On-line predictive inferences in reading: Processing time *during* versus *after* the priming context

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Prior research suggests that predictive inferences take time to construct on-line. The present study examines the relative contribution of time available during and after reading an inducing context. In six experiments, we manipulated the presentation rate of the context and the delay between the onset of the last word in the context and a target word. A predicting, or a control, sentence context was followed by a target word, which represented the predicted event or an unlikely event. The results indicated that increasing the time available during reading of the context improved comprehension of explicit information, but it did not affect construction of inferences. In contrast, increasing the delay at the end of the context did not affect explicit comprehension, but it enhanced the probability of inferences, as revealed by shorter latencies in naming the predictable target word after the inducing context, relative to the control context. These findings show that readers defer making predictive inferences until 1 sec after the sentence context has been read, regardless of the time available when they are processing the context.

Predictive inferences are anticipations of likely events, or elaborations about "what will happen next," based on implicit information in a message (Fincher-Kiefer, 1993; Keefe & McDaniel, 1993; McKoon & Ratcliff, 1986; Trabasso & Magliano, 1996). For example, *the car started* might be a predictive inference drawn when one is reading, *Diego got into his car, put the key in the ignition, and turned it clockwise while he pressed the accelerator*. These inferences are assumed to make an important contribution to comprehension, as well as to behavior. They enable us to anticipate forthcoming information or stimuli, and thus facilitate (1) processing of this new information and (2) adaptive reaction to anticipated stimuli. Because of this useful preparatory function, it seems reasonable that predictive inferences can be drawn on-line. However, the possibility of multiple alternatives to forecast, the limitation of working memory resources, and the interruption of other ongoing processes could impose a delay in the generation of this type of inference on-line.

The minimalist hypothesis (McKoon & Ratcliff, 1992, 1995) and the constructionist theory (Graesser, Singer, & Trabasso, 1994) agree that these inferences are not normally encoded on-line. The reason is that they are not nec-

essary to establish coherence in the text (minimalist hypothesis) or in the situation model (constructionist theory). However, both models admit that predictive inferences could be generated on-line if the predictable event is readily available in, or if it is highly constrained by, the context. Nevertheless, even if made on-line under certain restricted conditions, predictive inferences are not automatic according to either model. Rather, they would be strategic elaborations, and therefore should take time to develop.

Prior research has obtained both negative and positive results regarding the hypothesis that predictive inferences are generated during reading. These inferences were not detected in some early studies (Duffy, 1986; Potts, Keenan, & Golding, 1988; Singer & Ferreira, 1983; or only "minimally" in McKoon & Ratcliff, 1986), nor in two more recent studies (Magliano, Baggett, Johnson, & Graesser, 1993; Millis & Graesser, 1994). In contrast, other studies have provided data that support the hypothesis that these inferences are drawn on-line (Calvo & Castillo, 1996; Fincher-Kiefer, 1993, 1994, 1995, 1996; Keefe & McDaniel, 1993; Lea, 1995; Murray, Klin, & Myers, 1993; Whitney, Ritchie, & Crane, 1992). One explanation for the negative findings may be concerned with not meeting the criteria specified by the minimalist hypothesis and the constructionist theory regarding context constraints (i.e., the predicting context must strongly imply *one* main, well-known, and readily available consequence). Thus, both Magliano et al.'s (1993) and Millis and Graesser's studies used materials in which the proportion of participants who could produce the inference (target word) in "what happened next" questions was rather low.¹ Another reason is concerned with not keeping the inference concept "in attentional focus" (Lea, 1995; Murray et al., 1993) or

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"foregrounded" (Keefe & McDaniel, 1993; Whitney et al., 1992) until the time of test, which might have affected some of the earlier studies (e.g., Potts et al., 1988).

Most of the studies that have detected on-line predictive inferences could not determine their time course, though. The reason is that most procedures allowed self-paced presentation of the inducing contexts and of the probe, and timing parameters between the context and the probe were not manipulated (Fincher-Kiefer, 1993, 1994; Keefe & McDaniel, 1993; Lea, 1995; Murray et al., 1993; Whitney et al., 1992). Nevertheless, under these self-paced timing conditions, carryover effects have been observed, which suggests that predictive inferences take time to construct. Thus, Calvo and Castillo (1996, Experiment 2; 1998, Experiment 2) presented a continuation sentence after the inducing context that the participants read at their own pace word by word. The continuation sentence included (1) a target word that represented the predicted event, followed by (2) a posttarget region, and (3) a final region that elaborated the predicted event. There was no effect on reading times for the target word itself, but reading times for the posttarget region and/or the final region were facilitated by the prior inducing context.

A second group of studies have controlled timing parameters either by means of fixed-pace word-by-word rapid serial visual presentation (RSVP) of the context or by means of variations in stimulus onset asynchrony (SOA) between the onset of the last context word and the target word (Calvo & Castillo, 1996, Experiment 1; Fincher-Kiefer, 1995, 1996). The results from this second group of studies also suggest that predictive inferences require time to be made, since they were detected under a 1,000-msec SOA (Fincher-Kiefer, 1995, 1996) and a 1,250-msec SOA condition (Calvo & Castillo, 1996), but not with a 500-msec SOA (Calvo & Castillo, 1996). However, neither Fincher-Kiefer nor Calvo and Castillo manipulated the RSVP, since they only used a single presentation rate. Therefore, with neither of these two approaches can we demonstrate whether it is during or after processing of the inducing context that predictive inferences need time to construct.

Accordingly, the aim of the present study was to investigate the relative contribution of processing time available *during* versus *after* the context. Assuming that predictive inferences are slow to develop, the question is whether this additional time is required after the context has been processed, or whether it is sufficient to have additional time during the presentation of the context. This question is theoretically important because of its relevance to determining the time course of inferences. Assuming that predictive inferences can occur on-line, there is still an important distinction regarding the moment they are drawn. They could be initiated during reading of the context, and completed and refined later, as suggested by the graded view of the minimalist hypothesis (McKoon & Ratcliff, 1986, 1990). Alternatively, readers could wait and compute these inferences at the end of sentence bound-

daries (Kintsch, 1988; Millis & Graesser, 1994, p. 595). In the former case, the time available *during* context processing would have an important contribution to predictive inferencing. Reduced time would impair inferencing, whereas increased time would improve it. Furthermore, additional during-context time could compensate for the lack of time after the context. In contrast, if predictive inferences are generated at sentence boundaries, the critical factor to construct inferences would be the amount of time available *after* the end of the context.

The methodological approach to separate the contribution of processing time during versus after the inducing context involves the combined manipulation of RSVP and SOA (see Magliano et al., 1993; Millis & Graesser, 1994). We followed this approach in a series of steps in Experiments 1–6, reported in this paper. In order to determine the contribution of processing time *during* the context, the RSVP presentation rate was (1) equivalent to that used in Calvo and Castillo (1996; 100% rate: Experiments 1 and 2), (2) slowed down (the available reading time was increased by 50%; 150% rate: Experiments 3 and 4), or (3) speeded up (66.6% rate: Experiments 5 and 6). In order to determine the contribution of processing time *after* the context, the SOA interval between the onset of the last word in the context and the onset of the target word was either of (1) 500 msec (Experiments 1, 3, and 5) or (2) 1,500 msec (Experiments 2, 4, and 6).

The basic procedure involved the presentation of contexts that were either predictive (inference) or nonpredictive (control) of a highly probable event, followed by a target word that the participants were to name. The target word represented either a concept related to the predicted event (predictable) or an unrelated concept (unpredictable event). The latency to pronounce the target word is an index of activation of the concept that the word represents (Keenan, Golding, Potts, Jennings, & Aman, 1990), and it can demonstrate whether inferences are generated on-line. The evidence for this consists of facilitation (shorter latencies) in naming the predictable target word after the predicting context, relative to when the word is presented after the control context. Additional evidence involves inhibition in naming (longer latencies) the unpredictable target word after the predicting context, relative to when the word appears after the control context.²

PRELIMINARY STUDIES

Before the experimental phase, we conducted several studies and analyses in order to select appropriate context sentences and target words. The aims were (1) to control for possible word-based priming effects, which might contaminate the sentence priming effects responsible for inferences; (2) to ensure that the predicting contexts, but not the control contexts, could actually induce inferences, and that these could be expressed in particular words; and (3) to make the predicting and the control contexts

equivalent in number of words, as well as to equate the predictable and the unpredictable target words in terms of length and lexical frequency.

Control of Word-Based Priming

According to Keenan et al. (1990), one problem with activation measures of inferencing, such as naming times, is that inference concepts can be activated not only by drawing an inference because of text-based priming, but also by merely reading *individual* words that are highly associated with them (p. 296). An approach dealing with this problem has been used previously (e.g., McKoon & Ratcliff, 1986; Potts et al., 1988). It consists of controlling the possible contribution of word priming by making the predicting and the control contexts equivalent in relevant content words.

In order to make both contexts comparable, we identified those words in the predicting contexts that could be related to their respective target words. We used a comprehensive dictionary of synonyms and associates in Spanish (Ortega, 1990). Subsequently, those words in the predicting contexts with any semantic relationship to the target words were also incorporated in the control contexts. As a result, the mean number of content words shared by the predicting and the control contexts was 4.35 ($SD = 0.66$), which is 42.2% of the total number of content words in each context. Therefore, the possible facilitation effects of the inducing contexts could not be attributed to their greater word priming, relative to the control contexts, because the probability that the target word representing the inference might be primed by individual words was identical in both contexts.

Context Constraints and Strategic Construction of Inferences

A norming sentence completion study was performed to expose potential predictive inferences, with a procedure and assumptions similar to those of the "what happens next" question-answering studies (e.g., Magliano et al., 1993). The aims were to ascertain which inferences could actually be made during comprehension, whether the reader population had the prerequisite knowledge, and whether the inferences were expressible in language.

In this study, 104 undergraduates (different from those participating in the following experiments) (1) were presented with a predicting context (e.g., *Diego got into his car, put the key in the ignition, and turned it clockwise while he pressed the accelerator. The car . . .*) or a control context (e.g., *Diego left the car keys in the ignition and asked the mechanic to revise the brakes and the accelerator. The car . . .*), (2) were asked to write the first word that came to mind, and then (3) were asked to complete the unfinished sentence with a short phrase using that word. The one-word predictions (or close synonyms) served as targets. Two targets were selected for each context: predictable (e.g., *started*) and unpredictable (e.g., *misfired*).

Initially, 84 passages were presented, of which 40 were selected for the experiments.

The *predictable* target words referred to highly likely consequences following the inducing context, and to plausible—but unlikely—consequences following the control context. They were mentioned by 82.4% of participants ($SD = 12$) after the 40 *predicting* sentences used in Experiments 1–6. The respective mean for the same target words that were mentioned after the *control* contexts was 8% ($SD = 11$). The *unpredictable* target words alluded to plausible, but unlikely, consequences after either the predicting or the control context. They were mentioned by 2% of participants ($SD = 4$) after the *predicting* sentences, and 3% ($SD = 9$) after the *control* contexts.

Our .82 predictability score represents high context constraints and availability of well-known information on the predictable events. Therefore, we have presumably met an important requisite for these inferences to be generated on-line, according to the constructionist theory (Graesser et al., 1994) and the minimalist hypothesis (McKoon & Ratcliff, 1992). This score is higher than the one obtained by Magliano et al. (1993) and Millis and Graesser (1994) for their materials (see note 1), with which they did not detect predictive inferences.

Analyses of Sentence Length, Word Length, and Lexical Frequency

The preceding studies suggest that the concepts related to highly probable events (1) can be inferred during reading, compared with concepts concerned with the unlikely events; and (2) that this can happen with the predicting context, but not with the control context. However, this comparison both between predictable and unpredictable targets, and between predicting and control contexts, requires that the two types of words, and contexts, be equivalent in terms of psycholinguistic characteristics that may influence naming latency. Word length and lexical frequency affect several component processes in reading (de Vega, Carreiras, Calvo, & Alonso, 1990; Haberlandt & Graesser, 1985). Accordingly, these factors should be controlled by making them comparable for the different conditions.

The predicting and the control contexts were constructed with equivalent sentence length (M number of words = 20.6, both contexts; $SD = 3.6$ and 4.1, respectively). In addition, the predictable target words did not differ from the unpredictable words either in number of characters ($M = 6.64$ vs. 6.67, respectively; $SD = 1.63$ vs. 1.56, respectively) or in word frequency (Alameda & Cuetos, 1995; $M = 33.2$ vs. 35.4, respectively; $SD = 46.0$ vs. 57.9, respectively).

EXPERIMENTS 1–6

We conducted six experiments successively, each characterized by a different RSVP rate and/or SOA interval. However, in order to directly evaluate the combined ef-

fects of time available during (RSVP) and after (SOA) the context, we are presenting the six experiments as if they were one large study. We did not manipulate SOA and RSVP as within-subjects factors because this could have been potentially disruptive to reading comprehension: It would have introduced uncertainty about the timing of the target word.

Experiments 1 (100% RSVP rate + 500-msec SOA) and 2 (100% RSVP rate + 1,500-msec SOA) are an extension of Calvo and Castillo's (1996) first experiment, in which they detected inferences with a 1,250-msec SOA, but not with a 500-msec SOA, using materials that were characterized by a .67 predictability score. The aims of the new experiments were to examine whether enhanced context constraints (a .82 score in the present studies) would induce inferences even in the 500-msec SOA and maximize them when the SOA was increased. Experiments 3 (a slower 150% RSVP rate + 500-msec SOA) and 4 (150% RSVP rate + 1,500-msec SOA) were performed to assess whether the absence of inferential activity in the 500-msec SOA (both in Calvo & Castillo, 1996, and in the present Experiment 1) was due to a quick context presentation rate and whether a slower rate would compensate for the lack of time (500-msec SOA) and/or potentiate (i.e., RSVP $\times$ SOA interaction) the effect of the time available at the end of the context (1,500-msec SOA). Finally, we conducted Experiments 5 (a faster 66.6% RSVP rate + 500-msec SOA) and 6 (66.6% RSVP rate + 1,500-msec SOA) to explore whether a reduction in the context presentation time would also reduce inferential activity, even with sufficient time available at the end of the context.

If predictive inferences depend on the amount of processing time *during* the context, then they should be more likely under the slower (150% RSVP) rate of presentation of the context, relative to the normal (100% RSVP) rate, and they would not occur under the quickest (66.6% RSVP) rate, regardless of the SOA condition. In contrast, if the critical temporal factor is the delay *after* the context, then inferences should be drawn in the longer (1,500-msec SOA) interval, but not in the shorter (500-msec) interval, regardless of the time available to read the context. An interaction between both time factors is also possible.

Method

Participants. In each experiment, 64 different Spanish psychology undergraduates participated for course credit.

Materials and Design. The same 40 short Spanish passages were presented in all experiments. Each was composed of (1) one predicting sentence context, (2) one nonpredicting, control sentence context, (3) one target word that was predictable in the predicting sentence context because it represented the predicted event, and (4) one target word that was not predictable in either sentence context because it represented an unlikely event (see the Appendix).³ On each trial, participants were presented with either a predicting or a control context of each passage, followed by either a predictable or an unpredictable target word.

For each experiment, a 2 (priming context: predicting vs. control) $\times$ 2 (target type: predictable vs. unpredictable) within-subjects factorial design was used. Four lists of materials were constructed, each consisting of 10 predicting contexts followed by predictable targets, 10 control contexts followed by predictable targets, 10 predicting contexts followed by unpredictable targets, and 10 control contexts followed by unpredictable targets. The assignment of targets to the predicting or the control context was reversed across the lists so that a given participant saw a particular context and target only once. Each participant received one list, with 40 trials in random order.

Procedure. Sentences and words were presented on a computer screen. Stimulus presentation and response collection were controlled by ALR-486 computers. Sentences were shown word by word with a fixed-pace RSVP procedure. In the 100% RSVP rate (Experiments 1 and 2), each word was exposed for 300 msec, plus 25 msec per character (estimated mean word exposure across an average sentence: 418 msec). These presentation times were based on a word-by-word self-paced study using the moving-window technique (de Vega et al., 1990; see also Haberlandt & Graesser, 1985). In the 150% RSVP rate, each word was presented for 450 msec, plus 37.5 msec per character (estimated mean word exposure: 628 msec). In the 66.6% RSVP rate, the respective times were 200 and 17 msec (estimated mean word exposure: 279 msec). In addition, for all experiments, there was a 50-msec blank interval between words. The last word in the contexts—that is, the pretarget word—always lasted for 450 msec in all experiments, regardless of RSVP and SOA. Accordingly, in the 500-msec SOA (Experiments 1, 3, and 5), there was a blank interval of 50 msec between the *end* of the pretarget word and the *onset* of the target word; this blank interval was 1,050 msec in the 1,500-msec SOA (Experiments 2, 4, and 6).

Each trial began when the participant pressed the spacebar. Five hundred milliseconds later, the words of the context sentence appeared (and disappeared) on the center of the screen, one at a time, according to the temporal parameters noted earlier. After the corresponding SOA at the end of the context, the target word appeared flanked by asterisks (e.g., *** started ***). Participants had been warned that the asterisks were the cue to pronounce the word in between. A small microphone attached to the participant's chin and connected to the computer registered the naming responses. Participants were told to say the target words as quickly as they could, trying not to make errors. The target word remained on the screen until the participant made a vocal response. Then a comprehension question was presented on the screen. It consisted of a recognition test, which reworded (by means of synonyms or paraphrases) the content of the trial sentence.⁴ Participants responded by pressing one of two keys ("yes" or "no"). After that, the instruction to begin a new trial appeared on the screen. There were 12 practice trials.

Naming latencies were timed (in milliseconds) from the onset of the target word to the onset of the participant's response. We included the comprehension questions to lead the participants to believe that the experiment was about comprehension of explicit information (thus trying to prevent voluntary inference strategies), to ensure that they were comprehending the sentences, and to examine the effects of the timing parameters.

Results

Pronunciation errors occurred less than 1% of the time and did not vary significantly as a function of experimental conditions. Regarding naming latencies, we used two criteria to deal with outliers. First, reaction times that were above 2,000 msec or below 300 msec were replaced by scores of 2,000 or 300, respectively, which repre-

Table 1
Mean Naming Latencies (in Milliseconds) and Difference Between
Control and Predicting for the Predictable and the Unpredictable
Target Words Following the Predicting Context and the Control Context,
as a Function of Stimulus Onset Asynchrony (SOA, in Milliseconds)
and Rapid Serial Visual Presentation (RSVP) Rate

Experiment	SOA	RSVP (%)	Target	Predicting	Control	Difference
1	500	100	predictable	689	684	-5
			unpredictable	718	710	-8
2	1,500	100	predictable	637	683	46*
			unpredictable	699	709	10
3	500	150	predictable	684	694	10
			unpredictable	710	721	11
4	1,500	150	predictable	647	692	45*
			unpredictable	721	714	-7
5	500	66.6	predictable	701	716	15
			unpredictable	732	747	15
6	1,500	66.6	predictable	631	659	28†
			unpredictable	681	678	-3

Note—The difference score (control - predicting) indicates the extent to which the target concept is activated after the predicting context has been read, relative to the control context. Positive scores reveal facilitation in the predicting condition; negative scores show inhibition. * $p < .05$ both by subjects and by items. † $p < .05$ by subjects; $p = .066$ by items.

sented 0.65% of total scores. Second, reaction times that still were above or below 2.5 SD (in a particular combination of experimental conditions) from the mean were replaced by the participant's mean score $\pm 2.5 SD$ in that condition, which affected 1.6% of scores.

Separate analyses for each experiment. We conducted 2 (context) $\times$ 2 (target) analyses of variance (ANOVAs) on both subject (F_1) and item (F_2) mean naming latencies (Table 1).⁵ All analyses are significant at the .05 level unless otherwise indicated, and all planned comparisons used the Bonferroni procedure to control error rate.

In Experiment 1 (100% RSVP; 500-msec SOA), naming times were faster for the predictable target words than for the unpredictable target words [$F_1(1,63) = 24.38$, $MS_e = 2,051$; $F_2(1,78) = 5.45$, $MS_e = 6,871$].

In Experiment 2 (100% RSVP; 1,500-msec SOA), the effects of the type of target depended on the context [$F_1(1,63) = 5.49$, $MS_e = 3,898$; $F_2(1,78) = 4.18$, $MS_e = 2,845$]. For the predictable target words, naming latencies were faster following the predicting context than following the control context [difference = 46 msec; $F_1(1,63) = 23.62$, $MS_e = 2,869$; $F_2(1,78) = 13.71$, $MS_e = 2,845$]. For the unpredictable target words, there was no significant difference between the predicting and the control context (difference = 10 msec; both $F_s < 1.0$).

In Experiment 3 (150% RSVP; 500-msec SOA), naming times were faster for the predictable than for the unpredictable target words [$F_1(1,63) = 31.78$, $MS_e = 1,436$; $F_2(1,78) = 6.44$, $MS_e = 4,883$].

In Experiment 4 (150% RSVP; 1,500-msec SOA), the effects of the type of target depended on the context [$F_1(1,63) = 13.97$, $MS_e = 3,121$; $F_2(1,78) = 12.67$, $MS_e = 2,215$]. For the predictable target words, naming latencies were faster after the predicting context than after the control context [difference = 45 msec; $F_1(1,63) = 34.08$, $MS_e = 1,886$; $F_2(1,78) = 17.26$, $MS_e = 2,216$]. For the

unpredictable target words, there was no difference between the predicting and the control context (difference = -7 msec; both $F_s < 1.0$).

In Experiment 5 (66.6% RSVP; 500-msec SOA), naming times were faster for the predictable than for the unpredictable target words [$F_1(1,63) = 20.16$, $MS_e = 3,129$; $F_2(1,78) = 6.40$, $MS_e = 6,156$], and they were faster following the predicting context than following the control context [$F_1(1,63) = 6.83$, $MS_e = 2,159$; $F_2(1,78) = 4.47$, $MS_e = 2,061$].

In Experiment 6 (66.6% RSVP; 1,500-msec SOA), the effects of the type of target depended on the context [$F_1(1,63) = 9.73$, $MS_e = 1,638$; $F_2(1,78) = 3.45$, $MS_e = 2,836$, $p = .066$]. For the predictable target words, naming latencies were faster after the predicting context than after the control context [difference = 28 msec; $F_1(1,63) = 9.50$, $MS_e = 2,600$; $F_2(1,78) = 5.34$, $MS_e = 2,836$]. For the unpredictable target words, there was no difference as a function of context (difference = -3 msec; both $F_s < 1.0$).

Combined analyses for Experiments 1–6. In order to obtain a comprehensive view of the contribution of processing time during versus after the context, data from all experiments were combined. For this purpose, we con-

Table 2
Mean Comprehension Accuracy Scores
(Percentage of Items That Were Answered Correctly) as a
Function of Stimulus Onset Asynchrony (SOA, in Milliseconds)
and Rapid Serial Visual Presentation (RSVP) Rate

Experiment	SOA	RSVP (%)	<i>M</i>	<i>SD</i>
1	500	100	85.6	8.2
2	1,500	100	86.8	7.5
3	500	150	89.0	6.0
4	1,500	150	88.4	6.6
5	500	66.6	81.0	8.6
6	1,500	66.6	81.8	9.3

ducted $2 (\text{context}) \times 2 (\text{target}) \times 2 (\text{RSVP}) \times 2 (\text{SOA})$ ANOVAs on comprehension scores and naming scores.

Mean comprehension accuracy scores for each experiment are shown in Table 2. The combined ANOVA yielded only a main effect of RSVP rate [$F(1,378) = 29.04$, $MS_e = 0.15$] (the data were available only by subjects). Post hoc Scheffé t tests indicated that comprehension of explicit information was higher with the slower (150% RSVP) rate ($M = 88.7\%$ of questions right) than with the normal (100% RSVP) rate ($M = 86.2\%$; $p < .05$), which were superior to the quickest (66.6% RSVP) rate ($M = 81.4\%$; both, $ps < .001$).

In regard to naming latencies, the magnitude of the context $\times$ target interaction depended on the SOA condition (three-way interaction) [$F_1(1,378) = 13.52$, $MS_e = 2,767$; $F_2(1,468) = 6.38$, $MS_e = 3,427$]. RSVP did not have any effects. In order to break down this interaction, a further ANOVA was performed on each level of the SOA factor, and the RSVP factor was collapsed. At the 500-msec SOA level, only the effect of target type emerged. At the 1,500-msec SOA level, there was a strong context $\times$ target type interaction [$F_1(1,191) = 27.25$, $MS_e = 2,865$; $F_2(1,238) = 17.95$, $MS_e = 2,619$]. Planned contrasts revealed that, for the predictable condition, latencies were faster after the predicting context than after the control context [difference = 40 msec; $F_1(1,191) = 60.99$, $MS_e = 2,461$; $F_2(1,238) = 33.90$, $MS_e = 2,619$]. For the unpredictable condition, there was no difference as a function of context (difference = 0 msec; both $F_s < 1.0$). The (nonsignificant) difference scores for the predictable and the unpredictable conditions in the 500-msec SOA condition were 7 and 6 msec, respectively (Table 1). Therefore, the predicting context facilitated naming of the predictable target words only under the 1,500-msec SOA, regardless of RSVP rate.

GENERAL DISCUSSION

The findings from these experiments are consistent with findings from prior research demonstrating that predictive inferences need time to develop on-line. However, a specific contribution of this study is concerned with whether it is during or after processing of the inducing context that additional time is necessary. The answer to this question has implications regarding where and when these inferences are constructed.

On-line Predictive Inferences: The Contribution of Time Available During Versus After the Context

Facilitation (shorter latencies) for the *predictable* target words following the predicting context, relative to the control context, indicates that inferences were drawn in the priming condition when there was 1 sec available after the end of the context (1,500-msec SOA). Facilitation was not observed if there was no additional time after the context (only 50 msec; 500-msec SOA).

Accordingly, predictive inferences occur on-line, but need time to develop. This is relatively consistent with extant models of inferences in reading—the minimalist

hypothesis (McKoon & Ratcliff, 1992, 1995) and the constructionist theory (Graesser et al., 1994).⁶ Though they have argued that predictive inferences are not normally generated on-line, ready availability in memory and high context constraints would make these inferences more likely. With the integrated context/target presentation (see note 3) and the high predictability score of the events in our predicting contexts (see Preliminary Studies section), we have presumably met these criteria. Furthermore, according to the aforementioned models, predictive inferences involve strategic processes, and therefore they should take time to construct. Though these models have not specified the time conditions of the delayed generation of predictive inferences, it is implied that they should take more than 500 msec (see Graesser et al., 1994, p. 383), which is in agreement with our data. This is also consistent with the fact that predictive inferences have been detected under *self-paced* reading conditions (Calvo & Castillo, 1996, 1998, Experiment 2 in both studies; Fincher-Kiefer, 1993; Keefe & McDaniel, 1993; Lea, 1995; Murray et al., 1993; Whitney et al., 1992)—which allow readers use additional time before the probe—but not under fixed-pace conditions (Magliano et al., 1993; Millis & Graesser, 1994), unless 800 msec or more are provided after the context (Calvo & Castillo, 1996, 1998, Experiment 1 in both studies; Fincher-Kiefer, 1995, 1996).

However, there is one limitation in all the prior studies demonstrating on-line inferences: They cannot determine how much of the time needed by inferences involves processes that occur during reading of the context, relative to processes that take place after the explicit information in the context has been encoded. The reason is concerned with the fact that the self-paced reading studies (Calvo & Castillo, 1996, 1998, Experiment 2 in both studies; Fincher-Kiefer, 1993, 1994; Keefe & McDaniel, 1993; Lea, 1995; Murray et al., 1993; Whitney et al., 1992) did not manipulate the interval before the probe. The fixed-pace studies that have been reported (Calvo & Castillo, 1996, 1998; Fincher-Kiefer, 1995, 1996) did not manipulate the context presentation rate. The combined manipulation of both timing parameters—that is, SOA interval and RSVP rate—is necessary to answer this question.

In the present study, it was the interval at the end of the context, but not the rate of presentation of the context, that made a contribution to the generation of predictive inferences: Predictive inferences emerged when there was a 1,500-msec SOA interval, even if the RSVP rate was fast enough to reduce comprehension of explicit information; in contrast, they were not made when there was only a 500-msec SOA interval, even though the RSVP rate was very slow to allow enhanced comprehension. Accordingly, the additional time to draw these inferences is required at the end of the context. Alternatively, additional time during processing of the context facilitates comprehension of explicit information in the context, but not inferences. Obviously, a further reduction in the time to process the context could be detrimental to draw

inferences, even if there were enough time at the end of the context. This is precisely what Magliano et al. (1993) and Millis and Graesser (1994) found for bridging inferences. But, if the context processing time is sufficient to comprehend a significant portion of the explicit information (e.g., 81%, in our Experiment 6), additional during-context time has no influence on inferencing.

Furthermore, this additional time during processing of the context neither *compensates* for the lack of time at the end of the context nor *potentiates* the effect when there is additional time available after the context. This is revealed by the lack of an interaction between the SOA and RSVP factors. A compensatory function would imply that inferences should be made under the 500-msec SOA when the RSVP rate is slowed down. A potentiation function would imply that in the 1,500-msec SOA a slower RSVP rate (relative to a quicker rate) should increase activation of inferences (i.e., the control – predicting difference score). Neither of these effects was observed. Therefore, we can rule out the hypothesis that the effects of the time available at the end of the context might depend on the time available during processing of the context.

Theoretical Implications

These findings are relevant to conceptualizing the time course of predictive inferences: Predictive inferences are not generated (or initiated) until after the whole context has been processed. In contrast, the fact that it was the context presentation rate, and not the postcontext interval, that affected comprehension of explicit information, suggests that its responsible processes take place immediately, during the processing of context.

There are three theoretical positions regarding the time course of inferences. For all of them, different types of inferences could be made on-line. However, the on-line concept is rather broad, encompassing at least two possibilities: (1) as soon as each part (e.g., word) of explicit text information is being processed or (2) shortly after it has been processed. One of the three theoretical positions is the *immediacy* hypothesis, which has been discussed by Garrod and Sanford (1994) with regard to inference processing. Inferences responsible for local text coherence, such as anaphors and bridging inferences, could be made immediately. If so, they should be sensitive to manipulations of the context presentation time. This is precisely what happened in Magliano et al.'s (1993) and Millis and Graesser's (1994) studies: A reduction in the RSVP rate impaired bridging inferences, even when there was enough time at the end of the context. Accordingly, the immediacy hypothesis can be valid for local coherence inferences, but there is no empirical support regarding elaborative inferences.

A second, intermediate, position is the *graded* view of the minimalist hypothesis (McKoon & Ratcliff, 1986, 1990), according to which elaborative inferences can be drawn over variable time scales, with varying degrees of specificity and degrees of strength. One implication is

that predictive inferences might be initiated (in minimal form) during the processing of the context and completed later, after the end of the context. From our data regarding a lack of effect of the context presentation rate, we could argue that either these inferences were not made—not even minimally—during the presentation of the context, or that the early (during-context) partial processes were not necessary and could be compensated by later (post-context) time. However, it is also possible that all phases of the graded process, both the earlier—minimal and general activation—and the later—refinement and completion of the inference—take place after the context. Only this last interpretation would be compatible with our findings.

A third theoretical position is the strategic *postcontext elaboration* hypothesis: Inferences are deferred until after the whole inducing context is read, during the sentence wrap-up period (e.g., Kintsch, 1988; Till, Mross, & Kintsch, 1988). Similarly, Millis and Graesser (1994, p. 595) stated the assumption that readers wait until sentence boundaries to compute inferences. Our findings are entirely consistent with this position: Readers encode all the explicit information during the presentation of the context (if this presentation time is reduced, comprehension of explicit information is impaired); in contrast, construction of inferences starts after the presentation of the context (reducing postcontext time prevents inferences). The conclusion that other elaborative inferences, such as thematic inferences, take time at the end of the context, but can be made even though the context presentation rate is rather fast (Till et al., 1988)⁷ is also in accordance with this hypothesis.

Nevertheless, it could be argued that this third conceptualization might be applicable only to fixed-pace presentation of the inducing contexts: Since readers have no control over the time available during the context, they might simply process what they see and wait for possible elaborations in the text. That is, this procedure might induce a passive strategy regarding construction of inferences. However, the carryover effects observed under self-paced reading (see, e.g., Calvo & Castillo, 1996, 1998) argue against this interpretation. With a self-paced reading procedure, facilitation does not occur on the target word itself, but on the posttarget and final regions of a continuation sentence following the predicting context (Calvo & Castillo, 1996, 1998). Thus, even when readers have all the time they need to process the context, they delay the generation of the inference until clear evidence is found. This further confirms that enhanced processing time during the context does not facilitate predictive inferencing. In fact, when predictive inferences are not made under fixed-pace presentation (Millis & Graesser, 1994, Experiment 1), self-paced presentation does not enable readers to draw them (Millis & Graesser, 1994, Experiment 2).

Conclusion and Practical Implications

Predictive inferences need more than 500 msec of processing time to emerge—*after the onset* of the last word

of the inducing context. They require 800 msec (Calvo & Castillo, 1996; Fincher-Kiefer, 1995, 1996) or 1,050 msec (Experiments 2, 4, and 6, in the present study) *after the end* of the context. Time available during the presentation of the context does not modify the effect of the delay after the context.

However convincing this conclusion may sound, it should also be applicable to normal reading circumstances, beyond experimental conditions. An important practical implication follows if predictive inferences take around 1 sec to construct:⁸ In naturalistic reading (and listening), by the time these inferences were activated, a reader (or listener) would be processing the next sentence. Given the severe constraints on working memory during discourse processing, it may seem unreasonable to assume that these inferences could be generated. Actually, Fincher-Kiefer (1996) and Keefe and McDaniel (1993) found that priming disappeared if the inference probe was separated from the supporting sentence by an additional nonrelevant sentence. Processing of the next sentence would interfere with the construction of predictive inferences, or with their maintenance in working memory, since these inferences are only temporarily activated (Keefe & McDaniel, 1993) and not encoded in the text representation (Fincher-Kiefer, 1995, 1996).

There are a number of arguments to address this concern. It is certainly possible that predictive inferences are not normally made during processing of connected discourse. This would be particularly likely when we have no control over the pace of presentation of the context (e.g., when listening to discourse), or when the sentence that follows the inducing sentence is irrelevant to the inference concept. However, first, often we can use self-paced reading (and even stop the speaker to request additional information or clarification). In this case readers can provide themselves with enough time to generate a suggested inference, and resume reading after that. Actually, when the target word is embedded in a continuation sentence, priming indicative of inferential activity also occurs, though it is evident only in the regions *following* the target word (Calvo & Castillo, 1996, 1998). Accordingly, elaborative inferences can be drawn during carry-over processes. Furthermore, texts often provide more than one source for inferences; several text ideas are combined to support the inference. Fincher-Kiefer (1996) has shown that if the sentence following the predicting context supports (or is consistent, though it does not confirm) the inference, then the inference concept continues to be available during the processing of a subsequent neutral sentence. Therefore, with certain restrictions, predictive inferences can also occur in normal reading.

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NOTES

1. Thus, Magliano et al. (1993) admitted that a proportion of only .26 participants could generate the inference (target word) in the question-answering protocols when they were asked to say "what happened next" for each predicting context in a previous norming study. Millis and Graesser (1994) said that "idiosyncratic answers that were generated by only one subject were excluded" (p. 588), which implies a rather low predictability score. Nevertheless, it should be noted that, with comparable mean production scores (.30 in Magliano et al., 1993)—after "why" questions—causal antecedent inferences (i.e., causes that explain events and actions) emerged.

2. The rationale for including the unpredictable condition is concerned with detection of potential inhibitory effects. If the inference concept representing the predicted event is activated, then alternative, inconsistent concepts are likely to be inhibited. Accordingly, it should take longer to process the unpredictable target word after the predicting context than after the control context, because the reader would have to deactivate the prior inference concept first. *Self-paced reading times* for a continuation sentence have proved to be longer either when an earlier description of explicit information was inconsistent with it (e.g., Albrecht & O'Brien, 1993; Hakala & O'Brien, 1995) or following a break that contradicted an earlier intended causal (Klin, 1995) or predictive inference (Calvo & Castillo, 1998). This suggests that alternative concepts are inhibited, regardless of whether the source is explicit information or an inference. Nevertheless, since we found no inhibitory effects in the present study, using *fixed pace* presentation and *naming times*, this issue will not be discussed further.

3. Our materials differed from those used in other studies in several respects, apart from the inclusion of an unpredictable condition to explore inhibitory effects. First, though our contexts were shorter (than, e.g., those in Fincher-Kiefer, 1995; Murray et al., 1993; Whitney et al., 1992), length has proved not to be critical (Murray et al., 1993), and other studies with short contexts have also yielded evidence for predictive inferences (e.g., Keefe & McDaniel, 1993). Probably the most im-

portant factor is the degree of context constraints on the predictability of a main event, which was high in our materials. Second, most of the other studies presented the target word separate from the context, whereas we integrated them syntactically (i.e., a pretarget word—e.g., *The lift*, in the first example of the Appendix—was the last word in the context and acted as the subject of the predictable action, represented by a verb [target word] in the corresponding third person and past tense—e.g., *went up* instead of the infinitive form). We did this in order to make the transition from the reading task to the naming task more natural, to avoid truncation of the normal flow of syntactic processes, and to keep the inference concept activated until the time of test. Fincher-Kiefer (1993) and Hess, Foss, and Carroll (1995) used a similar procedure.

4. In further studies, performance on this test (with the same materials) was related to individual differences both in reading span [$r(169) = .33, p < .001$] and in prior vocabulary knowledge [$r(169) = .36, p < .001$]. This—besides the fact that comprehension scores varied as a function of the RSVP rate in the present studies—suggests that the recognition test was sensitive to comprehension processes.

5. Three factors can account for the fact that our mean naming latencies were longer than those observed in the other studies on predictive inferences that used the naming task in English (Keefe & McDaniel, 1993; Lea, 1995; Murray et al., 1993; Potts et al., 1988; Whitney et al., 1992). In these studies, the range of naming latencies varied from 401 to 423 (Potts et al., 1988) to 537–595 (Keefe & McDaniel, 1993). First, none of these studies included an unpredictable condition, which has proved to yield longer latencies in our own experiments. Second, the other studies used less conservative truncation criteria for outliers than we did (e.g., ± 2.0 SD in Potts et al., 1988; or from 4.3% to 5.2% of the data scores were excluded in Murray et al., 1993). Third, all of these studies used self-paced presentation instead of a fixed-pace procedure, which places higher working memory demands at the point when the probe appears (i.e., the reader is still wrapping up the end of the context when he/she has to process the target word). And, finally, the test words in the other studies were shorter than in our study. Thus, most of these studies borrowed and adapted McKoon and Ratcliff's (1986) materials, with an average number of 4.41 characters for the target words (ours were 151% longer).

6. A distinction has been made in the constructionist theory between superordinate goal inferences and causal consequence inferences. A main difference is concerned with the perceived intentionality of the agent of the targeted action: Goal inferences refer to goal expectancy (i.e., the goal that motivates an agent's action), whereas pure predictive inferences refer to outcome predictions. We segregated items concerned with intentional actions (e.g., *Diego ... the car started*) from those involving nonintentional events (e.g., *Maria ... cut herself*; see the Appendix) and included this factor in a type of inference $\times$ context $\times$ target $\times$ RSVP $\times$ SOA ANOVA on naming data. Neither the main effects of inference type nor its interaction with any of the other factors were statistically significant (all F s < 1.0). Accordingly, pure causal consequence items showed the same pattern of results as the superordinate goal items.

7. Till et al. (1988) used an RSVP of 333 msec per word, which is very similar to our fastest rate, 329 msec, including the 50-msec between-word interval.

8. We are grateful to Joe Magliano for suggesting this implication.

APPENDIX
Example of Experimental Passages
(Translated into English)*

Predicting Context:

On arriving at the &entrance of the &building where he had his &apartment, Francisco entered the &lift, pressed the button and it began to &move.

Control Context:

Francisco bought an &apartment in the &building with the luxurious &entrance, but he hardly used the &lift to &move from one floor to another.

(Predictable/Unpredictable Target):

The lift **went up/went down**.

Comprehension questions. P: Predicting; C: Control; T: True; F: False:

P: Francisco was leaving the building (F)

C: Francisco was selling his apartment (F)

Predicting Context:

Lola was eager to &know the end of the &novel, so she lay down comfortably and opened it at the &page she had reached the last time.

Control Context:

Lola &knew the author of the &novel whose photo appeared on the first &page of the newspaper, so she phoned to congratulate her on her success.

(Predictable/Unpredictable Target):

Lola **read/counted**

P: Lola opened the novel at the last page (F)

C: Lola was a relative of the novel's author (F)

Predicting Context:

Three days before the &examination the &student went to the &library, looked for a separate &table and opened his ¬ebook.

Control Context:

The &student, who was very tired after finishing his &examination, forgot his ¬ebook and left it on a &table in the &library.

(Predictable/Unpredictable Target):

The student **studied/slept**

P: The student kept apart from the other people (T)

C: The examination was exhausting for the student (T)

Predicting Context:

The woman went into the &church, spoke with the &priest for a few minutes, and afterward she &knelt down in front of the &altar.

Control Context:

After speaking with the &priest for a few minutes in front of the &church's &altar, the woman &knelt down to tie her shoe.

(Predictable/Unpredictable Target):

The woman **prayed/wrote**

P: The woman talked with the priest for a short time (T)

C: The woman talked with the priest briefly (T)

Predicting Context:

While Maria &walked &barefoot over the rocks, she &put her foot &down, without realizing, on a piece of &glass which had been left on the &floor.

Control Context:

To avoid &putting her dirty shoes &down on the &floor, Maria &walked &barefoot until the &glass display cabinet and placed the present in it.

(Predictable/Unpredictable Target):

Maria **cut herself/slipped**

P: Maria was walking barefoot on the sand (F)

C: Maria soiled the floor with her shoes (F)

Note—Target words in bold letters. Ampersands (&) indicate the content words shared by the predicting and the control contexts, in order to control for word-based priming (see Preliminary Studies section). Ampersands and words in parentheses did not appear in the stimuli.

*In the translation from Spanish to English, apart from the difficulty to capture the nuances that constitute induction of the predicted event, there is lack of correspondence because of lexical (e.g., *went up* or *went down*—two words each—are equivalent to *subió* and *bajó*, respectively—one word in Spanish), semantic, syntactic, and pragmatic differences between the two languages.

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