects online, in order to connect them with anticipatory fixations in online spoken language comprehension. The priming studies only provide a final response time, so it is less clear exactly when and how the effect occurs—specifically, whether or not there is an anticipatory component to the increased facilitation. The current study combines the high temporal resolution eye-tracking paradigm and the repetition proportion manipulation to examine whether repetition proportion produces anticipatory eye movements in the time period prior to target word onset as well as the ultimate facilitative effect on reaction times.

Finally, many psycholinguistic studies involve repeated presentation of the same stimuli in different contexts or conditions. Researchers seem aware that this kind of repetition may interfere with effects of interest as evidenced by their use of filler stimuli or counterbalancing schemes. However, to our knowledge, the effect of item repetition has not been explicitly examined for these sorts of studies. The current study constitutes a step in that direction and, thus, aims to provide some methodological guidance or considerations for future studies.

The current study used a word-to-picture matching task and tracked participants' eye movements starting when the pictures appeared on the screen, prior to the onset of the target word. The trial sequence included pairs such that some items were repeated from one trial to the next in each pair. The first trial in a pair was akin to a prime in that it could provide some information about the next trial. The critical manipulation was how frequently the first and second trial in a pair had the same target, analogous to the proportion of repetition priming trials. This paradigm differs in several ways from previous investigations of the effects of repetition proportion described above. Most crucially, in the masked priming paradigms that have been used, participants were typically unaware that a prime context has been presented and were therefore unaware of the repetition proportion manipulation.

2. Methods

2.1. Participants

Analyses included a total 44 undergraduate students at the University of Connecticut, who received course credit for their participation. Six additional participants were excluded due to complete track loss on over 15% of trials. All participants were native English speakers and indicated normal or corrected-to-normal vision and hearing.

2.2. Stimuli

Stimuli consisted of 164 items from Rossion and Pourtois' (2004) color versions of Snodgrass and Vanderwart's standardized set of line drawings and 16 additional pictures of a similar style. All pictures were normed in a set of two name agreement studies completed by 11 and 9 participants, respectively. The average object agreement (name agreement with alternative responses closely related to the target accepted; e.g., “hat” for “cap”) for all items used in the study was 97% (range: 56%–100%).

The 180 items were composed of 30 sets of six items, which allowed for items to be displayed in four-item arrays with some new and some repeated items from one trial to the next within trial pairs. To examine how the variables of interest are modulated by semantic relatedness, half of these sets were semantically related, and half were unrelated. However, there were no statistically significant interactions between relatedness and any of the reported effects, so in the interests of brevity and clarity, this manipulation will not be discussed further. The full stimulus list is provided in Appendix A. For counterbalancing and equating purposes, within each set of six items, items were arbitrarily assigned to a letter “condition” (A through F) and the letter conditions equated on length and word frequency across sets such that, for example, item “As” did not differ on average from item “Bs”, etc. There was no overall difference in length or frequency between items in related sets and unrelated sets.

Target words were recorded by a female speaker in the context of a carrier phrase (“Find the…”), so that targets would sound as natural as possible. The target was then taken out of the carrier phrase to be presented as a single word in order to ensure that the anticipatory time window contained no coarticulatory information about target identity. The average duration of the target words was 700 ms. Neither related and unrelated items nor letter conditions differed significantly in duration. The intensity of all final sounds files was normalized.

2.3. Design

On each trial, participants had to pick which of four object images matched a spoken word. There was a between-subjects manipulation of the proportion of target repetition from one trial to the next, resulting in three Versions of the task (Sometimes, Always, and Never). The Versions were named to indicate how often a previous trial's target, if it reappeared on the next trial, would be the next trial's target. Table 2 provides an overview of the target repetition proportion in all Versions, and they are discussed in more detail in the following sections. Appendix B shows how the items in each stimulus set were distributed among the various conditions in each Version of the task.

2.3.1. Version 1: Sometimes

Trials were grouped into pairs such that exactly two objects from the first trial in a pair were present on screen during the second trial in the pair. There were three conditions reflecting which items were repeated and which were new on the second trial in a pair. In the Target Repeat condition, the second trial's target was the same as the first trial's target and the distractors were one non-target item repeated from the first trial and two new items. In the Target Old condition, the second trial's target was an item that was present in the first trial but not that trial's target; the distractors were the first trial's target and two new items. In the Target New condition, the second trial's target was one of the new items and the distractors were the target from the first trial, one non-target item from the first trial, and one other new item. Fig. 1 shows an example of all trials from one item set.

Each item in a set appeared an equal number of times throughout the experiment. Five of the six items in each set were used as targets; one appeared as the target twice (in the Target Repeat condition), and one never appeared as the target. Although within a set it was impossible to match all items on length and frequency, the letter condition equating described above ensured that, across sets, all item types were equated in word length and frequency. That is, overall, the repeated targets, repeated non-targets, and new items were equated in word length and frequency. This equating applied to all Versions since the same stimuli were used.

The trial pairs were arranged into three lists such that each list contained an equal number of trials from each condition and an equal number of related and unrelated trials. Each item set appeared only once in each list and in all three conditions across lists. All participants saw all lists, and order was counterbalanced across participants.

2.3.2. Version 2: Always

In the Sometimes Version described above, when a previous trial's target reappeared in the next trial, it was sometimes the target again and sometimes not. In this Version, if the previous trial's target reappeared, it was always the target again. This was the case for half of the trial pairs—those in the Target Repeat condition. As in the Sometimes Version, in this condition, the second trial's target was the same as the first trial's target; the distractors were two new items and one repeated non-target item from the previous trial. The second half of trial pairs was divided between two types of filler conditions. In the “Filler-New” condition, the second trial's target was a new item; another new item and two non-target items repeated from the previous trial appeared as distractors. In the “Filler-Old” condition, a non-target item from the previous trial was the next trial's target; one other repeated non-target item and two new items were distractors. Importantly, the previous trial's target never reappeared as a distractor in either Filler condition. An example of trials from one item set in this Version is shown in Fig. 2.

Each item in a set appeared an equal number of times throughout the Target Repeat and Filler trials. Three of the six items in each set were used as targets, and one of those items appeared twice as the target (in the Target Repeat condition). The trial pairs were arranged into two lists such that each list contained an equal number of trials in the Target Repeat condition and in the Filler conditions. Each item set appeared only once in each list and in both conditions (Target Repeat and one of the Filler conditions) across lists. Participants saw both lists, and order was counterbalanced across participants.

2.3.3. Version 3: Never

In this Version, the previous trial's target reappeared in the second trial of every pair, but it was never the target again. Only the Target New and Target Old conditions from the Sometimes Version were included, with no Target Repeat condition.

Each item in a set appeared an equal number of times throughout the experiment. Four of the six items in each set appeared as targets. The trial pairs were arranged into two lists such that each list contained an equal number of trials in the two conditions. Each item set appeared only once in each list and in both conditions across lists. Participants saw both lists, and order was counterbalanced across participants.

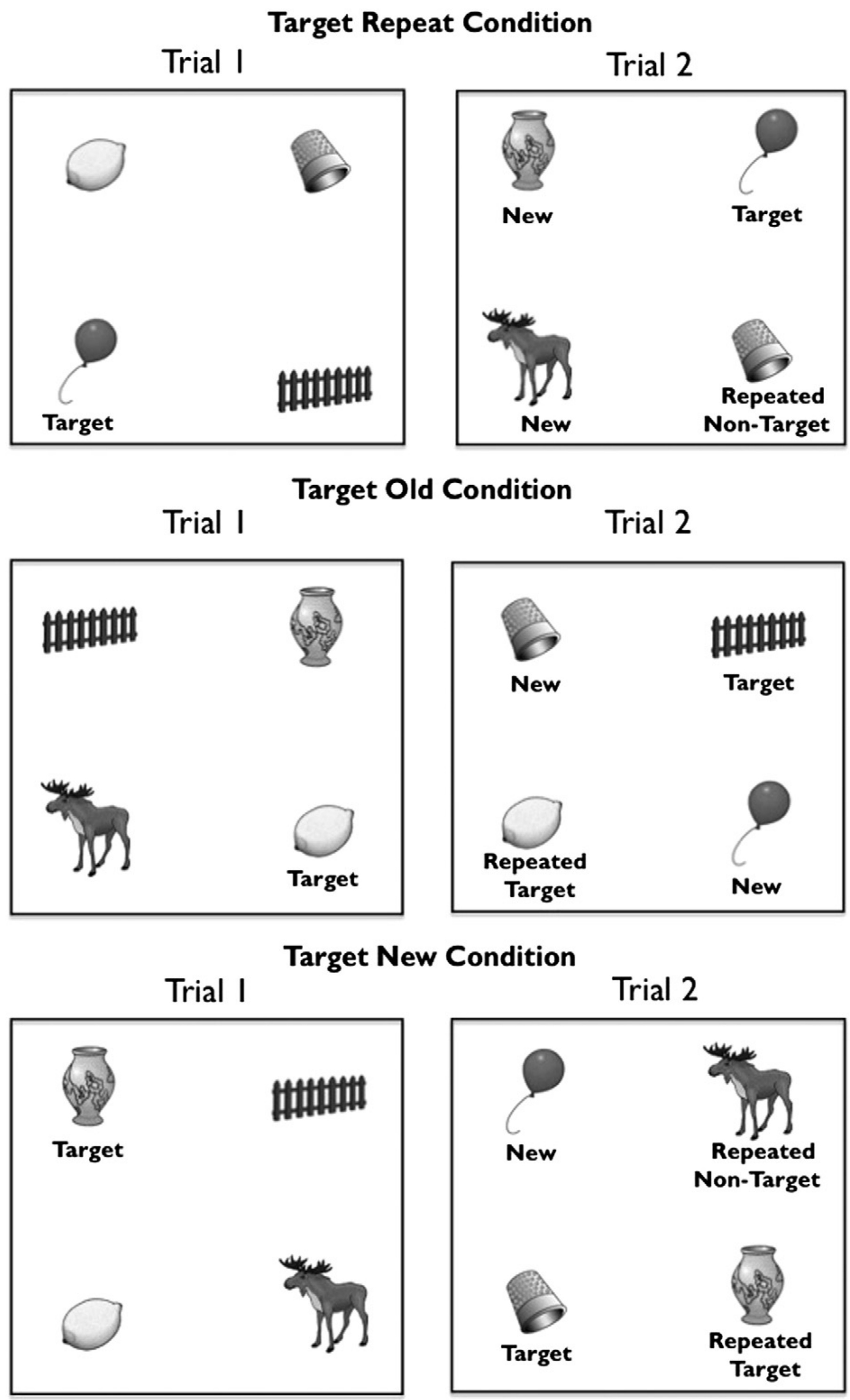

Fig. 1. Example of all trials from all conditions for an item set in the Sometimes Version.

2.4. Procedure

Participants were seated in front of a computer and an SR Research EyeLink 1000 Desktop Mount eye-tracker, which was used to record participants' left eye gaze position at a sampling rate of 250 Hz. Calibration was performed with an average error of less than 2°. Ten practice trials with accuracy feedback were followed by either 180 experimental trials in the Sometimes Version or 120 experimental trials in the Always or Never Versions. To start each trial, participants clicked on a central fixation cross, after which four pictures appeared on the screen in the arrangement shown in Figs. 1 and 2. The location of each item in the array was randomized. The target word played after a 1000-ms preview period, and the trial ended when the participant clicked on one of the four images. Stimuli were presented and responses were recorded using E-Prime Professional 2.0.

2.5. Data analysis

The fixation time course data were analyzed using growth curve analysis (GCA; Singer & Willett, 2003), a multilevel orthogonal

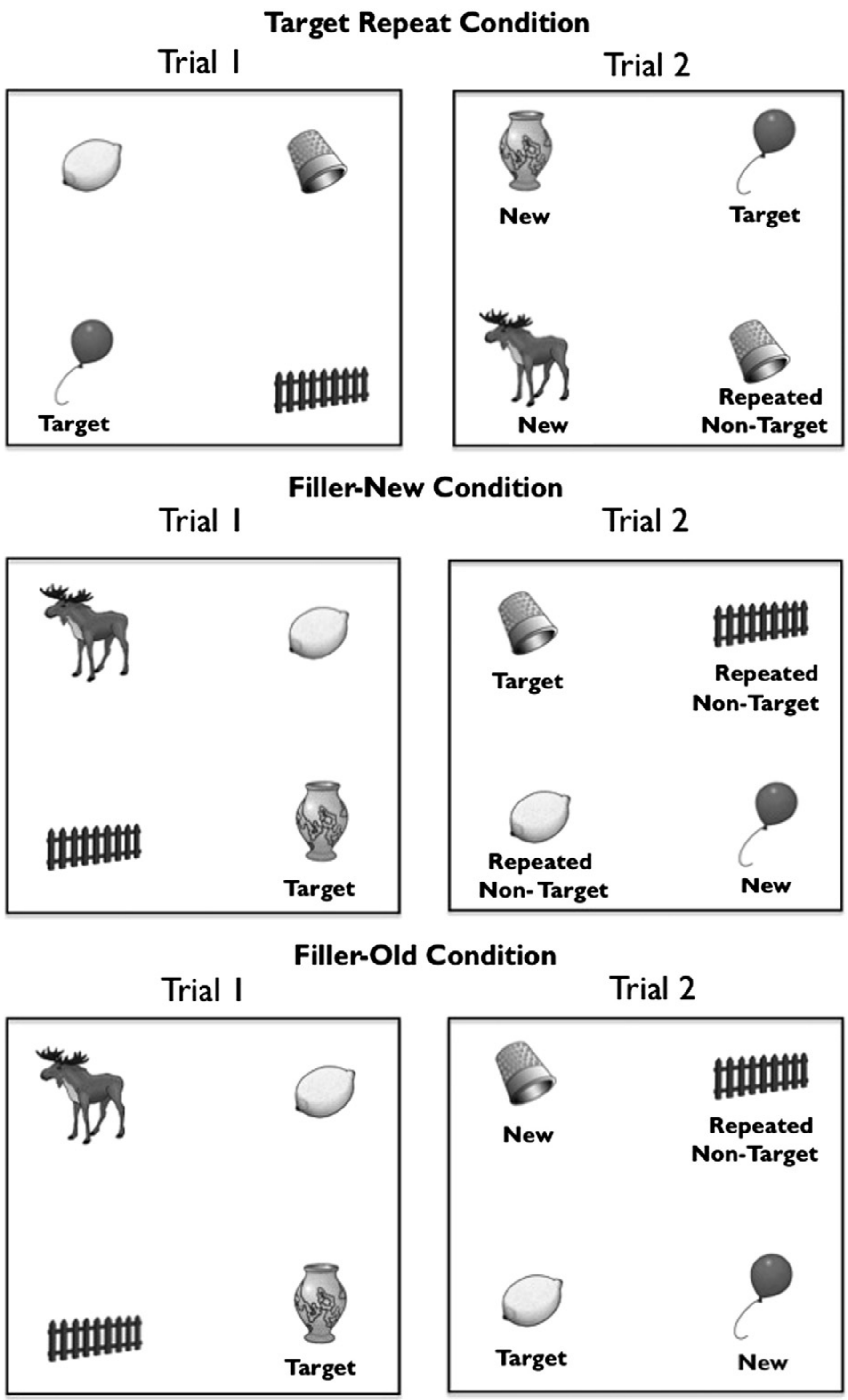

Fig. 2. Example of all possible trials from all conditions for an item set in the Always Version. Each item set appeared in the Target Repeat condition and one of the Filler conditions—either Filler-New or Filler-Old.

polynomial regression method developed to assess change over time (for extensions to eye tracking during spoken language, see Magnuson, Dixon, Tanenhaus, & Aslin, 2007; Mirman, Dixon, & Magnuson, 2008). Specifically, we used GCA to examine the effects of Version (the proportion of target repetition from one trial to the next when the previous target reappeared in the second trial) and item type within each Version (the role of an item in Trial 2 relative to Trial 1) on the time course of fixation probabilities. This analysis method can provide information not only about whether our manipulations significantly influenced fixations (driven, we assume, by the underlying patterns of word activation and competition) but also how and when this influence unfolded.

The Level-1 model used second-order polynomials to capture the overall time course of the fixation curves. Level-2 fixed effects captured the way (if any) that Version (Sometimes, Always, Never) modulated the Level-1 time terms (for a detailed description see Mirman, Dixon, et al., 2008). Effects on the intercept term capture differences in overall average curve height (i.e., whether one Version received an overall higher proportion of fixations to a given item during the time window being analyzed, analogous to mean fixation proportion in the analysis window). Overall differences in slope appear as effects on the linear time term, and differences in the centered rise and fall rate of curves are captured by effects on the quadratic term. The model also included random effects of participants and participants-by-condition(s) on all time terms to model random variation between individuals. Effects of parameters were evaluated using model comparisons with χ^2 tests for improvement in model fit and parameter-specific p-values were estimated using the normal approximation (i.e., treating the t-value as a z-value; for discussion and evaluation of this approach see Barr, Levy, Scheepers, & Tily, 2013).

3. Results

3.1. Accuracy and reaction time

Participants correctly selected the named object on almost every trial (99.4% accuracy overall). Logistic regression revealed no significant effects of Version (i.e., repetition proportion) on accuracy (all $p > 0.18$).

Analysis of reaction times excluded 2.2% of data: pairs of trials in which the participant selected the wrong item on either trial, in which an item was selected before the start of the target word, or in which one or both trials were missing due to data loss. Mean RTs for the first and second trial in each condition of each Version are shown in Table 1. We were specifically interested in whether repetition priming varied by the proportion of trials in which the target was the same as the previous trial's. Fig. 3 shows a measure of repetition priming—the mean difference in reaction time (RT) between the first and second trials in each pair. The first analysis focused on the rightmost pair of bars, which are the cases in which a target was repeated from one trial to the next (i.e., the Target Repeat condition in the Always and Sometimes Versions, both of which included 30 trial pairs per subject; by definition, there were no such trials in the Never Version). An ANOVA revealed a main effect of Version ($F(1, 30) = 9.06$, $p = 0.005$), with more priming in the Always Version, when the previous trial's target was always the target again if it appeared in the subsequent trial. This result is a variation on Bodner and Masson's (2001) finding that primes exert a greater influence on processing when they are more valid sources of information. Processing was facilitated when a target was repeated from one trial to the next (as in the Sometimes Version), and this facilitation was greater when the presence of the previous trial's target on the next trial indicated that it *would* be the target again, rather than that it *might* be the target again.

These results indicate that repetition priming was strengthened by stronger information about what the next trial's target would be. Next, we examined the case in which there was strong information about what the next trial's target would *not* be. In each pair of trials in the Never Version, the first trial's target reappeared in the next trial but was never the target again, so it could essentially be “ruled out” as the next trial's target. In contrast, in the Sometimes Version, the first trial's target always reappeared in the next trial and might or might not be the next trial's target. In other words, in the Sometimes Version, the reappearance of the first trial's target provided probabilistic information about what role it would play in the current trial, but it provided unambiguous information for participants in the Never Version.

Table 1
Mean RT in milliseconds for the first and second trial in each condition of each Version, with standard deviation in parentheses.

Version	Condition	Mean Trial 1 RT	Mean Trial 2 RT
Sometimes	Target New	1374 (409)	1297 (355)
	Target Old	1349 (388)	1309 (347)
	Target Repeat	1312 (402)	1054 (272)
Always	Target Repeat	1359 (337)	995 (384)
Never	Target New	1475 (434)	1345 (371)
	Target Old	1463 (591)	1368 (380)

Table 2
Target repetition proportion in each Version.

	Sometimes	Always	Never
Total number of trials	180	120	120
Total number of trial pairs	90	60	60
Number of pairs in which T1 target item reappears on T2	90	30	60
Number of pairs in which T1 target item is the target again on T2	30	30	0
% Overall target repetition throughout experiment	33%	50%	0%
% Target repetition when T1 target reappears on T2	33%	100%	0%

We compared the leftmost and middle pairs of bars in Fig. 3: the Target New and Target Old conditions of the Sometimes and Never Versions—cases in which the previous trial's target reappeared as a distractor. Prior to target onset, this item could not be ruled out as the target in the Sometimes Version but could be ruled out as the target in the Never Version based on the target repetition proportion. A 2 (Version) × 2 (condition) ANOVA revealed a main effect of Version ($F(1, 31) = 5.72$, $p = 0.02$), a marginal effect of condition ($F(1,31) = 3.30$, $p = 0.08$), and no significant condition-by-Version interaction ($F(1,31) = 0.001$, $p = 0.97$). The larger facilitation from Trial 1 to Trial 2 in the Never Version compared to the Sometimes Version (main effect of Version) reflects an effect of non-repetition proportion: facilitation effects for target non-repetition trials were larger when the repetition proportion throughout the experiment was 0% than when it was higher (but still occurred on the minority of trials). The marginal effect of condition resulted from slightly more exaggerated facilitation in the Target New condition for both the Sometimes and Never Versions.

In sum, whenever target repetition proportion provided strong information about the role of the previous trial's target in the next trial, facilitation from Trial 1 to Trial 2 was greater than when the information provided by target repetition proportion was weaker.

3.2. Anticipatory eye movements

For all analyses of eye movement data, we considered data only from the second trial of each pair since we were interested in whether

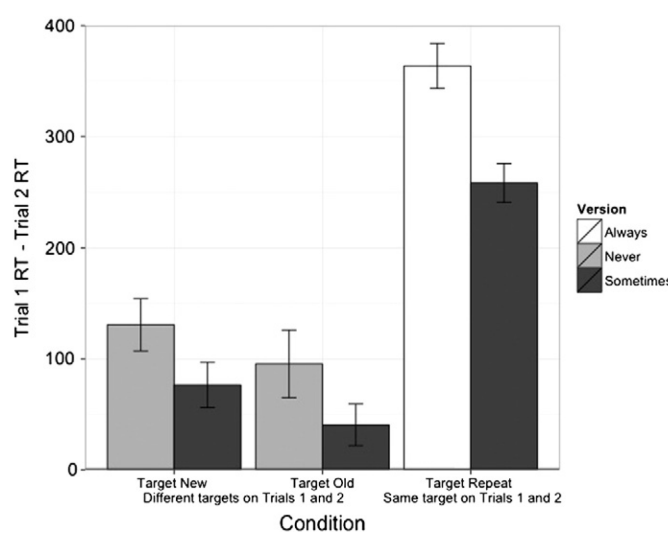

Fig. 3. Mean decrease in RT (ms) from Trial 1 to Trial 2. The leftmost and middle pairs of bars represent cases in which the previous trial's target reappeared as a distractor on the next trial. Throughout these experiments, a repeated target was either sometimes (dark gray bars) or never (light gray bars) the target again. The rightmost pair of bars represents cases in which the same target was repeated from one trial to the next. The presence of a repeated target in the display indicated that it would always (white bar) or sometimes (dark gray bar) be the target again.

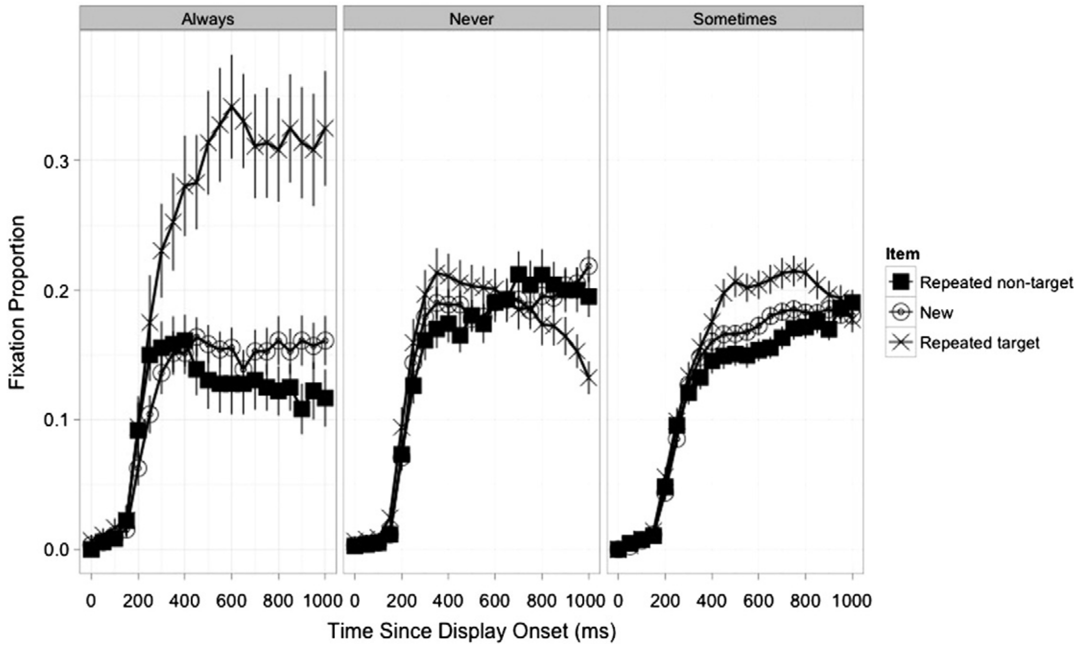

Fig. 4. Mean fixations to each item type during the preview period in the three Versions.

participants would make anticipatory eye movements based on the information from the first trial. The analyses were applied to fixation data starting 200 ms after the onset of the display, to allow time for planning and execution of the first fixation driven by the display, and lasting until the onset of the target word (1000 ms after display onset). Fixation probabilities for each item type were calculated in 50-ms time bins over all second trials for each condition in each Version (excluding trial pairs on which the participant made an incorrect response on either trial). On critical trials, the types of images in the display during the preview period were the same across all conditions and Versions: the previous trial's target, an item repeated from the previous trial that was not the previous trial's target, and two new items—and there was not yet any indication of what the target would be. The Filler-Old and Filler New conditions in the Always Version differed in that they did not include the previous trial's target; these conditions were not included in analyses of the preview period. All analyzed conditions contained the same number of second trials (30), but since condition distinctions were not yet relevant during the preview period, analyses contained a different number of second trials for each Version—90 trials in the Sometimes Version (30 Target Repeat, 30 Target New, 30 Target Old), 60 in the Never Version (30 Target New, 30 Target Old), and 30 in the Always Version (30 Target Repeat).

Fig. 4 shows mean fixations to each item type in the three Versions during the anticipatory period prior to target onset. Table 3 contains the details of the GCA results, organized by item comparison and Version. In the Always Version (left panel), there was a preference to look at the repeated target. The overall higher mean fixations to this item resulted in strong effects of item type on the intercept when repeated targets were compared to new items and repeated non-target items.

As in the Always Version, the repeated target was fixated more than other item types in the Sometimes Version (right panel). There was a significant effect of item type on the intercept when repeated targets were compared to new items and repeated non-target items. However,

Table 3
GCA results from analyses of the effect of item type on fixations in each Version from 200–1000 ms during the preview period. The values in the cells are parameter estimates with SE in parentheses.

Effect of item type on	Repeated Target vs. New Item	Repeated Target vs. Repeated Non-target Item	Repeated Non-target Item vs. New Item
Always			
Intercept	0.14 (0.04) ***	0.15 (0.04) ***	−0.01 (0.04)
Linear	0.13 (0.07) ~	0.22 (0.07) ***	−0.09 (0.07)
Quadratic	−0.10 (0.05) *	−0.13 (0.05) **	0.03 (0.05)
Sometimes			
Intercept	0.02 (0.01) *	0.03 (0.01) **	−0.01 (0.01)
Linear	0.01 (0.03)	0.02 (0.03)	−0.01 (0.03)
Quadratic	−0.03 (0.02) ~	−0.06 (0.02) ***	0.03 (0.02) ~
Never			
Intercept	0.002 (0.01)	0.005 (0.01)	−0.002 (0.01)
Linear	−0.08 (0.04) *	−0.11 (0.04) **	0.03 (0.04)
Quadratic	−0.04 (0.03)	−0.03 (0.03)	−0.01 (0.03)

~$p < 0.1$.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

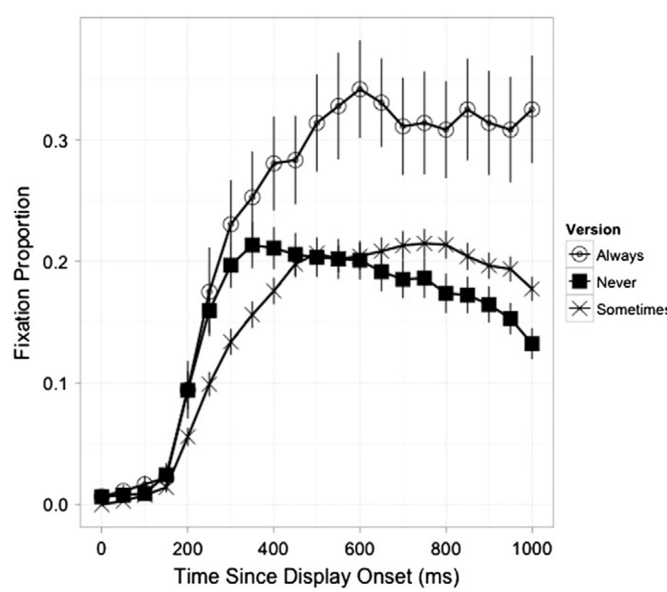

Fig. 5. Mean fixations across the three Versions to the previous trial's target during the subsequent trial's preview period.

Table 4
GCA results from the analysis of the effect of Version on fixations to the repeated target item from 200 to 1000 ms during the preview period. The values in the cells are parameter estimates with SE in parentheses.

Effect of Version on	Always vs. Never	Always vs. Sometimes	Never vs. Sometimes
Intercept	0.10 (0.04) **	0.10 (0.03) **	0.002 (0.03)~
Linear	0.19 (0.07) **	0.05 (0.07)	−0.13 (0.06) *
Quadratic	−0.06 (0.04)***	0.05 (0.04)	0.02 (0.03)

~ $p < 0.1$.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

the effect in Always Version was stronger and emerged earlier in the trial time course than in the Sometimes Version. Table 3 shows that for the repeated target (first two columns), parameter estimates are in the same direction for both Versions but are substantially larger for the Always Version.

In the Never Version (middle panel), looks to the repeated target declined over the course of the preview period, ultimately dropping below the other item types. Because this pattern of fewer fixations to the repeated target was not present throughout the entire time window, the effect of item type on the intercept was not significant. However, the downward slope of fixations to the repeated target did result in a significant effect of item type on the linear term when repeated targets were compared to new items and repeated non-target items. For all three Versions, there were no significant effects of item type when new and repeated non-target items were compared.

Fixations to the repeated target across all three Versions are shown together in Fig. 5 and GCA results are in Table 4. There was an effect of Version on the intercept, with more fixations to the repeated target in the Always Version than the Sometimes and Never Versions. The difference in looks to the repeated target in the Sometimes and Never Versions was more subtle, but there was an effect of Version on the linear term due to the steeper decline in looks to the repeated target throughout the preview period in the Never Version. There were no such differences among Versions in fixations to the new and repeated non-target items.

If these regularities are learned over the course of the experiment, then these effects should emerge gradually as participants experience more and more trials that contain these regularities. Fig. 6 shows the fixation data for the repeated target in each Version divided into four “blocks”: the first, second, third, and fourth quarter of trial pairs. Including a block-by-Version interaction effect (with block treated as a continuous variable) on the intercept significantly improved model fit for these data ($\chi^2(2) = 11.12, p = 0.004$).

Table 5 shows the GCA results for the effect of block on fixations to the repeated target in each Version separately. There were significant effects of block on the intercept and linear terms in the Always Version. Participants became more likely to fixate the repeated target during the preview period as the experiment progressed and they gained more experience with the trial structure, which presumably led to a greater ability to use that information to anticipate the target in the Always Version.

Fixations to the repeated target also changed over time in the Sometimes Version; there was a significant effect of block on the quadratic term. However, the effect of block on fixations in this Version was in the opposite direction, compared to the effect seen in the Always Version: fixations to the repeated target decreased throughout the experiment (the quadratic effect indicates that the curve in fixations to the repeated target item became flatter over time), such that there was little difference among fixations to the various item types by the end of the experiment. In this Version, the trial structure did not provide useful information about what the target would be, and fixation data broken down by block showed that participants did learn this over the course of the experiment. However, there was a preference for repeated targets in the first block despite the fact that targets were only repeated on one-third of trial pairs, and more generally, a given trial's target had only a 16.7% chance of being the target on the next trial. We note that 16.7% seems substantially higher than the word repetition rate in typical language contexts (i.e., people rarely say the same word twice in a row, certainly less than one out of every six words), so target repetition may have been particularly salient at the beginning of the experiment, before participants had had sufficient experience with the trial structure.

In the Never Version, there was no change in fixations to the repeated target during the preview period over the course of the experiment; no effects of block were significant. This may have resulted from a floor effect.

4. Discussion

The present study replicated and extended previous findings that repetition priming effects are larger when the proportion of repetition trials is larger using a new task and paradigm. The critical finding was that increased repetition priming effects were reflected in online anticipatory fixation patterns, thus connecting them to the large literature

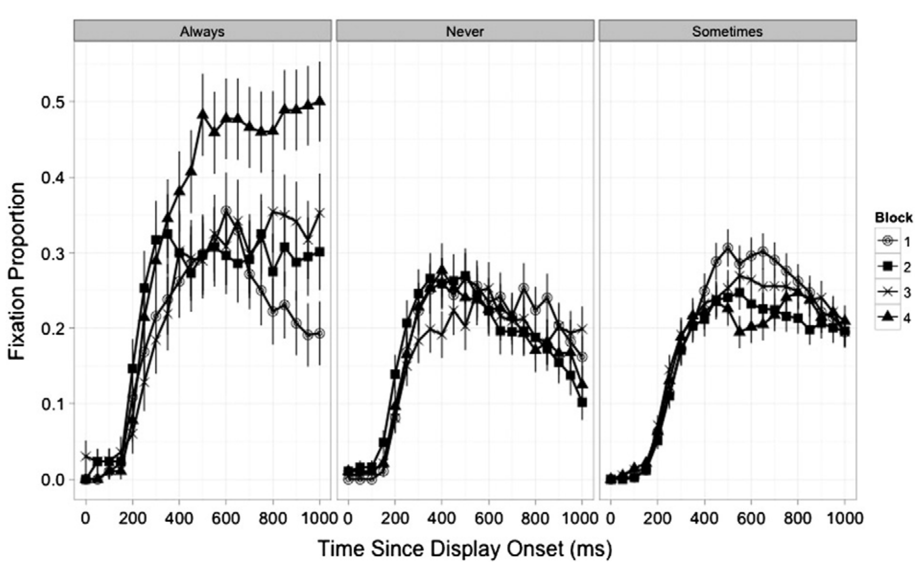

Fig. 6. Mean fixations to the repeated target over time (by the first, second, third, and fourth quarter of trials) for each Version.

Table 5
GCA results from analyses of the effect of block on fixations to the repeated target item in each Version from 200 to 1000 ms during the preview period. Block was treated as a continuous variable. The values in the cells are parameter estimates with SE in parentheses.

Effect of Block on:	Always	Sometimes	Never
Intercept	0.04 (0.01)**	−0.01 (0.01)~	−0.01 (0.01)
Linear	0.11 (0.04)**	−0.003 (0.02)	−0.01 (0.03)*
Quadratic	−0.01 (0.03)	0.04 (0.01)**	0.004 (0.02)***

~ $p < 0.1$.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

investigating online anticipatory effects in language comprehension. Repetition proportion has been shown to influence processing in terms of final reaction time, but the current study showed that this facilitation occurs even before target processing begins. Participants were able to anticipate what the target would be (and would not be) when regularities in the trial structure provided information about target identity. Because these effects were induced by regularities within the experiment, the results also suggest that anticipatory eye movements can reflect general prediction/anticipation mechanisms that are not specific to long-term linguistic knowledge or other domains in which participants already have a good deal of experience.

In addition to anticipatory effects based on the probability that a target would be repeated, participants exhibited a preference to look at the repeated target during the preview period even in the Sometimes Version, in which target repetition occurred only in a minority of trial pairs. Examining the data broken down by block revealed that participants exhibited a bias to look at the previous trial's target early in the experiment and this bias gradually decreased as participants learned that target repetition was unlikely. Thus, it appears that even a relatively low proportion of target repetition trials within an experiment can cause a previous trial's target to have a higher baseline.

In an earlier account of the effect of repetition proportion on priming, Bodner and Masson (2001) proposed that an episodic representation is created even for masked primes and the recruitment of these representations is contingent on their validity (repetition proportion) after the target is presented. The results of the current study do not speak directly to this account, given the use of non-masked primes and other paradigm differences. However, the present findings do suggest an anticipatory—rather than a retrospective—locus; we saw an influence of repetition proportion even before target processing began for the trial following the presentation of the prime. Eyetracking allowed us to examine this time period prior to target onset, but it is certainly possible that target processing was additionally influenced by repetition proportion in a way separate from anticipation of the target.

Another difference between the present findings and those observed in masked priming studies emerged in the nature of the effect over the course of the experiment. Whereas the influence of prime validity appeared early and was stable across blocks in masked priming tasks (Bodner & Masson, 2001), we saw a build-up of the effect over time. In part, this may reflect differences in time scale: Bodner and Masson's masked priming experiments began with 40 practice trials and their blocks consisted of 100 trials, the present study had only 10 practice trials and the blocks contained 30–45 trials (depending on the version), so we may have detected the build-up simply because we looked at a finer time scale. In addition, immediate target repetition is quite noticeable, so it is reasonable to assume that participants recognized that items were being repeated from one trial to the next, though it is not clear to what extent they were employing conscious strategies based on that information. The anticipatory eye movements we observed could potentially reflect participants' explicit strategies or implicit expectations. It will be important to distinguish between these accounts and explore the issue further in future studies. In either case, the crucial finding is the way in which behavior is shaped by repetition.

The present study forms a bridge between studies that have demonstrated sensitivity to within-experiment regularities and those that demonstrated anticipatory eye movements based on language or real-world regularities. The main finding was that proportion of target repetition from one trial to the next in a word-to-picture matching experiment influenced anticipatory eye movements. This demonstrates that implicit expectations built up by repetition proportion in masked priming paradigms (Bodner & Masson, 2001) can also be observed in an implicit measure of anticipation (eye movements) in a naturalistic task. Further, participants exhibited anticipatory effects of the type shown for language and real-world regularities in response to a within-experiment regularity, suggesting that listeners integrate all available information and constraints to predict or anticipate upcoming words. Constraining information need neither be linguistic, nor temporally present; such expectation-based results reinforce the need for careful control over experiment-wise information in designing visual world studies.

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Appendix A

Stimuli sets used in the current experiment

Letter condition	A	B	C	D	E	F
	Related					
	Pineapple	Banana	Strawberry	Orange	Apple	Pear
	Pepper	Carrot	Mushroom	Asparagus	Onion	Broccoli
	Giraffe	Rhino	Camel	Lion	Monkey	Zebra
	Bird	Cat	Dog	Frog	Mouse	Rabbit
	Octopus	Dolphin	Lobster	Fish	Alligator	Walrus
	(Baseball) Glove	(Tennis) Racket	(Baseball) Bat	(Soccer) Net	Football	(Football) Helmet
	Pliers	Wrench	Hammer	Drill	Saw	Screwdriver
	Grasshopper	Caterpillar	Spider	Ant	Fly	Bee
	Train	Car	Sailboat	Motorcycle	Airplane	Bike
	Pants	Shirt	Dress	Vest	Skirt	Jacket
	Violin	Drum	Guitar	Piano	Accordion	Harp
	Ear	Finger	Leg	Arm	Nose	Lips
	Peacock	Rooster	Owl	Duck	Penguin	Ostrich
	Bed	Dresser	Sofa	Chair	Desk	Table
	Microwave	Stove	Toaster	Blender	Dishwasher	Refrigerator

Appendix A (*continued*)

Letter condition	A	B	C	D	E	F
	Unrelated					
	Peanut	Barn	Level	Ashtray	Hanger	Raccoon
	Balloon	Thimble	Lemon	Fence	Vase	Moose
	Scissors	Umbrella	Tomato	Wagon	Deer	Broom
	Pencil	Doll	Glasses	Moon	Telephone	Bus
	Bowl	Kangaroo	Cloud	Ladder	Cigarette	Iron
	Hat	Flower	Stool	Toothbrush	Rollerskate	Watermelon
	Sun	Well	Donkey	Pitcher	Bow	Trumpet
	Bell	Horse	Top	Windmill	Ambulance	Pumpkin
	Butterfly	Ruler	Necklace	Celery	Gun	Snowman
	Cannon	Thread	Pipe	Ball	Watch	Frying pan
	Glass	Suitcase	Flute	Crown	Barrel	Key
	Wheel	Heart	Kettle	Grapes	Cap	Snake
	Thumb	House	Leopard	Kite	Jar	Sandwich
	Leaf	Ring	Television	Church	Helicopter	Pig
	Envelope	Turtle	Cake	Belt	Hair	Anchor

Appendix B

Distribution of stimuli sets into the various conditions in each Version of the task

Version	Condition	Prop. of trial pairs in condition	Number of trial pairs in condition	Trial 1				Trial 2			
				Target	Distractors			Target	Distractors		
Sometimes	Target Repeat	0.33	30	A	B	C	D	A	B (repeated non-target)	E (new item)	F (new item)
	Target Old	0.33	30	C	D	E	F	D	C (repeated target)	A (new item)	B (new item)
	Target New	0.33	30	E	C	D	F	B	E (repeated target)	F (repeated non-target)	A (new item)
Always	Target Repeat	0.5	30	A	B	C	D	A	B (repeated non-target)	E (new item)	F (new item)
	Filler-Old	0.25	15	E	F	C	D	C	D (repeated non-target)	A (new item)	B (new item)
	Filler-New	0.25	15	E	F	C	D	B	A (new item)	C (repeated non-target)	D (repeated non-target)
Never	Target Old	0.5	30	C	D	E	F	D	C (repeated target)	A (new item)	B (new item)
	Target New	0.5	30	E	C	D	F	B	E (repeated target)	F (repeated non-target)	A (new item)

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