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Modern linguists understand their enterprise to be one of describing a particular class of mental representations and the computations that the mind employs in relating these representations to each other (see, for example, the summary in Carston, 1988). Mental representations have, of course, traditionally formed the domain of psychologists, and those with an interest in language have sought to find evidence that the representations and procedures postulated by Chomskyan transformational linguistics do in fact have "psychological reality," that is, are the ones used by people to understand language. Initial efforts in the 1960s and early 1970s aiming to show that language comprehension directly employs transformational grammars were unsuccessful (Fodor, Bever, and Garrett, 1974), but more recent work has proven extremely fruitful (see Tanenhaus, 1988, for a review).

Several recent studies have examined the processing of sentences which linguistic theory claims contain gaps (or traces) (see Fodor, 1989, for a review). A gap or trace (indicated by [e] in the following examples) occurs when an element of a sentence occupies a position in the surface structure different from the position it occupies in the underlying representation (D-structure). For example, sentences containing WH-words generally contain a gap: "Who did the Martian destroy [e] with a ray-gun?" Linguists speak of the WH-word as having "moved" from the post-verbal position to the beginning of the sentence (in this example), leaving a trace at its original (D-structure) position.

One line of psycholinguistic studies has examined the processing of sentences in which the moved element is clearly marked as having been moved (i.e., sentences containing moved WH-phrases) (Clifton and Frazier, 1989; Frazier and Flores d'Arcais, 1989; Tanenhaus, Boland, Garnsey, and Carlson, 1989). These studies typically take the linguistic analysis of such sentences for granted and then attempt to test particular hypotheses about the strategies the human parsing mechanism uses to handle these constructions.

Another line of research has examined sentences without clearly marked moved elements (Bever and McElree, 1988; Nicol, 1988; MacDonald, 1989). The explicit aim of these studies has been to find evidence that the structures postulated in linguistic theory correspond to the representations used during comprehension. For example, consider the following sentences (from Bever and McElree, 1988):

(1) The astute lawyer who faced the female judge was suspected [e] constantly.
(2) The astute lawyer who faced the female judge was suspicious constantly.

Despite their ostensible similarity, these sentences have very different structures according to the currently dominant linguistic theory, Government and Binding Theory (Chomsky, 1981). In (1), there is assumed to be a trace of the subject in the post-verbal position (marked by [e]), because the subject ("the astute lawyer") is the direct object of the verb ("suspect") in the underlying structure (D-structure). In other words, someone suspected the lawyer. In (2), no trace is posited, since "suspicious" is simply an adjective. Bever and McElree (1988) reasoned that the subject of the sentence should be more active in the mind of the comprehender following the sentence with a trace (1) than following the sentence without a trace (2). This is because when the reader encounters the verb phrase "was suspected," he or she must postulate a trace or, in other words, must realize that the subject of the sentence is in fact the logical object of the verb. Bever and McElree (1988) presented sentences like (1) and (2) to subjects one phrase at a time, after which the subjects had to make a recognition decision to a probe of the adjective ("astute") in the subject noun phrase. They found that subjects were faster to respond Yes after they had read (1) than after they had read (2). This suggests that comprehenders do indeed posit a trace of the subject after the passive verb in sentences like (1).

Similar results were reported by MacDonald (1989) using a better control condition. Her additional control condition was sentences containing adjectival passives, which have exactly the same morphology as true verbal passives (the typical <u>-ed</u> ending) but are in fact adjectives, not verbs. Sentences (3) to (5) are examples of her materials:

(3) The new mayor at the center podium was shot [e].
(4) The new mayor at the center podium was furious.
(5) The new mayor at the center podium was surprised.

Sentence (5) contains an adjectival passive. That "surprised" is an adjective rather than a verb can be seen by the fact that, for example, it can be modified by "very," an adverb which cannot modify a verb: "was very surprised," but not "was very shot." Other linguistic tests can be applied to determine that "surprised" is not, under the most obvious interpretation, really a verb but is an adjective (Levin and Rappaport, 1986; Wasow, 1977). Hence, there is no trace in (5), even though the surface structure is otherwise identical to that in (3). MacDonald (1989) found that subjects were faster to respond to a probe of "mayor" following (3) than following (5). Subjects were also faster following (3) than (4), replicating Bever and McElree (1988).

Of course, if, as the evidence suggests, subjects are indeed positing traces as part of the comprehension process, then this should increase the comprehension time for sentences containing traces relative to those that do not. This is because, all other things being equal, comprehending a sentence containing a trace requires additional operations (such as detecting that a trace is required, adding the trace to the representation, etc.) over and beyond what is required to comprehend a sentence that does not contain a trace. According to this reasoning, (3) should take longer to read than (5). While MacDonald (1989) did collect reading times for her materials and found no difference between (3), (4), and (5), these sentences were always preceded by a context sentence (identical in all three conditions), so reading time was undoubtedly influenced by processes relating the two sentences, making interpretation of the null result difficult. What is needed is an examination of comprehension time for these kinds of sentences in the absence of any preceding context.

A relevant reading-time study was conducted by De Vincenzi (1989; see also Clifton and De Vincenzi, 1990). In Italian, the subject of a sentence can come after the verb. When the verb is an unergative verb, the post-verbal subject must be related to the pre-verbal subject position (i.e., there is a trace before the verb), but when the verb is an unaccusative verb there is no trace (Belletti, 1988). The following sentences illustrate the contrast (ha and e are auxiliary verbs):

(6) Unergative:

Questa volta [e] ha esitato una cara amica
This time hesitated a dear friend

ad aiutarci a translocare.
to help us move.

(This time a dear friend hesitated to help us move.)

(7) Unaccusative:

Questa volta e venuta una cara amica
This time came a dear friend

ad aiutarci a translocare.
to help us move.

(This time a dear friend came to help us move.)

DeVincenzi (1989) used a self-paced, phrase-by-phrase reading task to examine how people process these sentences. The phrase of interest was the phrase containing the verb and the post-verbal subject. She found that reading time was longer for the unergative verbs (6) than for the unaccusative verbs (7), lending support to the idea that readers postulate traces in the manner that linguistic theory predicts.[1]

In English it is possible to test the hypothesis that a trace increases comprehension time by examining the active versions of sentences whose passive versions are adjectival (such as those used by MacDonald, 1989):

(8) The terrorists shot the new mayor.
(9) The terrorists surprised [e] the new mayor.

Current linguistic theory (e.g., Belletti and Rizzi, 1988) holds that the subject of a verb like "surprise" originates post-verbally (similarly to the passive of "shot"). These verbs are called Object State-of-Mind or Theme-Experiencer verbs, because they say something about the state of mind of the object of the verb (the Experiencer) rather than about the subject of the verb (the Theme). I will refer to these verbs as Theme-Experiencer ("TE") verbs and to verbs such as "shot," whose subjects originate in a pre-verbal position, as unmarked verbs. The evidence that active TE verbs contain a trace after the verb is primarily internal to linguistic theory, but this analysis does makes some sense intuitively: The subject of such a verb is clearly not an Agent performing an action specified by the verb. Rather some property of the subject has an effect on the mental state of the object of the verb (the Experiencer).

In the two experiments reported here, subjects read active and passive versions of sentences containing unmarked verbs or TE verbs. The linguistic representations discussed above, together with the assumption that the processes involved in postulating a trace take time, lead to straightforward predictions. Active sentences containing TE verbs (which require a trace) should take longer to read than active sentences containing unmarked verbs (which do not require a trace). The opposite should hold for passive sentences: passive sentences containing unmarked verbs (with a trace) should be slower than those containing TE verbs (adjectival passives, without a trace).[2]

Experiment 1

In the first experiment, subjects read sentences on a computer screen and pressed a button when they had understood each sentence. The experiment was designed originally to examine intersentential priming due to syntax and verb type, but it also provided a way to test the trace theory. The experiment employed two sets of sentences. One set used unmarked verbs, and the other used TE verbs. Since the sentences in the two sets were not matched for word frequency or plausibility, the unmarked sentences cannot be compared directly to the TE sentences. However, the trace theory predicts an interaction of the following form: the difference between the active and passive forms of a sentence should be much greater when the verb is an unmarked verb than when it is a TE verb. When the verb is an unmarked verb, the difference is between a short sentence without a trace (the active version) and a long sentence with a trace (the passive version). But when the verb is a TE verb, the difference between active and passive is between a short sentence with a trace and a long sentence without a trace. Hence, the difference between active and passive should be smaller for the sentences with TE verbs.

Method

Subjects. The subjects were 64 students at the University of Massachusetts. They were all native English speakers. The subjects received course credit for their participation in the experiment, which lasted approximately half an hour.

Materials. Ninety-six experimental sentences were composed. Half used unmarked verbs, and half used TE verbs. Examples are given in Table 1.

Table 1

Sample Materials from Experiment One

Unmarked Active

The pirates beheaded the stowaway.

Unmarked Passive

The stowaway was beheaded by the pirates.

Theme-Experiencer Active

The dolphin intrigued a scuba-diver.

Theme-Experiencer Passive

A scuba-diver was intrigued by the dolphin.

No verb appeared in more than one sentence. There were three versions of each sentence: an active version, an active progressive version, and a passive version. The active progressive version was included as a control condition for purposes relating to the priming aspect of the study and is not relevant to the present question. All the sentences had animate subjects and objects. The sentences with unmarked verbs and the sentences with TE verbs were approximately equal in length, and each experimental sentence fit on one line of the computer display.

In addition to the experimental sentences, 50 distractor sentences were composed. These sentences tended to be longer and more syntactically complex than the experimental sentences. Several of them contained potential garden paths. The purpose behind these manipulations was to encourage the subjects to view the single-line sentences (the experimental ones) as the easier sentences in the experiment and hence to read them as naturally as possible.

Two material sets were constructed. Forty-eight of the experimental sentences (24 unmarked and 24 TE) were randomly assigned to Set A, and the other forty-eight were assigned to Set B. This division into sets was for purposes of the priming study. For half the subjects the prime sentences were drawn from Set A and the target sentences from Set B, while for the other half this was reversed. Half the target sentences were in the active voice and half were in the passive voice. For each subject, the order of the targets and distractors was randomized, and then a randomly selected prime in the appropriate version was inserted before each target. (Hence, the prime was not related to the target.) Each subject read as targets 12 active unmarked sentences, 12 passive unmarked sentences, 12 active TE sentences, and 12 passive TE sentences. Over subjects, each item appeared equally often in the active and passive voices and equally often as a prime and as a target.

<u>Procedure</u>. A 5-minute practice session consisting of ten items familiarized the subject with the procedure. The sentences were presented on a computer screen in front of the subject. The subject initiated presentation of each sentence by pressing the thumb button on a response box. After reading the sentence, the subject pressed the thumb button again, and the next sentence was displayed. One quarter of the sentences were followed by a True/False question. The subject answered the questions by pressing the right-hand lever to answer "True" and the left-hand lever to answer "False." A micro-computer controlled the presentation of the sentences and recorded the reading time for each sentence and the response to each

question. The subjects were encouraged to read the sentences as quickly as they could and to press the thumb button just as soon as they had understood the sentence.

Results

Sentence reading times that were greater than five seconds or more than three standard deviations from a subject's mean reading time (less than 2% of the data) were eliminated from the data analyses. Subjects averaged 88% correct on the comprehension questions. Unless otherwise noted, effects are reported as significant only if the probability of a Type I error is equal to or less than .05 both in analyses by subjects ($F1$) and in analyses by items ($F2$).

There were no significant effects of the prime sentences on the target sentences, so the target sentences can be treated as if they had occurred in isolation. Table 2 gives the mean reading time in milliseconds for the target sentences, as well as the difference between the active and passive versions for each type of verb.

Table 2

Mean Sentence Reading Time in Experiment One (in milliseconds)

	Active	Passive	Difference
Unmarked	2005	2267	262
Th-Exp	2069	2224	155

The only significant main effect was that passives took longer to read than actives ($F_1(1,63) = 64.15$, MS_e = 173503; $F_2(1,94) = 101.13$, MS_e = 83638), which is to be expected since passive sentences are longer than their corresponding active sentences. An analysis of variance showed that the predicted interaction of verb type and syntax was significant: the active-passive difference was greater for unmarked verbs than for TE verbs ($F_1(1,63) = 5.42$, MS_e = 133883; $F_2(1,94) = 6.36$, MS_e = 83638). In fact, the pattern of results was exactly as predicted by the trace theory, with active TE sentences tending to be slower than active unmarked sentences ($F_1(1,63) = 4.41$, MS_e = 117152, $p = .04$; $F_2(1,94) < 1$) and with passive TE sentences being (non-significantly) faster than passive unmarked sentences.

Discussion

The results from the first experiment were entirely consistent with the predictions derived from the trace theory, providing evidence that readers do postulate traces during the comprehension process. However, there are two worries about the interpretation of these results. The first is that whole-sentence reading times reflect not only initial syntactic analysis but also later semantic and pragmatic interpretation, thus weakening any claim that the results provide direct evidence for processes occurring at the syntactic analysis stage. The second concern is that direct comparison of the TE and unmarked verbs is not appropriate, since they occurred in different sentences which were matched only on length and not on word frequency or any other measures. (However, the absence of a main effect of verb type suggests that any differences between the sentences did not affect reading time.)

Experiment 2

To address the concerns about the first experiment, the second experiment used a different task and different materials. In this experiment, subjects' eye movements were monitored as they read sentences similar to those in the first experiment. Many previous studies have demonstrated that eye movement data can be used as an accurate measure of on-line processing (Rayner, Sereno, Morris, Schmauder, and Clifton, 1989). With regard to the materials, all factors were manipulated within items (rather than across items), and the length and word frequency of the nouns and verbs were controlled.

In addition to the manipulation of verb type and syntax, the second experiment also varied the animacy of the noun that played the role of Theme in the sentences. If the predicted results are found both with animate and inanimate Themes, it would be further evidence that the effect is due to the syntactic properties of the verbs and not to semantic or idiosyncratic properties of the nouns in the sentences.

Method

Subjects. The subjects were 40 students at the University of Massachusetts. They all had normal uncorrected vision and were native speakers of English. They received either course credit or $5.00 for their participation in the experiment, which lasted approximately 25 minutes.

Materials. Thirty-two sentence sets were composed, each containing eight two-clause sentences. Table 3 contains a sample set from the experiment.

Table 3

Sample Sentence Set from Experiment Two

ANIMATE THEME SENTENCES

Unmarked active
The contractor praised the carpenter, although he had often been late for work.

Unmarked passive
The carpenter was praised by the contractor, although he had often been late for work.

Theme-Experiencer active
The contractor puzzled the carpenter, although they had worked together for quite some time.

Theme-Experiencer passive
The carpenter was puzzled by the contractor, although they had worked together for quite some time.

INANIMATE THEME SENTENCES

Unmarked active
The carpenter praised the blueprint, although it wasn't very well drawn.

Unmarked passive
The blueprint was praised by the carpenter, although it wasn't very well drawn.

Theme-Experiencer active
The blueprint puzzled the carpenter, although it was very well drawn.

Theme-Experiencer passive
The carpenter was puzzled by the blueprint, although it was very well drawn.

The 8 sentences in each set resulted from orthogonally varying in the first clause the three factors of Verb Type (unmarked or Theme-Experiencer), Syntax (active or passive), and Animacy of the Theme noun. The three nouns that were used in each set were equated as closely as possible on length and on frequency of occurrence (Francis and Kucera, 1982), with a mean frequency of 20 occurrences per million and a mean length of 7 letters. The two verbs were also matched. The mean frequency and length were 20 and 8, respectively, for both types of verb. Although the first clause was the region of interest, the first word or two of the second clause was kept constant for all sentences in a set, so that any effect of parafoveal preview of the upcoming material would be identical in all conditions.

The 32 experimental items were presented along with 88 sentences that were part of different experiments or were distractors. True/false comprehension questions followed approximately one quarter of the sentences in the experiment.

Design. A 2 X 2 X 2 repeated measures design was used, with factors of Animacy of Theme, Verb Type, and Syntax. Each subject read one sentence from each of the 32 sets, as well as the additional 88 sentences. Thus, each subject read four sentences in each of the eight conditions, and each sentence set appeared equally often in every condition, across subjects. The order of presentation was randomized for each subject.

Apparatus. Subjects' eye movements were recorded by a Generation V Stanford Research Institute Dual Purkinje Eyetracker interfaced to an AT-class personal computer that controlled the experiment. The eyetracker has a resolution of 10 minutes of arc. Eye movements were recorded from the right eye, and viewing was binocular. Every millisecond, the computer sampled the horizontal and vertical position of the right eye and recorded the beginnings and ends of fixations. Subjects were seated 78 cm from a Sony Trinitron 1302 CRT on which the experimental items were displayed. Four-and-a-half characters of text equalled one degree of visual angle. Letters were presented in lower case except for the first letter of a sentence. The brightness of the screen was adjusted for each subject to a comfortable level and was held constant through the experiment.

Procedure. A bite bar was used to prevent head movements during the experiment. The session began with a 3-5 minute calibration procedure, followed by a five-minute practice session which familiarized the subject with the procedure and the types of items that would be presented during the experiment. The practice consisted of eight sentences. The subject was instructed to read each sentence for comprehension and was told that a comprehension question would follow some of the items. The subject was encouraged to read as he or she normally would. Each trial was preceded by a calibration-check target at the point where the first word of the sentence would appear. After reading each item, the subject pressed a key which removed the item from the screen. Then, if there was a question, the word QUESTION was displayed on the screen for 600 ms, and the question was presented below it. Subjects pressed one of two keys to answer True or False to the questions, and incorrect responses resulted in an error message appearing on the screen for 1500 ms. The entire session lasted approximately 25 minutes.

Results

Each subject's data were processed to remove short fixations standing alone and to merge short fixations adjacent to longer fixations. Fixations shorter than 80 milliseconds in duration and only one character away from the prior or next fixation were merged with that prior or next fixation. Fixations shorter than 40 milliseconds and less than three characters away from the prior or next fixation were deleted. Any remaining fixations that lasted less than 100 ms were excluded from the analyses. Trials on which the eyetracking system lost track of the eye were also eliminated. Overall, 2.2% of the data were lost due to track losses. Subjects averaged 90% correct on the comprehension questions.

Table 4 shows the subjects' mean first pass reading times in all eight conditions for various regions of the first clause. The regions are: (1) the subject region, (2) the region incorporating the subject and the verb, (3) the object or by-phrase region, and (4) the entire first clause. A subject's first pass time for a region is the sum of the eye fixation durations the subject makes in the region, starting with the very first fixation in the region and ending when the subject moves his or her eyes to the next region or to a preceding region.[3] Table 4 also gives the first pass times for the whole clause expressed in milliseconds per character.

Table 4
Mean First Pass Times for Analysis Regions in Experiment Two
(in milliseconds; numbers in parentheses are milliseconds per character)

	SUBJECT	SUBJECT and VERB	OBJ/BY-PHRASE	WHOLE CLAUSE
ANIMATE THEME SENTENCES				
Unmarked active	The contractor	praised	the carpenter, ...	1248 (37.0)
	373	708	420	
Unmarked passive	The carpenter	was praised	by the contractor, ...	1433 (35.0)
	393	823	494	
Theme-Experiencer active	The contractor	puzzled	the carpenter, ...	1279 (37.7)
	428	753	409	
Theme-Experiencer passive	The carpenter	was puzzled	by the contractor, ...	1333 (32.6)
	391	774	490	
INANIMATE THEME SENTENCES				
Unmarked active	The carpenter	praised	the blueprint, ...	1273 (37.7)
	411	759	414	
Unmarked passive	The blueprint	was praised	by the carpenter, ...	1456 (35.6)
	408	861	463	
Theme-Experiencer active	The blueprint	puzzled	the carpenter, ...	1308 (38.8)
	433	806	388	
Theme-Experiencer passive	The carpenter	was puzzled	by the blueprint, ...	1392 (33.8)
	386	800	537	

Since the results of analyses on the millisecond per character measures were the same as for analyses on the unadjusted reading times, the unadjusted times will be discussed. Effects are reported as significant only when the probability of a Type I error is less than or equal to .05 in both subjects and items analyses.

Time on the whole clause. The only significant main effect on the first pass reading times for the whole first clause was that passive sentences took longer to read than did active sentences ($F_1(1,39) = 36.41$, $MS_e = 35218$; $F_2(1,31) = 9.22$, $MS_e = 80136$), as they did in the first experiment. The opposite effect was obtained in the ms/char analysis, indicating that passives are read faster than would be predicted if reading time were determined solely by the number of characters in the sentence. Since the additional words in a passive sentence are very short, high-frequency function words (the auxiliary and the word "by"), it is not surprising that passives are read at a faster rate than actives.

Only the predicted interaction of verb type and syntax came close to significance ($F_1(1,39) = 9.00$, $MS_e = 29292$, $p<.005$; $F_2(1,31) = 3.31$, $MS_e = 49967$, $p<.08$). (See Figure 1.) The clauses with active TE verbs (1293 ms) did not differ significantly from the clauses with active unmarked verbs (1261 ms), although the means were in the predicted direction (TE slower than unmarked). In the passive, clauses with unmarked verbs (1445 ms) were significantly slower than clauses with TE verbs (1363 ms) ($F_1(1,39) = 8.84$, $MS_e = 30505$; $F_2(1,31) = 4.16$, $MS_e = 41873$), as predicted.

Examining processing over the course of the clause. An advantage of the eyetracking technique is that we can examine the pattern of eye fixations as the subject reads through the sentence. If, as hypothesized, a linguistic trace increases processing load, then differences between the conditions should first show up when the subject has information about the verb, but not before. The perceptual span in reading is asymmetrical about the fixation point, and it is sometimes possible to identify the word to the right of the one being fixated (see Rayner and Pollatsek, 1989, for a summary of the relevant research). Hence, in the sentences in this experiment, fixations on the subject may sometimes reflect processing of the verb.

FIGURE 1
Interaction of Verb Type and Syntax
Over the Entire Clause

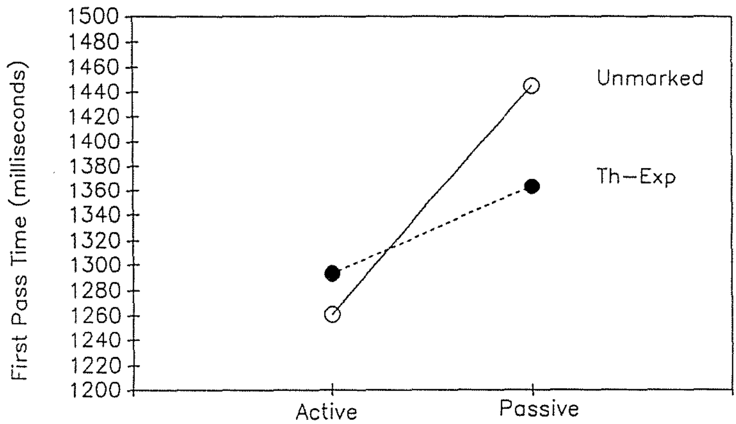
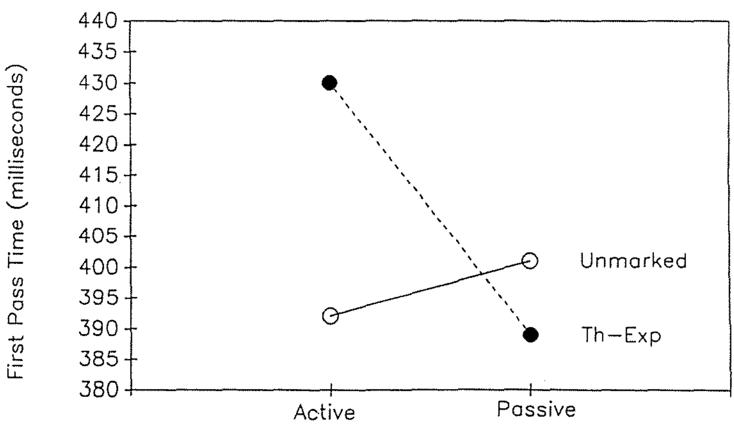


FIGURE 2
Interaction of Verb Type and Syntax
in the Subject Region



Subjects' first fixations in the subject region (made up of the determiner and the noun) did not differ among the conditions (all Fs < 2), but the data from the first pass times demonstrate that subjects had begun processing the next word (either the verb in the active sentences or the auxiliary in the passive sentences) during their second and later fixations in the subject region. This can be seen clearly in Figure 2, which shows a significant interaction between Verb Type and Syntax ($F_1(1,39) = 14.83$, $MS_e = 3468$; $F_2(1,31) = 4.05$, $MS_e = 8061$). In the active conditions, first pass times for the subject region were significantly slower when the verb was a TE verb (430 ms) than when it was an unmarked verb (392 ms) ($F_1(1,39) = 15.68$, $MS_e = 3755$; $F_2(1,31) = 6.03$, $MS_e = 7078$). In the passive conditions, where the next word was an auxiliary verb which was the same for both types of main verb, first pass time in the subject region did not differ significantly between the TE verbs (389 ms) and the unmarked verbs (401 ms). None of the other interactions or main effects was significant in both subjects and items analyses, although main effects of Verb Type and Syntax and an interaction of Animacy and Verb Type were close to significance.

If the region of analysis is extended to include the verb region, where subjects should have been processing the verb even in the passive conditions, the results for actives and passives can be compared directly. Table 4 includes the first pass times for the region made up of the subject and the verb. This region was read significantly faster in the active sentences than in the passive sentences ($F_1(1,39) = 20.82$, $MS_e = 12883$; $F_2(1,31) = 8.28$, $MS_e = 26883$). Also, sentences with an Inanimate Theme were read significantly more slowly than those with an Animate Theme ($F_1(1,39) = 11.28$, $MS_e = 12445$; $F_2(1,31) = 5.96$, $MS_e = 17677$). Animacy of Theme did not interact with any of the other variables (all Fs < 1). The predicted interaction of verb type and syntax was again significant ($F_1(1,39) = 14.58$, $MS_e = 13819$; $F_2(1,31) = 7.37$, $MS_e = 20180$), as can be seen in Figure 3. Both predictions were borne out: in the active conditions, the TE verbs (780 ms) were read significantly slower than the unmarked verbs (734 ms) ($F_1(1,39) = 6.43$, $MS_e = 13157$; $F_2(1,31) = 4.22$, $MS_e = 14874$), while in the passive conditions the TE verbs (787 ms) were read significantly faster than the unmarked verbs (842 ms) ($F_1(1,39) = 7.80$, $MS_e = 15185$; $F_2(1,31) = 5.09$, $MS_e = 17111$).

FIGURE 3
Interaction of Verb Type and Syntax
in the Subject and Verb Region

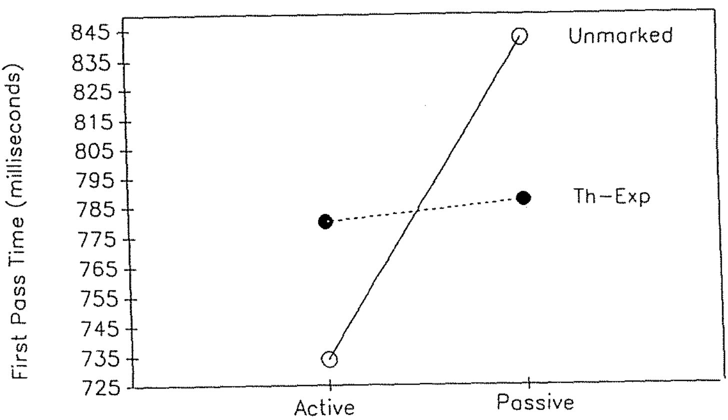
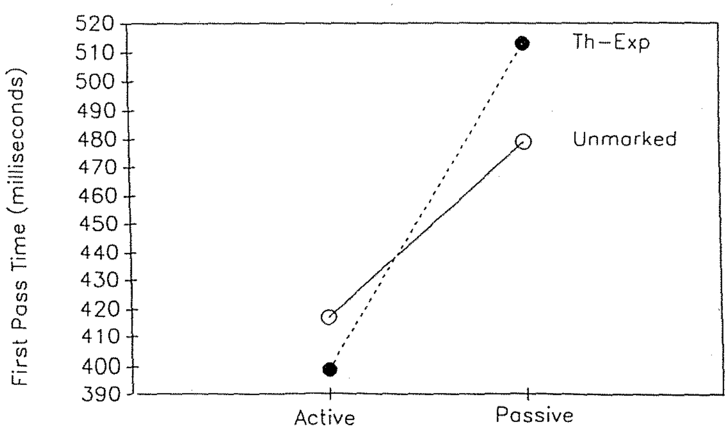


FIGURE 4
Interaction of Verb Type and Syntax
in the Object/By–Phrase Region



Time on the object/by-phrase. The pattern of results was quite different for the region containing the object or the by-phrase. (See Table 4.) Firstly, Animacy of Theme, which had a main effect on first pass reading time for the region of the subject and verb, had no such effect on the object/by-phrase region (all $\underline{F}$s < 1; the interaction of Animacy of Theme and Region was significant). More importantly, the interaction of Verb Type and Syntax took a significantly different form in the object/by-phrase region. As can be seen in Figure 4, the active conditions did not differ significantly in reading time (if anything, the objects of TE verbs (399 ms) were read more quickly than those of unmarked verbs (417 ms)), and the by-phrases of passive TE verbs (513 ms) were read more slowly than the by-phrases of the unmarked verbs (479 ms). However, this interaction was qualified by a significant three-way interaction with Animacy of Theme ($\underline{F}_1(1,39) = 4.23$, $\underline{MS}_e = 44876$; $\underline{F}_2(1,31) = 6.87$, $\underline{MS}_e = 5411$). Table 5 presents the first pass times for the object or by-phrase region alone.

Table 5

First Pass Time on the Object or By-Phrase in Experiment Two (in milliseconds)

ANIMATE THEME SENTENCES

	Active	Passive
Unmarked	420	494
Th-Exp	409	490

INANIMATE THEME SENTENCES

	Active	Passive
Unmarked	414	463
Th-Exp	388	537

An examination of the table shows that for the Animate Theme sentences (in which the object or the by-phrase noun was always animate even when it was not a Theme), only Syntax had an effect, while for the Inanimate Theme sentences, Syntax and Verb Type interacted. Although the individual contrasts in these analyses lack power, the pattern of results for this region can be summarized as follows: Reading time on the object of active verbs did not differ across conditions, while reading time on the by-phrases of passive sentences was slow for TE verbs with inanimate Themes.

Discussion

The results confirm the findings of the first experiment and support the hypothesis that as part of understanding a sentence people construct a representation similar to the representation postulated by current linguistic theory. The verbs of sentences which linguistic theory assumes contain traces (TE actives and unmarked passives) took longer to process than the verbs of matched sentences that did not contain traces (unmarked actives and TE passives).

The tendency for sentences with an inanimate Theme to take longer to read than sentences whose Theme was animate (significant for the region comprising subject and verb) could be due to uncontrolled differences in plausibility or in the ease with which an appropriate scenario can be constructed for these sentences. This effect showed up late (i.e., on the by-phrase) in passive TE sentences with an inanimate Theme because it was only at that point that the subjects could tell that the Theme of these sentences was inanimate. In the other conditions with inanimate Themes, the inanimate Theme was either the subject of the sentence (in passive unmarked sentences and active TE sentences) or was identifiable when the verb was being fixated (active unmarked sentences). This explains why the Animacy effect was most pronounced on the region comprising the subject and verb.

General Discussion

The two experiments reported here provide evidence that readers represent the syntactic structure of sentences in a form isomorphic to that postulated by linguistic theory. Active sentences with unmarked verbs, which do not contain a trace, were read faster than active sentences with TE verbs, which do contain a trace. Passive unmarked sentences, which contain a trace, were read more slowly than passive TE sentences, which do not contain a trace. The results for the passives are consistent with the results of MacDonald's (1989) study, which examined probe responses following verbal and adjectival passives. The verbal (unmarked) passives in her experiment, which contain a trace and which produced long reading times in the current experiments, produced faster response times to probes of the noun associated with the trace than did the adjectival (TE) passives, which contain no trace. The current experiments extend previous work by examining a case -- active TE verbs -- where the arguments for the presence of a trace are clearly internal to linguistic theory and do not correspond to any naive intuitions about linguistic structure. That these active TE verbs took longer to read in the present experiments is evidence that the linguistic analysis for these verbs proposed by Belletti and Rizzi (1989) is correct: the subjects of active TE verbs have a trace after the verb.

It is important to note that an explanation of the results in terms of semantic differences between the verb types cannot account for the interaction between verb type and syntax. Thus, for example, TE verbs may specify a more abstract relation between their arguments than matched unmarked verbs, which would explain why it takes longer to read the active TE verbs, but this semantic difference is also present in the passive sentences, so the same prediction would hold for the passives, contrary to the results obtained in both experiments.

The simplest explanation for the results is that, at some stage, comprehenders construct a syntactic representation of the sentence they are reading or hearing. This representation is similar to the representation assumed in the linguistic theory of Government and Binding (Chomsky, 1981), i.e. it contains traces, and constructing a representation containing a trace takes more time than constructing one without a trace. Taken together with the experiments discussed in the Introduction, the two experiments presented here provide evidence that linguists are correct to view their theories as theories about mental representations and that psychologists can test those theories experimentally.

Footnotes

1. Another potentially relevant reading-time study is a self-paced, word-by-word experiment conducted by Carrithers (1989). In fact, some of her conditions were identical to those in the studies reported here and resulted in very different findings. Unfortunately, however, the study suffered from methodological difficulties (e.g., not every subject provided an observation in every condition) that make interpretation of the results problematic.

2. It is almost always possible to interpret a TE passive (e.g., "Billy was frightened by Sally") as a verbal passive (with a trace) by treating the noun in the by-phrase as an Agent deliberately untertaking an action calculated to affect the subject's state of mind. This is not the usual interpretation of this kind of sentence, but even if subjects in an experiment were to treat some TE passives as equivalent to unmarked passives, this would only decrease the chance of observing a difference between the two verb types in the passive.

3. Note that the first pass time for the whole clause will often be greater than the sum of the first pass times for the subject and verb region and the object/by-phrase region. This is because the first pass time on the whole clause includes regressions from the object/by-phrase region to the subject and verb region.

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