On the Processing of Japanese Wh-Questions: An ERP Study

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Abstract

The processing of Japanese wh-questions was investigated using event-related brain potentials (ERPs). Unlike in English or German, a wh-element in Japanese need not be displaced from its canonical position, but instead needs a corresponding Q(uestion)-particle to indicate its interrogative scope. We tested to see if there were any processing correlates specific to these features of Japanese wh-questions. Both mono-clausal and bi-clausal Japanese wh-questions elicited right-lateralized anterior negativity (RAN) between wh-words and corresponding Q-particles, relative to structurally-equivalent yes/no-question control conditions. These results suggest a reliable neural processing correlate of the dependency between wh-elements and Q-particles in Japanese, which is similar to effects of (left) anterior negativity seen between wh-fillers and gaps in English and German, but with a right- rather than left-lateralized distribution. It is suggested that the scope of a Japanese wh-element is disambiguated by the incremental formation of a long-distance dependency with its corresponding Q-particle.

Section: Cognitive and Behavioral Neuroscience
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1. Introduction

1.1 Wh-movement languages and filler-gap dependencies

Wh-questions—i.e., questions that contain wh-elements such as ‘what’ and ‘who’—have long been a focus of linguistic research not only in the field of theoretical syntax (Chomsky, 1981, 1986, 1995, among many others) but also in the field of language processing (e.g., Fodor, 1978, 1989; Crain and Fodor, 1985; Stowe, 1986; Frazier and Clifton, 1989; de Vincenzi, 1991, among others). In terms of electrophysiological processes, there have been a number of studies that have investigated the processing of wh-questions using ERPs (Kluender and Kutas, 1993a,b; McKinnon and Osterhout, 1996; Müller et al., 1997; Kluender and Münte, 1998; Kaan et al., 2000; Fiebach et al., 2001, 2002; Felser et al., 2003; Phillips et al., 2005; Gouvea et al., submitted). These studies have been done in English and German, both of which are so-called “wh-movement” languages that require wh-elements to be displaced to the beginning of a clause.

Consider (1a): the wh-object What in English must be displaced to the beginning of its clause (except in the case of an “echo question” like Calvin brought WHAT?), rather than appear in canonical post-verbal position, as does the non-wh object pizza in (1b).

(1) a. Wh-question

What did Calvin bring __ ?

b. Yes/no-question

Did Calvin bring pizza?

In the psycholinguistic literature, the displaced wh-element is called a “filler” while the canonical position is called a “gap”, and these are said to be dependent on each other for successful sentence interpretation. This is because a filler is generally ambiguous in terms of its grammatical function (such as “subject” or “object”) and semantic role (such as “agent” or “patient”) until the parser hits the gap position and is able to unambiguously identify this missing information (cf. Fodor, 1989).
The processing of this “filler-gap dependency” has been associated with an ERP component known as left anterior negativity (LAN). The LAN is a negative voltage deflection that is larger over the front of the head than over the back and is often left-lateralized. It has been observed in a transient/phasic form, with a duration of a few hundred milliseconds, and in a slow wave/potential form, with a duration of several seconds. Besides phrase structure and morphosyntactic violations (e.g., Neville et al., 1991; Coulson et al., 1998; Martin-Loeches et al., 2005; see Vos et al., 2001 for a review), LAN has been linked with increased working memory load in associating the displaced wh-filler with its gap (e.g., Kluender and Kutas, 1993a,b; King and Kutas, 1995a; Müller et al., 1997; Kluender and Münte, 1998). For instance, Kluender and Kutas (1993a,b) reported phasic LAN effects at the positions immediately following the filler and the gap of various English object wh-questions, and concluded that both the storage of a filler in working memory and its retrieval1 for filler-gap assignment are indexed by LAN effects. Likewise, King and Kutas (1995a) reported a relatively frontal, negative slow wave between the filler and the gap, as well as a phasic LAN effect immediately following the gap, in response to English object relative clause sentences.

More recent studies have reported P600 effects instead of LAN effects at the gap location. The P600 is a positivity that typically peaks 500-800 ms after stimulus onset and is typically broadly distributed over the head with a bilateral centro-posterior maximum. For instance, Kaan et al. (2000) found P600 effects at the pre-gap position of wh-questions (*bring* in 1a) in comparison to yes/no-questions. Based on this, they argued that the P600 indexes the difficulty of syntactically integrating wh-fillers in the on-going parse (also see Gouvea et al., submitted). Other recent studies have reported the combination of both slow/phasic LAN and P600 effects in wh-questions in

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1 This process has been recently argued to be the parser’s backward search through memory for an appropriate entity to establish a dependency (Kwon et al., in prep. based on data for Korean relative clauses; see Ueno and Garnsey, 2008 for a similar LAN effect for Japanese relative clauses).
English (Phillips et al., 2005) and German (Fiebach et al., 2001, 2002; Felser et al., 2003), as well as in “scrambled” (see Section 1.2 below) wh-questions in Japanese (Ueno and Kluender, 2003).

1.2 Japanese: A wh-in-situ language

Unlike English and German, Japanese is a “wh-in-situ” language in which wh-words stay in the same canonical SOV (subject-object-verb) position as their non-wh counterparts. As shown in (2), ‘pizza’ and ‘what’ typically occupy the same position.

(2)

a. カルビンが ピザを 持ってきたんですか。
Calvin-ga pizza-o mottekita-ndesu-ka.

‘Did Calvin bring pizza?’

b. カルビンが 何を 持ってきたんですか。
Calvin-ga nani-o mottekita-ndesu-ka.

‘What did Calvin bring?’

Although it is also possible in Japanese to displace objects to the beginning of the clause, this involves another process called “scrambling” (see Saito 1985, 1992 for syntactic considerations and Yamashita 1997, 2002, Ueno and Kluender, 2003, and Hagiwara et al., 2007 for processing considerations).

While displacement/scrambling is optional, Japanese wh-words always require a question (Q) particle ka or no (meaning ‘whether’) at the end of the clause, as in (3a).2 Wh-questions without a Q-particle are ungrammatical in Japanese, as shown in (3b).3

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2 The only exception is when a question is spoken with a rising intonation, which can be interpreted as a prosodic version of a Q-particle.

3 Here a non-question particle -yo ‘you know’ is inserted after the verb to block possible rising intonation imposed implicitly by the reader.
In addition, the Q-particle *ka* determines the interrogative scope of a wh-element.

Interrogative scope can be defined as the domain of the sentence that is being questioned. In wh-movement languages, such as English and German, the position of a wh-element at the beginning of a clause transparently indicates its interrogative scope within the sentence. For instance, both (4a) and (4b) consist of two clauses, main and embedded. The wh-element *what* can be placed either at the beginning of the embedded clause as in (4a), yielding an embedded clause wh-question (traditionally termed an “indirect question”)[^4], or at the beginning of the main clause as in (4b), yielding a main clause wh-question (also termed a “direct question”). Although in daily conversation one might actually provide the referent of the wh-word (*pizza*) in answer to either type of question for pragmatic reasons, the logical response to the two is different. The logical answer to an embedded clause wh-question like (4a) would be *yes* or *no*, since no element in the main clause is questioned by a wh-word, while the logical answer to a matrix clause wh-question like (4b) would be the referent of the wh-word (*pizza* in this case), and cannot be *yes* or *no*.

[^4]: More strictly speaking, (4a) is both an embedded clause wh-question and a (main clause) yes/no-question. The embedded clause wh-question only would be *Hobbes asked what Calvin brought*. However, the form shown in (4a) is used because it is more parallel to the ERP stimuli discussed later.
(4) Wh-movement languages (e.g., English)

a. Embedded clause wh-question

[Did Hobbes ask [what Calvin brought ___]]? Logical Answer: Yes, he did.

b. Main clause wh-question

[What did Hobbes say [Calvin brought ___]]? Logical Answer: Pizza.

In Japanese, the position of the Q-particle rather than the position of the wh-element indicates the interrogative scope. While the wh-elements in the indirect (embedded clause) question (5a) and the direct (main clause) question (5b) both remain in the embedded clause, the Q-particle ka appears at the end of the clause bearing interrogative scope, either the embedded (5a) or the main clause (5b), yielding an embedded (5a) or main clause (5b) wh-question.

(5)

a. Embedded clause wh-question

[|Hobbes-wa [Calvin-ga nani-o mottekita-ka] kiki-mashi-ta-ka|
Hobbes-TOPIC Calvin-NOM what-ACC brought-Q ask-POLITE-PAST-Q]

‘Did Hobbes ask what Calvin brought?’

b. Main clause wh-question

[|Hobbes-wa [Calvin-ga nani-o mottekita-to] ii-mashi-ta-ka]?
Hobbes-TOPIC Calvin-NOM what-ACC brought-that say-POLITE-PAST-Q]

‘What did Hobbes say Calvin brought?’

For main clause wh-questions like (5b), a non-question particle to ‘that’ is attached to the embedded verb.

Thus, in English a wh-element is displaced to the left of its gap and marks its own scope as shown in (6a), while in Japanese a Q-particle appears to the right of the corresponding wh-element to mark its scope (6b).
In this sense, the wh-scope marking system in Japanese can be said to be almost a mirror image of the wh-scope marking system in English.

1.3 Processing of Japanese wh-questions

As discussed above, Japanese wh-elements typically stay in their canonical subject-object-verb positions, and in addition, case-markers (e.g., -ga ‘NOMINATIVE’, -o ‘ACCUSATIVE’) are usually attached to wh- (as well as non-wh-) nouns. Therefore, the semantic role and the grammatical function of a Japanese wh-element are typically unambiguous. However, what is ambiguous is its interrogative scope. Unlike the processing of wh-questions in wh-movement languages like English or German, where the parser can immediately read the interrogative scope relations off the position of wh-elements, the parser in a wh-in-situ language like Japanese is unable to determine the scope of a wh-element until the related Q-particle is encountered.

Perhaps because of this necessity, experimental evidence suggests a close relationship between Japanese wh-elements and Q-particles. In an ERP study, Nakagome et al. (2001) examined the processing of mono-clausal wh-questions with (grammatical) and without (ungrammatical) Q-particles at the sentence-final verb position, and reported a P600 effect in response to wh-questions without Q-particles. In a self-paced reading experiment, Miyamoto and Takahashi (2002) reported that main clause wh-questions like (5b) were read more slowly than embedded clause wh-questions.
(like 5a) at the embedded verb position, i.e., ‘verb-that’ without a Q-particle was read more slowly than ‘verb-Q’ in the embedded clause. They argued that, like the dependency that exists between a displaced wh-filler and its gap position in wh-movement languages, there is a dependency between a wh-word and a related Q-particle in wh-in-situ languages. Due to this dependency, Japanese readers expect a Q-particle as soon as they encounter a wh-word, in the same way that English readers expect a gap as soon as possible after encountering a filler (e.g., Crain and Fodor, 1985; Frazier and Clifton, 1989). Main clause wh-questions were read more slowly than embedded clause wh-questions because they violated this expectation (also see Aoshima et al., 2004).

Building on these prior studies, we used ERPs to gain a clearer view of the temporal dynamics involved in processing the relationship between wh-words in situ and their corresponding Q-particles in mono-clausal and bi-clausal Japanese wh-questions. We hypothesized that there would be a neural signature of the dependency between Japanese wh-elements and their Q-particles, similar to that seen in wh-movement filler-gap dependencies in English or German (as well as in scrambling dependencies in Japanese, Ueno and Kluender, 2003). In particular, we expected to see slow anterior negative potentials between wh-words and their corresponding Q-particles, similar to those seen between displaced sentence constituents and their corresponding gaps, and either phasic LAN or P600 effects at the Q-particle position itself, similar to ERP effects typically seen at gap positions, as schematized in (7).
(7)

a. Filler-gap dependency for wh-movement languages (e.g., English, German)

\[
\begin{align*}
\text{What did Calvin bring \_?} \\
\text{FILLER} & \quad \text{GAP} \\
\text{slow wave LAN}
\end{align*}
\]

b. Wh-Q dependency for wh-in-situ languages? (e.g., Japanese)

\[
\begin{align*}
\text{カルビンが \_を持てきたんですか。} \\
\text{Calvin-ga} & \quad \text{nani-o} & \quad \text{mottekita-ndesu-ka} \\
\text{Calvin-NOM} & \quad \text{what-ACC} & \quad \text{brought- POLITE-Q} \\
\text{WH} & \quad \text{Q} \\
\text{slow wave LAN?}
\end{align*}
\]

‘What did Calvin bring?’

On the other hand, as outline above, Japanese exhibits enough different syntactic properties that one might also expect to see different ERP effects in the processing of Japanese wh-questions. For example, since Japanese is a left-branching and strictly head-final language, it is possible that the processing of wh-in-situ questions in Japanese could elicit some other type of ERP effect not evident in the processing of wh-movement questions in English and German, which are right-branching, (mostly) head-initial languages. Moreover, in Japanese the parser has to cope with wh-elements missing a different type of information—namely, interrogative scope—than English and German wh-fillers, whose grammatical functions and semantic roles are initially unclear, and this could cause an ERP difference as well. In any event, investigating the processing of syntactically distinct languages allows us to explore properties of these language-related ERP components, as different types of dependencies in different languages may result in only partially overlapping processes, and thus partially overlapping ERP effects. This may reveal language-universal vs.
language-specific aspects of the processing of wh-questions and lead to better understanding of anterior negativities and perhaps of posterior positivities as well.

2. Experiment 1

Experiment 1 investigated the processing of mono-clausal Japanese wh-questions as a first step toward the above-stated goals. The processing of two types of wh-questions was compared with that of their yes/no-question counterparts. Wh-questions included wh-in-situ questions with wh-objects in situ and scrambled wh-questions with scrambled wh-objects; yes/no-questions included yes/no-in-situ questions with demonstrative objects in situ and scrambled yes/no questions with scrambled demonstrative objects as shown in Table 1 (see Section 5.1.2 for details).

2.1 Results

The mean correct response rate for comprehension questions across participants was 91% (S.D. 5.2%); thus no participant’s data had to be excluded from the ERP analyses based on poor comprehension performance. Comparisons were made both at wh-elements themselves as well as from the words following wh-elements to the sentence-final verb-Q complex, in order to see if there was any neural signature of the wh-Q dependency shown in (7).

2.1.1 Lexical effects at wh-elements

ERPs in response to wh-pronouns (‘what-ACC’ 何を and ‘who-ACC’ 誰を)—whether scrambled or in situ—exhibited both larger P200 components and larger and earlier N350 components than the ERPs to demonstrative pronouns (‘that-ACC’ それを and ‘that-person-ACC’ あのを). Figure 1a shows ERPs to wh- vs. demonstrative pronouns collapsed across in situ and scrambled conditions; results of relevant ANOVAs are displayed in Table 2. ANOVAs performed in a latency window of 200 to 300 ms poststimulus onset confirmed that the P200 elicited by wh-
words was of greater mean amplitude than the P200 to demonstratives over right frontal regions. Similarly, ANOVAs performed on mean amplitude measures in a latency window of 300 to 375 ms confirmed that the N350 elicited by wh-words was larger than that elicited by demonstratives, especially over the left hemisphere. Additional ANOVAs performed on peak latency (rather than mean amplitude) measures in a window of 250 to 450 ms indicated that the N350 in response to wh-words also peaked earlier than the N350 elicited by demonstratives, especially over posterior regions.

While the larger P200 component and larger and earlier N350 component in response to wh-words initially gave the impression of a wh-Q dependency effect, closer examination showed that these differences were instead due to lexical processing differences between wh-words and demonstratives (Figure 1b). The P200 effect (i.e., larger P200s to wh-words than to demonstratives) was related to the graphic complexity of wh-words, which consisted solely of Chinese characters (kanji) in our stimulus set, as these require on average more strokes to write than phonemic (kana) representations. Trend analyses (cf. Keppel, 1982) on P200 amplitude (collapsed across electrodes for the four wh- and demonstrative pronouns) in terms of stroke count revealed a significant linear component for total stroke count \([F(1,57) = 14.21, p < .001]\); none of the other higher-order (quadratic, cubic) trend components was significant. Correlations between P200 amplitude and frequency or word length did not reveal any similar significant linear trend component.

The N350 mean amplitude effect (i.e., a larger N350 response to wh-words than to demonstratives), on the other hand, was related solely to word length: among stroke count, frequency, and word length, only word length revealed a significant linear trend component by itself \([F(1,57) = 4.76, p = .033]\). Previous research has shown that the latency of lexical processing
negativities correlates with word frequency and/or length (Neville et al., 1992; Osterhout et al., 1997; King and Kutas, 1995b, 1998). Trend analyses on the N350 peak latency effect (i.e., the N350 to wh-words peaking earlier than that to demonstratives) thus revealed a significant linear trend component \[F(1, 57) = 6.89, p = .012\] for word length, but not for frequency or stroke count.

In sum, wh-words in comparison to demonstratives elicited a larger P200 component and an earlier, larger N350 component. Mean amplitude of the P200 correlated with graphic complexity as measured by stroke count, whereas both the latency and the amplitude of the N350 correlated solely with word length.

2.1.2 Right-lateralized negativity between wh-elements and Q-particles

To test more directly for brain responses to the dependency between a wh-word and its corresponding Q-particle at sentence end, we also examined ERPs to the words following wh-words up to and including the sentence-final verb-Q complex. The two in situ conditions and the two scrambled conditions ((a) vs. (b) and (c) vs. (d) in Table 1) were compared separately, as it was assumed that comparing minimal sentence pairs, differing only in the presence of a wh-word, would reveal effects specific to the processing of wh-questions alone.

2.1.2.1 Wh-in-situ questions vs. yes/no-in-situ questions

The glosses of the relevant experimental sentences for the wh-in-situ question vs. yes/no-in-situ question comparison are given in (8), with the point of comparison capitalized. This was a single-word average at the sentence-final verb position (‘discovered-Q’), as wh- and demonstrative objects in situ immediately preceded the verb (Figure 2).
On visual inspection, wh-in-situ questions appeared to elicit greater negativity after 300 ms post-stimulus onset of ‘discovered-Q’, especially over the right side of the head. ANOVAs performed within a latency window of 300-600 ms\(^5\) revealed a significant main effect \[F(1, 19) = 9.91, p = .005\] and a marginal condition x hemisphere interaction \[F(1, 19) = 3.01, p = .099\] within the temporal array, indicating a greater negativity with a tendency toward right-lateralization in response to wh-in-situ questions. There was no accompanying P600 effect in response to the verb-Q complex in wh-in-situ questions.

---Figure 2---

2.1.2.2 Scrambled wh-questions vs. scrambled yes/no-questions

The glosses of the relevant experimental sentences for the scrambled wh-question vs. scrambled yes/no-question comparison are given below in (9), with the point of comparison capitalized. ERPs to words following scrambled wh- and demonstrative objects up to and including the verb-Q complex (‘reckless adventurer-NOM finally discovered-Q’\(^6\)) were examined (Figure 3).

---Figure 2---
a. The local newspaper-to according

**what-ACC** that RECKLESS ADVENTURER-NOM FINALLY __ DISCOVERED-Q.

‘According to the local newspaper, what did that reckless adventurer finally discover?’

b. The local newspaper-to according

**that-ACC** that RECKLESS ADVENTURER-NOM FINALLY __ DISCOVERED-Q.

‘According to the local newspaper, did that reckless adventurer finally discover that?’

Visual inspection of these four-word averages revealed a sustained right-lateralized anterior negativity starting about 300 ms after the onset of ‘adventurer-N’ and continuing through to sentence end in the scrambled wh-question condition.

--Figure 3--

ANOVAs performed in a latency window of 300 ms poststimulus onset of ‘adventurer-N’ to sentence end, including the sentence final verb-Q complex ‘discovered-Q’ (950 to 2600 ms from the pre-stimulus baseline) showed a significant interaction between condition and hemisphere in the parasagittal array \[F(1, 19) = 6.40, p = .02\], as well as a significant condition x hemisphere x anteriority interaction in the temporal array \[F(2, 38) = 3.37, p = .045\]. These interactions were due to greater slow potential negativity over right anterior regions in response to scrambled wh-questions relative to scrambled yes/no-questions. When the averages of the two conditions were re-baselined at the onset of the sentence-final verb-Q position, there were no additional effects.

To sum up, wh-in-situ questions elicited right-lateralized negativity at the sentence-final verb-Q position, and scrambled wh-questions elicited slow anterior negative potentials, especially over the right side of the head, from the subject noun to the sentence-final verb-Q position.

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averages of an adjective, a noun, an adverbial, and a verb-Q complex, as in ‘reckless adventurer-NOM finally discovered-Q’
2.2 Discussion

Wh-questions in comparison to yes/no-questions elicited two types of effects in the present experiment. The first involved lexical effects in response to wh-words: compared to demonstratives, wh-words elicited larger P200s and an earlier and larger amplitude N350 (Figure 1). The larger P200 correlated with stroke count, whereas both the latency and the amplitude of the N350 correlated with word length. The second effect was right-lateralized (anterior) negativity between wh-words and Q-particles. Wh-in-situ questions in comparison to yes/no-in-situ questions elicited greater right-lateralized negativity at the sentence-final verb-Q position (Figure 2), while the last few words of scrambled wh-questions (including the verb-Q complex) elicited greater right-lateralized anterior negativity than the same four words in scrambled yes/no-questions (Figure 3). In what follows, we will discuss each of these effects in turn.

2.2.1 Lexical effects at wh-elements

Wh-words in comparison to demonstratives elicited larger P200s and earlier and larger N350s, with P200 amplitude correlating with stroke count, and N350 amplitude/peak latency with word length. The interaction between P200 amplitude and stroke count most likely reflects local visual processing of complex Chinese characters, consistent with reports of larger P200s when local features are attended to (Kotchoubey et al., 1997) and claims relating the P200 to visual targets and attention (Luck and Hillyard, 1994; O’Donnell et al., 1997). Additionally, Takashima et al. (2001) reported that open-class words (nouns, verbs) elicit larger P200s than closed-class words (particles, auxiliary verbs) in Japanese. However, this effect is confounded by the fact that open-class words tend to be written in Chinese characters (kanji), while closed-class words are usually written in visually less complex phonemic characters (kana). Our results, showing that even graphically complex closed-class words elicit larger P200s, strongly suggest that graphic complexity rather than word class is the crucial variable in P200 amplitude differences within the Japanese lexicon (also
see Liu, Perfetti, and Hart, 2003 for discussion of the P200 as an index of visual-graphic processing in Chinese). As for the N350, word length was the only factor that showed a significant linear trend for both the earlier peak latency and the larger amplitude of the effect. This is in part consistent with Osterhout et al. (1997) (which however also reported a frequency-based correlation that was not evident in the present study), in that shorter wh-words elicited earlier peaks than longer demonstratives. The amplitude difference is in line with Neville et al. (1992), who reported that longer open-class words in comparison to shorter ones elicited more positive ERPs following the P200 over frontal regions (Neville et al., 1992: Figure 5). It is interesting that frequency, which has been reported to exert a strong influence over lexical ERP effects in English (Osterhout et al., 1997; King and Kutas, 1995b, 1998), played no apparent role in the present study.

2.2.2 Right-lateralized negativity between wh-elements and Q-particles

The negativity occurring between wh-words and the verb-Q complex did not have an identical distribution in in situ vs. scrambled wh-questions: wh-in-situ questions elicited right-lateralized negativity, while scrambled questions elicited right anterior negativity. However, the two effects had several other aspects in common, namely, question type (elicited by wh-questions), point of occurrence (after processing wh-words), polarity (negative), and lateralization (right-lateralized). In addition, there may be some commonality in the latency of the two effects. For the scrambled comparison, the effect was seen in response to the final few words of the sentence (starting at ‘adventurer-N’ for some electrodes) (Figure 3). For the in situ comparison, there was only one word, the sentence final verb-Q complex, but the negativity continued across the epoch (Figure 2). Thus both may actually be sustained rather than phasic effects. From the above, it seems plausible to consider the two effects to be at least somewhat related to each other. Thus we

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7 Although the morphology of their waveforms differs from ours, in both cases, longer words elicited more positive (or less negative) ERPs than shorter words following the P200. That is, in the present study, longer demonstratives elicited ERPs that were more positive than those elicited by shorter wh-words.
provisionally treat the two as one type of right-lateralized negativity and proceed with our discussion.

There are several possible ways to interpret this effect. One is as a “sentence-end wrap-up” effect. However, previous reports of such effects involve N400-like negativities with posterior distribution at the end of sentences containing syntactic and semantic anomalies (Osterhout and Holcomb, 1992; Hagoort et al., 1993; Osterhout and Nicol, 1999), or a widely distributed negativity, also at the end of sentences containing syntactic and semantic anomalies (Friederici and Frisch, 2000). These effects have been interpreted as showing that the kinds of processing problems that initially evoke N400/P600 effects mid-sentence also make it difficult to integrate the meanings of sentence-final words. However, unlike studies with anomalies, the stimulus sentences used in the present experiment were all grammatical, and our negativity effects were not preceded by N400/P600 effects earlier in the sentence. In addition, the distribution of the negativity was anterior rather than posterior for at least the scrambled wh- vs. yes/no-question comparison. These points diminish the plausibility of a “sentence-end wrap-up” interpretation of the effect. Another possibility is that the effects indexed a dispreferred parse. However, to the best of our knowledge, dispreferred parse effects in otherwise grammatical sentences have been linked to the P600 elicited by the critical word (Osterhout and Holcomb, 1992; Osterhout et al., 1994; Friederici et al., 1996) rather than to any sentence-end negativity, rendering it unlikely that the right-lateralized negativity effects in the present study could be taken as an index of a dispreferred parse.

In view of the unlikeness of these other possibilities, the effect of right-lateralized (anterior) negativity most likely indexes some type of relationship between Japanese wh-words and Q-particles. This is consistent with previous experimental claims about Japanese wh-questions, as discussed in Section 1.3. Therefore, the first part of our hypothesis, that there is a neural correlate of
the dependency between a Japanese wh-element and its related Q-particle, seems to be well supported.

However, the second part, that the wh-Q dependency is processed in much the same way as a filler-gap dependency, is in need of further consideration. First, reported LAN effects elicited by visual presentation of stimuli involving wh-movement\(^8\) (Kluender and Kutas 1993 a,b; King and Kutas, 1995a; Kluender and Münte, 1998; Fiebach et al., 2001, 2002; Felser et al., 2003; Phillips et al., 2005) have always been either bilateral or left-lateralized, but curiously, our effects were right-lateralized. Second, the latency of the effect is unclear. The anterior negativity effects in response to filler-gap dependencies in English and German have been recognized as long-lasting slow potentials between filler and gap (King and Kutas, 1995a; Kluender and Münte, 1998; Fiebach et al., 2001, 2002; Felser et al., 2003; Phillips et al., 2005)\(^9\), as well as phasic forms at the gap position (Kluender and Kutas, 1993a,b; King and Kutas, 1995a). Recall that we predicted slow potentials between Japanese wh-elements and their corresponding Q-particles and possible phasic effects at the sentence-final verb-Q position, but at this point, we cannot tell whether wh-in-situ questions elicited a sustained or phasic effect, since they only had the sentence-final word for comparison. However, given that scrambled wh-questions did not elicit any additional phasic negativity at the sentence final verb-Q position when averages were re-baselined at this position, it seems more parsimonious to conclude, at least provisionally, that both effects belong to the family of slow potentials. Lastly, as for the P600, neither the in situ nor scrambled comparison revealed any effect

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\(^8\) Müller et al. (1997) used an auditory version of King and Kutas (1995) and examined ERPs to spoken object and subject relative clause sentences in English. This study also reported anterior negativity in response to object relative clause sentences, but the effect was lateralized to the right rather than the left side of the head, i.e. with an opposite asymmetry to that reported in King and Kutas (1995). Müller et al. speculated that this was perhaps due to some mechanism of auditory perception, such as more involvement of the right hemisphere.

\(^9\) Kluender and Kutas (1993a,b) used only single-word average windows for data analysis, and the sequence of single-word LAN effects at various sentence positions suggested that some of the phasic LAN effects may have been short time slices of longer-lasting slow negative potentials. This is also consistent with the results of King and Kutas (1995).
of positivity at the verb-Q position, where the hypothesized wh-Q dependency is presumably closed off.

Given the above, the question is whether the same pattern of results would be found not only in mono-clausal but also in bi-clausal wh-questions. As shown in (5) above, bi-clausal wh-questions in Japanese provide two possibilities for scope-marking, namely embedded vs. main clause scope of the wh-question. Experiment 2 investigated whether right-lateralized (anterior) negativity is elicited between wh-words and their corresponding Q-particles in bi-clausal wh-questions as well, and if such effects exist, whether they are sustained or phasic.

3. Experiment 2

The stimuli used in Experiment 2 were a slightly modified version of Miyamoto and Takahashi’s (2002) reading time study, with the embedded clause scrambled to the beginning of the sentence (note that scrambling is typical although not obligatory for a long embedded clause in Japanese; cf. Yamashita, 2002), as shown in Table 3 (see Section 5.2.2 for details).

--Table 3--

As schematized in (10), we predicted that if right (anterior) negativity (hereafter referred to as “RAN”) really indexes a dependency between a wh-element and a corresponding Q-particle, it should appear between the wh-element and the embedded verb-Q position in embedded clause wh-questions (10a), and between the wh-element and the main clause verb-Q in main clause wh-questions (10b).
(10) Predictions for Experiment 2

a. Embedded clause wh-question

\[ \text{wh-Q RAN?} \quad \quad \text{No RAN/P600?} \quad \quad \text{wh-Q RAN?} \]

専務がどんなパソコンを買ったか 経理の係長が聞きましたか。
[senmu-ga donna pasokon-o katta-ka] keiri-no kakaricho-ga kikimashita-ka?
director-N what.kind.ofPC-A bought-Q accounting-of manager-N asked.POL-Q

‘Did the accounting manager ask what kind of computer the director bought?’

b. Main clause wh-question

\[ \text{wh-Q RAN?} \quad \quad \text{No RAN/P600?} \quad \quad \text{wh-Q RAN?} \]

専務がどんなパソコンを買ったと経理の係長が言いましたか。
[senmu-ga donna pasokon-o katta-to] keiri-no kakaricho-ga iimashita-ka?
director-N what.kind.ofPC-A bought-that accounting-of manager-N said.POL-Q

‘What kind of computer did the accounting manager say the director bought?’

Recall that in Experiment 1, there was an evident RAN response to the verb-Q position of wh-in-situ questions when averages were baselined at the onset of the final word, but that this was not the case for the verb-Q position of scrambled wh-questions. Although we claimed it was therefore more parsimonious to treat the RAN effects to both types of questions as slow potentials, we did not offer definitive proof of this. The bi-clausal design of the present experiment was intended to test this claim more closely. Recall further that there was no phasic RAN effect in scrambled wh-questions—nor a P600 effect in either in situ or scrambled wh-questions—in response to the verb-Q position of Experiment 1. The stimulus materials of Experiment 2 allowed us to test once more for possible phasic RAN and/or P600 effects at equivalent positions, namely, at the embedded verb-Q position for embedded clause wh-questions and at the main verb-Q position for main clause wh-questions.
3.1 Results

The mean correct response rate to comprehension questions across participants was 87% (S.D. 8.0%). We investigated ERPs at various sentence positions as schematized in Table 4.

---Table 4---

3.1.1 Anterior negativity and lexical effects at wh-elements (Fig 4)

We begin by investigating ERPs at the beginning of the purported wh-Q dependency, namely the wh-modifier position. In 50% of the stimulus sets, the wh-modifier of the embedded object noun (‘computer-ACC’ in Tables 3 and 4) was *donna* ‘what.kind.of’, and its non-wh-counterpart was an adjective such as *atarashii* ‘new’ (as in ‘new computer-ACC’). The other 50% of the stimulus sets contained numeral classifiers such as *nan-bai-no* ‘what-cup-of (how many cups of)’ in the wh-conditions and *ni-hai-no* ‘2-cup-of’ in the non-wh-conditions (see Section 5.2.2 for details). Similar to Experiment 1, ERPs to both groups of wh-modifiers were compared to their non-wh-counterparts in order to see if there was any effect of wh-Q dependency formation and/or lexical wh-word processing at the position of the wh-modifier itself.

Figure 4 shows ERPs to wh- vs. non-wh-modifiers of the object noun phrase in the embedded clause (recall that the embedded clause was scrambled to the beginning of the sentence, as shown in Tables 3 and 4); results of relevant ANOVAs are displayed in Table 5. For both wh- and yes/no-questions, data were collapsed across embedded and main clause conditions, because they were identical at this sentence position. When all wh-modifiers and all non-wh-modifiers were compared, an effect of anterior negativity was observed in response to the wh-modifiers.\(^{10}\) For the

\(^{10}\) A left-lateralized N400 effect in response to non-wh-modifiers, significant only in adjective (‘what kind of’ vs. ‘new’) but not numeral classifier (‘what-cup-of’ vs. ‘2-cup-of’) pairs, was also present in this comparison; cf. midline electrodes Fz, Cz, and Pz in Figure 4 and columns marked “300-500 ms” in Table 5. This was caused by *reduced* N400 amplitude in response to ‘what.kind.of’, attributable to the following factors: a high rate of repetition (25% [50/200] of experimental sentences; Van Petten et al., 1991), high frequency of occurrence in the language (a mean frequency of 27,715 vs. 6,497 for the non-wh adjectives in Experiment 2; Amano and Kondo, 2000; Van Petten and Kutas, 1991), closed-class status (Münte et al., 2001), and low semantic content (Kluender and Kutas, 1993b; McKinnon and
anterior negativity in response to wh-modifiers, as shown in Table 5, ANOVAs performed in a latency window of 500-700 ms\textsuperscript{11} indicated that the ERPs to all wh-modifiers were more negative than the ERPs to all non-wh-modifiers, especially over anterior regions of scalp.\textsuperscript{12}

---Figure 4---

---Table 5---

Since wh- and non-wh-modifiers were controlled for length in Experiment 2 (see Section 5.2.2), there were no N350 differences equivalent to those seen in comparisons of wh-words with demonstratives in Experiment 1 (see Section 2.1.1). However, since it was not possible to control for stroke count in this manipulation, there were small but reliable P200 differences within adjective pairs and numeral classifier pairs, albeit in opposite directions: non-wh-modifiers in adjective pairs elicited a larger amplitude P200, whereas wh-modifiers elicited a larger P200 in numeral classifier pairs. Consistent with the results of Experiment 1, in both cases this was attributable to the use of more Chinese characters with higher stroke counts in the eliciting conditions, as discussed in Section 5.2.2.

We assume that the lexical differences seen in our comparisons of wh-modifiers to corresponding non-wh-modifiers were orthogonal to our main question of interest, which has to do with the processing of wh-Q dependencies in wh-in-situ languages: P200 differences correlated with graphic complexity, as in Experiment 1 (while N400 differences—see fn. 10—were attributable to the repetition, overall frequency, and closed-class status of \textit{donna} ‘what-kind-of’).

We suspect that the effect of anterior negativity in response to wh-modifiers, on the other hand, may

\footnotesize{Osterhout, 1996). As these variables have previously all been shown to reduce N400 amplitude independently, and since this was not a question of experimental interest in the present study, we will not discuss this N400 effect any further.\textsuperscript{11} It was not possible to measure the anterior negativity in response to wh-modifiers within a latency window of 300-600 ms as this window was confounded by the presence of an N400 effect in response to non-wh modifiers: see fn. 10 for details.\textsuperscript{12} Separate analyses within wh- vs. non-wh adjective pairs (e.g., ‘what kind of’ vs. ‘new’) and wh- vs. non-wh numeral classifier pairs (‘what-cup-of’ vs. ‘2-cup-of’) indicated that this negativity had an anterior distribution in response to wh-adjective pairs, but was right-lateralized in response to numeral classifier pairs.}
signal the start of a wh-Q dependency. To confirm this suspicion, we next turn to comparisons of entire wh-phrases, including both wh-modifiers and the head nouns they modify; after that, we turn to longer-ranging comparisons of intervening words between wh-phrases and clause-final Q-particles.

3.1.2 Right-lateralized (anterior) negativity between wh-elements and Q-particles

3.1.2.1 Embedded clause object noun phrase

The glosses of the experimental sentences, with the relevant point of comparison (the embedded object noun phrase) in all capitals, are given below in (11). For both wh- and yes/no-questions, data were collapsed across embedded and main clause conditions, as words were identical through the embedded object head noun position, ‘computer-A’ in (11) (Figure 5).

(11)

a. All wh

[Director-N WHAT.KIND.OF COMPUTER-A bought-Q/that] accounting-of manager-N asked/said-Q

‘Did the accounting manager ask what kind of computer the director bought?’

‘What kind of computer did the accounting manager say the director bought?’

b. All yes/no

[Director-N NEW COMPUTER-A bought-Q/that] accounting-of manager-N asked/said-Q

‘Did the accounting manager ask if the director bought a new computer?’

‘Did the accounting manager say that the director bought a new computer?’

In this comparison, visual inspection suggested a sustained anterior negativity in response to all wh-questions.13

ANOVAs run in the window of 500-1250ms14 revealed a significant main effect of condition in the midline [F(1,19) = 5.18, p = .035] and parasagittal [F(1,19) = 6.22, p = .022] arrays,

13 As in the comparison of wh-modifiers to non-wh-modifiers alone in Section 3.1.1, there was again a left-lateralized N400 effect in response to the object modifier position in all yes/no-questions. As discussed in fn. 10, this was caused by the reduced N400 amplitude to one closed-class item (“what.kind.of”) in 50% of the wh-questions.
14 The time window of 300-500 ms was again avoided due to the occurrence of the N400 effect: see fns. 10, 11, and 13.
indicating that all wh-questions were more negative than all yes/no-questions. To examine the scalp distribution of the negativity elicited by both wh-modifiers and the head nouns they modified (‘computer-A’ in 10), separate measurements were taken in the time windows of 500-700 ms for modifiers and 950-1250 ms (300-600 ms poststimulus onset of ‘computer-A’) for head nouns. For the 500-700 ms window (‘what.kind.of/what-cup-of’), there was a significant main effect of condition in the parasagittal $[F(1,19) = 5.63, p = .028]$ and temporal $[F(1,19) = 10.02, p = .005]$ arrays, plus a marginal condition x anteriority interaction in the temporal array $[F(2,38) = 2.90, p = .10]$. This indicated that wh-questions were overall more negative than yes/no-questions, with a tendency toward an anterior distribution of this negativity. For the 950-1250 ms window (‘computer-A’), there was a significant main effect of condition in the midline $[F(1,19) = 5.18, p = .035]$ and parasagittal $[F(1,19) = 6.22, p = .022]$ arrays, again indicating that wh-questions were more negative than yes/no-questions.

--Figure 5--

To summarize, just as was observed at the wh-modifier position itself, there was an effect of anterior negativity in response to the entire object noun phrase position (wh-modifier + object head noun, ‘what.kind.of computer-ACC/what-cup-of coffee-ACC’) within the embedded clause of wh-questions. This confirmed our suspicion that the negativity seen at the wh-modifier position (Figure 4) continued through the entire object NP of the embedded clause (Figure 5), and was therefore not attributable to mere graphic or lexical differences at the modifier position, as was the case for the P200 and N400 differences reported in Section 3.1.1. We next turn to the final position of the embedded clause, the clause-final verb, where the embedded and main clause wh-question conditions first diverged.
3.1.2.2 Embedded verb

The glosses of the experimental sentences with the relevant point of comparison in all capitals are given below in (12).

(12)
a. Main clause wh

[Director-N what.kind.of computer-A BOUGHT-THAT] accounting-of manager-N said-Q.

‘What kind of computer did the accounting manager say the director bought?’

b. Embedded clause wh

[Director-N what.kind.of computer-A BOUGHT-Q] accounting-of manager-N asked-Q.

‘Did the accounting manager ask what kind of computer the director bought?’

c. Main clause yes/no

[Director-N new computer-A BOUGHT-THAT] accounting-of manager-N said-Q.

‘Did the accounting manager say that the director bought a new computer?’

d. Embedded clause yes/no

[Director-N new computer-A BOUGHT-Q] accounting-of manager-N asked-Q.

‘Did the accounting manager ask if the director bought a new computer?’

This comparison allowed us to test our prediction, based on the results of Experiment 1, that an unresolved wh-Q dependency should elicit right-lateralized (anterior) negativity (RAN). Main clause wh-questions (12a) had no Q-particle attached to the verb of the embedded clause to close off the scope of the wh-phrase, while embedded wh-questions (12b) did contain a Q-particle limiting the scope of the wh-phrase to the embedded clause. There was no wh-Q dependency in the yes/no-question control (12c) at the embedded verb position. In this comparison, then, there should be an unresolved dependency at the embedded verb-‘that’/Q position of main clause wh-questions (12a), whereas the dependency should be resolved at this point in embedded wh-questions (12b), and there should be no such dependency present at all in main clause yes/no-questions (12c). Thus
the unresolved dependency of main clause wh-questions was predicted to elicit RAN relative to the resolved or unexistent dependencies of the other conditions. In addition, the comparison between embedded clause wh- (12b) and yes/no-questions (12d) at this sentence position allowed us to test for local RAN and P600 effects when the scope of embedded clause wh-questions was disambiguated.

Figure 6 shows ERPs to main clause wh-questions, embedded clause wh-questions, and main clause yes/no-questions at the embedded verb position. On visual inspection, when compared to both main clause yes/no-questions and embedded clause wh-questions, main clause wh-questions appeared to elicit a RAN effect that continued throughout the present epoch and into the next, as predicted. For the main clause wh- vs. yes/no-question comparison, ANOVAs performed in the 300-600 ms window showed no significant or marginal differences, while ANOVAs in the 300-900 ms window (i.e., through to the end of the epoch) revealed a significant condition x anteriority interaction in the midline array \[F(2, 38) = 3.74, p = .035\], as well as a marginal condition x hemisphere interaction in the parasagittal \[F(1, 19) = 3.36, p = .083\] and temporal \[F(1, 19) = 3.67, p = .071\] arrays. These results indicated that main clause wh-questions were more negative than main clause yes/no-questions over anterior regions of scalp, with a tendency toward a right anterior maximum (cf. Fp2 and F8 in Figure 6). Since this RAN effect appeared more pronounced toward the end of the epoch, separate ANOVAs were run in the 600-900 ms window for this comparison. This resulted in a significant or marginal condition x anteriority interaction in all three arrays \[midline: F(2, 38) = 6.94, p = .003; parasagittal: F(4, 76) = 4.43, p = .02; temporal: F(2, 38) = 3.10, p = .091\], as well as a significant or marginal condition x hemisphere interaction in the parasagittal \[F(1, 19) = 4.33, p = .051\] and temporal \[F(1, 19) = 4.86, p = .04\] arrays, indicating that the effect became stronger in the later time window, consistent with the visual impression.

--Figure 6--
For the main clause wh- vs. embedded-clause wh-question comparison, ANOVAs performed in the 300-600 ms window again showed no significant or marginal differences, but ANOVAs in the 300-900 ms window revealed a marginal condition x anteriority x hemisphere interaction in the temporal array \[F(2,38) = 2.88, p = .071\]. This suggested that main clause wh-questions in comparison with embedded clause wh-questions tended to be more negative over right anterior regions of scalp. Although the effect was statistically weak, separate measurements run in the 600-900 ms window showed improved results, just as was found in the main clause wh- vs. yes/no-question comparison above. There was a marginal condition x anteriority interaction \[F(2,38) = 3.27, p = .084\] and a significant condition x anteriority x hemisphere interaction \[F(2, 38) = 3.29, p = .05\] in the temporal array, indicating that the effect again became stronger in the later time window.

ERPs to embedded clause wh- vs. yes/no-questions were also compared at the embedded verb position. There were no phasic RAN or P600 effects apparent on visual inspection, or evidenced by ANOVAs performed in the 300-600 ms and 300-900 ms windows to detect additional phasic RAN effects, or by ANOVAs in the 500-800 ms window to detect a P600 effect. On the other hand, on visual inspection there appeared to be an N400-like effect—however, in response to embedded yes/no-questions relative to embedded wh-questions. ANOVAs run in the window of 300-500 ms revealed a marginal condition x anteriority interaction in the temporal array \[F(2, 38) = 3.01, p = .094\], indicating a small N400 effect to embedded yes/no questions at the back of the head (Figure 7a).

---Figure 7---

To summarize, main clause wh-questions elicited a RAN effect relative to both main clause yes/no-questions and embedded clause wh-questions that began at the embedded verb position but continued into the next word. As predicted, this effect seems related to the presence of an
unresolved wh-Q dependency in main clause wh-questions. Comparisons of embedded clause wh-
questions with embedded clause yes/no-questions revealed no additional phasic RAN or P600
effects in response to embedded wh-questions, consistent with the results with mono-clausal main
clause wh-questions in Experiment 1. However, there was a small N400 effect in response to
embedded yes/no-questions. This N400 effect may be due to a mismatch between a verb-Q string in
a non-wh construction that does not require a Q-particle (see Section 3.2.4).

3.1.2.3 From embedded to main clause verbs

In the previous section, we discussed RAN effects at the embedded verb position—where
wh-question conditions first diverged—that were related to the presence of an unresolved wh-Q
dependency in main clause wh-questions. These effects began at the embedded verb position in
accordance with our predictions, but became more pronounced toward the end of the epoch and
appeared to continue into the next word. If it is the case that RAN is always elicited by the presence
of an unresolved wh-Q dependency, then the RAN effect seen in response to main clause wh-
questions at the embedded verb position should in fact continue throughout the ensuing main clause
region until the scope-marking Q-particle is encountered at sentence end. Thus far in Experiment 2,
the RAN-like effects that we have seen in response to wh-modifiers (Figure 4), entire wh-object
noun phrases (Figure 5), and at the embedded verb of main clause wh-questions (Figure 6) suggest
that this should be the case. Moreover, the comparison shown in Figure 3 of Experiment 1, in which
a wh-phrase was separated from its scope-marking Q-particle by means of scrambling, suggests that
this continued RAN effect in the main clause should manifest as a slow right-lateralized anterior
negative potential.

With this prediction in mind, we now turn to an examination of the latter half of the stimulus
sentences, namely from the embedded verb to the main clause verb. The glosses of the experimental
sentences with the relevant points of comparison capitalized are given below in (13).
(13) a. Main clause wh
   [Director-N what.kind.of computer-Ą BOUGHT-THAT] ACCOUNTING-OF MANAGER-N SAID-Q
   ‘What kind of computer did the accounting manager say the director bought?’

b. Embedded clause wh
   [Director-N what.kind.of computer-Ą BOUGHT-Q] ACCOUNTING-OF MANAGER-N ASKED-Q
   ‘Did the accounting manager ask what kind of computer the director bought?’

c. Main clause yes/no
   [Director-N new computer-Ą BOUGHT-THAT] ACCOUNTING-OF MANAGER-N SAID-Q
   ‘Did the accounting manager say that the director bought a new computer?’

In this sentence region, a RAN effect should be evident only in main clause wh-questions (13a), as this is the only condition in which an unresolved wh-Q dependency still exists in the main clause. Embedded clause wh-questions (13b) have presumably already closed off this dependency at the embedded verb-Q position, and there should be need at all for a Q-particle in the main clause yes/no-question control condition (13c). Thus comparisons were made between main clause wh-questions (13a) vs. main clause yes/no-questions (13c), and between main clause wh-questions (13a) vs. embedded clause wh-questions (13b) in a latency window that covered the last four words of the sentence (‘bought-Q/that accounting-of manager-N asked/said-Q’), i.e., from the embedded verb through the sentence-final main clause verb.

Figure 8 shows the ERPs in response to these comparisons. A sustained anterior negativity in response to main clause wh-questions (13a) was observed in comparison with main clause yes/no-questions (13c).

--Figure 8--

ANOVA’s run in a latency window of 300-2600 ms revealed that there was a significant condition x hemisphere interaction [F(1,19) = 4.59, p = .043] and a marginal condition x anteriority interaction [F(2,38) = 3.76, p = .063] in the temporal array. This indicated that main clause wh-questions were
more negative than main clause yes/no-questions over the right side of the head, with a tendency toward a more anterior distribution.

However, this comparison was contaminated by the presence of an N400-like effect at sentence end in response to main clause yes/no-questions. This N400-like effect is indicated by the dotted arrows in Figure 8, as well as by the greater positivity seen in the “main wh – main yes/no” isovoltage map of Figure 8 in the 2250-2450 ms latency window (i.e., 300-500 ms post-stimulus onset of ‘said-Q’); it is also shown in a single-word average in Figure 7b. Statistics for this comparison will be reported below. What is important for present purposes is that when the final word of the sentence eliciting this N400-like effect in response to yes/no-questions was excluded from the average, the RAN effect to main clause wh-questions emerged more clearly. ANOVAs run in the 300-1950 ms window (from 300 ms poststimulus onset of ‘bought-that’ to the end of ‘manager-N’) revealed a significant or marginal condition x anteriority interaction in the midline array [F(2,38) = 3.87, p = .032] and temporal [F(2,38) = 2.51, p = .098] arrays, in addition to a significant condition x hemisphere interaction in the temporal array [F(1,19) = 4.7, p = .043] that was also seen in the four-word average including the final verb. This helps to confirm that the sustained negativity to main clause wh-questions had a right anterior distribution.

A similar sustained anterior negative response to main clause wh-questions (13a) was observed in comparison to embedded clause wh-questions (13b). This impression was supported by ANOVAs run in the 300-2600 ms window. There was a significant or marginal main effect of condition in the parasagittal [F(1,19) = 3.2, p = .09] and temporal [F(1,19) = 4.71, p = .043] arrays, as well as a marginal condition x anteriority interaction in the midline array [F(2,38) = 2.98, p = .095]. As in the previous main clause wh- vs. yes/no-question comparison, these results indicated

15 The four-word average also had a high rate of blinks at the sentence-final word (‘said-Q’) that skewed the data for the entire four-word epoch even after blink correction. On account of this, the three-word average file was used instead for statistical computation of this time window in order to maximize signal-to-noise ratio.
that main clause wh-questions were more negative than embedded clause wh-questions through the end of the sentence, with a tendency toward an anterior distribution of this negative difference.

We return now to the N400-like effect elicited by main clause yes/no-questions (13c) at the main clause verb + Q-particle complex. When the main clause wh- and yes/no-question conditions (13a vs. 13c) were re-baselined and compared at this sentence-final position, ANOVAs performed in latency windows of 300-900 ms (for phasic RAN effects) and 500-800 ms (for P600 effects) revealed no significant or marginal differences. The N400 effect mentioned above, on the other hand, became more apparent (Figure 7b). ANOVAs run in the latency window of 300-500 ms showed a marginal condition x hemisphere interaction in parasagittal \( [F(1,19) = 4.01, p = .06] \) and temporal \( [F(1,19) = 3.84, p = .065] \) arrays, as well as a significant condition x hemisphere x anteriority interaction in the parasagittal array \( [F(4, 76) = 3.77, p = .008] \). These interactions showed that main clause yes/no-questions (13c) were more negative than main clause wh-questions (13a) over left central regions. However, although the relative effect was larger on the left, the absolute values of the negative peak in response to main clause yes/no-questions were larger on the right, following the standard distribution of the N400. In other words, since main clause wh-questions (13a) were more negative over the right side of the head (due to the RAN effect), the relative difference with main clause yes/no-questions (13c) turned out to be larger over the left side of the head.

Similar re-baselining at the sentence-final verb-Q position for the main clause wh-question (13a) vs. embedded wh-question (13b) comparison revealed no additional significant or marginal effects in the latency windows of 300-500 ms (N400), 300-900 ms (RAN), or 500-800 ms (P600).

In summary, main clause wh-questions (13a) elicited right-lateralized anterior negativity when compared to main clause yes/no-questions (13c), and anterior negativity with no evidence of lateralization when compared to embedded clause wh-questions (13b) in the four-word window.
extending from the embedded verb to the sentence-final main clause verb position. No comparisons at the main clause verb-Q position revealed any additional phasic RAN or P600 effects. There was however an N400-like effect in response to main clause yes/no-questions for the main clause wh- vs. yes/no-question comparison (13a vs. 13c). This effect may be related to a mismatch between a non-wh construction and a Q-particle, as mentioned above in Section 3.1.2.2 with regard to the N400 effect seen in response to embedded clause yes/no-questions at the embedded verb-Q position (Figure 7a) (see Section 3.2.4 for further discussion).

3.2 Discussion

To summarize, we have seen effects of anterior negativity at various positions between wh-words and the corresponding Q-particles of wh-questions in multiple comparisons (Figures 4-6, 8). The effects found in the present experiment (and the mono-clausal experiment discussed in Experiment 1) were right-lateralized in the majority of cases, although they were sometimes bilaterally distributed. There were no local RAN or P600 effects at either the embedded verb-Q or main verb-Q position of the corresponding wh-questions, while there were some lexical (P200 and N400) effects associated with wh- and non-wh-modifiers (Figure 4) and N400 effects at the verb-Q positions of both embedded and main clause yes/no-questions (Figure 7).

Recall that the remaining questions from Experiment 1 were (a) whether RAN effects would be elicited between wh-words and their corresponding Q-particles for bi-clausal wh-questions with embedded vs. main clause scope, (b) whether such effects would be phasic or sustained, and (c) whether there would be local RAN or P600 effects at the scope-marking verb-Q positions. We address each question below in turn, followed by a brief discussion of the other effects.

3.2.1 RAN in response to wh-Q dependencies

In the present experiment, both main clause and embedded clause wh-questions elicited RAN effects from the wh-modifier position in the embedded clause to the relevant Q-particle
position, whether at the end of the embedded clause for embedded clause wh-questions or of the main clause for main clause wh-questions. As shown in Figures 4 and 5, all wh-questions in comparison with all yes/no-questions elicited an effect of anterior negativity in the embedded object noun phrase region. As shown in Figures 6 and 8, main clause wh-questions in comparison to embedded clause wh-questions and main clause yes/no-questions elicited (right-lateralized) effects of anterior negativity. These effects began at the wh-phrase (the onset of the purported wh-Q dependency) and persisted up to the corresponding Q-particle (the end of the wh-Q dependency), providing confirming evidence that they are correlated in some way with the presence of a wh-Q dependency. In addition, Experiment 2 provided stronger evidence against a “sentence-end wrap-up effect” account of the RAN effects seen in Experiment 1. There were (R)AN effects not only at sentence end, but also in response to words in the embedded clause starting at the wh-modifier position, five words before the final word of the sentence. Therefore, we can conclude that (R)AN effects are elicited between wh-words and their corresponding Q-particles in not only mono-clausal but also bi-clausal wh-questions, and that they seem to correlate with the dependency between a wh-word and its corresponding Q-particle.

3.2.2 Latencies of RAN effects

Experiment 2 clearly showed that the RAN effects in Experiment 2 were slow potentials, as the effect started at the wh-modifier position and continued to the relevant verb-Q position. This suggests that the right-lateralized negativity at the verb-Q position of mono-clausal wh-in-situ questions in Experiment 1 was elicited because the wh-phrase immediately preceded the verb-Q position, rather than as a response to the verb-Q position itself.

However, one difference between the two experiments was that the RAN effects elicited in Experiment 2 were apparent across the entire sentence while those elicited by scrambled wh-questions in Experiment 1 were seen only towards sentence end. This difference cannot be
attributed to differences in the distance between a wh-element and its corresponding Q-particle across the two experiments, as the mean number of words between wh-phrases and Q-particles collapsed across embedded and main clause wh-questions in the bi-clausal Experiment 2 was 2.4, while that in the mono-clausal Experiment 1 was 3. Instead, it may have something to do with the bi-clausal structure of the stimulus materials. In Experiment 2, 73% (100 out of 137) of wh-questions were bi-clausal; the only mono-clausal wh-questions were those of a single filler condition. On the other hand, in Experiment 1, only 20% of wh-questions (one filler condition: 25 out of 125 wh-questions) were bi-clausal. Thus when participants saw wh-elements in Experiment 2, they may have immediately expected a bi-clausal structure. This may have in turn caused an earlier onset of the RAN effect, as participants may have anticipated that some of the wh-Q dependencies (main clause wh-questions in particular) were going to be long (see Kluender and Münte, 1998 for a similar result in German wh-questions, and Frazier and Clifton, 1989 for increased processing costs for crossing a clause boundary).

3.2.3 Wh-Q resolution—no local RAN or P600 effect?

Just as in Experiment 1, Experiment 2 revealed no local RAN or P600 effect at the verb-Q positions at which wh-scope was disambiguated, either at the embedded verb-Q position for embedded clause wh-questions or at the main verb-Q position for main clause wh-questions.

3.2.4 Other ERP effects

Besides the RAN effect, several other effects were evident in Experiment 2. These effects included P200 effects in response to non-wh-adorjectives (‘new’) and wh-classifiers (‘what-cup-of’), an N400 effect in response to non-wh modifiers (see fn. 10), and small N400 effects in response to Q-particles in yes/no-questions.

The P200 effects were consistent with the finding of Experiment 1 that graphic complexity induces a larger P200 response. While *donna* ‘what.kind.of’ is written in all phonemic characters
(kana) as どんな, 97.5% of the adjectives such as atarashii ‘new’ 新しい included Chinese characters (kanji) that require more strokes to write and are graphically more complex. The latter elicited a larger P200. Likewise, although the numeral classifier pairs had the same kanji vs. kana ratio for wh- vs. non-wh-classifiers, wh-classifiers (‘what-cup-of’) elicited a larger P200, probably due to the remaining stroke count differences between the character ‘what’ 何 (higher stroke count) and the numeral characters used, such as ‘one’ 一, ‘two’ 二, ‘three’ 三, and ‘four’ 四 (lower stroke count).

Yes/no-questions elicited small but consistent N400 effects at two sentence positions, namely, at the embedded clause verb-Q position in response to embedded clause yes/no-questions (Figure 7a) and at the main clause verb-Q position in response to main clause yes/no-questions (Figures 7b and 8)\(^{16}\). These are likely to be effects of seeing an unexpected Q-particle in a sentence that otherwise could have ended as a declarative. That is, if there is no Q-particle at the end of a main clause yes/no-question, such as Senmu-ga atarashii pasokon-o katta-to keiri-no kakaricho-ga iimashita-ka ‘Did the accounting manager say that the director bought a new computer?’, the sentence would end as a declarative, as in Senmu-ga atarashii pasokon-o katta-to keiri-no kakaricho-ga iimashita ‘The accounting manager said that the director bought a new computer.’ Although there were many more questions than declaratives in the experimental materials (275 questions (79%) of the 350 experimental sentences), participants might still have expected declaratives by default, by virtue of their life experience. We also extend the same idea to embedded clause yes/no-questions, in that the parser was not expecting a Q-particle at the embedded verb position of embedded clause yes/no-questions. Since non-wh constructions do not require a Q-particle, there can be a mismatch effect when non-wh constructions are followed by a Q-particle, as independently shown in Miyamoto and Takahashi (2002).

\(^{16}\) This effect is unlikely to be due to the word length or frequency of ‘say’ and ‘ask’ verbs used for the two conditions, as each pair was matched for word length, and there was no statistically significant difference in the frequency of the two types of verbs (see Section 5.2.2).
4. General Discussion

The two experiments showed that both mono-clausal and bi-clausal Japanese wh-questions elicited right-lateralized anterior negativity (RAN) between wh-words and corresponding Q-particles relative to their yes/no-question counterparts. This pattern of results is similar to ERP effects seen between wh-fillers and gaps in English and German (and scrambled elements and their gaps in Japanese), and suggests a reliable neural processing correlate of the dependency between Japanese wh-elements and Q-particles, but with a right- rather than left-lateralized distribution. We will address some related issues below.

4.1 LAN vs. RAN

We have seen that both filler-gap dependencies and wh-Q dependencies elicit anterior negativity, often in the form of slow waves. As discussed above, filler-gap dependencies have been reported to elicit sustained left anterior negativities (King and Kutas, 1995a; Münte and Kluender, 1998; Fiebach et al., 2001, 2002; Felser, et al., 2003; Phillips, et al. 2005), which is in line with reports of similar effects caused by holding consonant strings and nonsense syllables in verbal working memory (Ruchkin et al., 1990, 1992; also see Münte et al., 1998 for sustained LAN for working memory load caused by sentential stimuli).

We consider our RAN effects analogous to these LAN effects for several reasons. First, although our effects were often right-lateralized, they were always found bilaterally and never solely on the right side of the scalp. In addition, it should be kept in mind that ours is not the first nor the only study to report bilateral and/or right-lateralized slow negative potentials in response to syntactic dependencies. Although anterior negativities have been found to be left-lateralized to varying degrees in several studies (hence the name LAN), there have been several observations of bilateral distributions (see Vos et al., 2001 for a review of variation in the lateralization of anterior negativities across studies). In fact, almost all of the reports of sustained LAN effects discussed in
relation to filler-gap dependencies (King and Kutas, 1995a; Münte and Kluender, 1998; Fiebach et al., 2001, 2002; Phillips et al., 2005) show a bilateral negativity which may be larger on the left, and there has been a report of right-predominant anterior negativity with auditory presentation (e.g., Müller et al., 1997, see fn. 8). Therefore, as discussed in Sections 2-3, it seems feasible to interpret the anterior negative slow potentials found in our study as an index of working memory load due to the dependency between a wh-element and its corresponding Q-particle in Japanese, as the parser would have to actively maintain an unresolved wh-element until its scope is disambiguated by a corresponding Q-particle. However, the question remains: why RAN instead of LAN?

One may think that since the Japanese writing system uses many Chinese characters (kanji), which tend to be graphically complex (see Section 2.2.1), the processing of a long-distance dependency written with kanji in Japanese might cause right-lateralization. In fact, there have been a number of reports of right-hemispheric advantages in kanji processing (e.g., Nakagawa, 1994; Yamaguchi et al., 2002; Nakamura et al., 2005), and it may even be possible to link the hypothesized kanji processing effect to reports of sustained R(A)N for retaining visual images (Barrett and Rugg, 1989; Mecklinger, 1998). However, comparisons between scrambled and canonical word order sentences in Japanese (which presumably involve the same processing operations as filler-gap dependencies) have been reported to elicit (L)AN instead of RAN (Ueno and Kluender, 2003; Hagiwara et al., 2007; see also Kwon et al., in prep. for a similar result with Korean scrambling). Most importantly, the stimulus sentences used in one such study (Ueno and Kluender, 2003) were identical to those used in Experiment 1 of the present study (but different combinations of the experimental conditions were compared), with the same set of kanji. Thus it is not very likely that all Japanese dependencies elicit RAN due to the use of kanji; rather, the lateralization difference seems specifically linked to certain properties of Japanese wh-questions.
The next possibility is a difference in the type of missing information the parser has to deal with for wh-movement and wh-in-situ questions. As discussed in Section 1, LAN effects found in wh-movement languages have been tied to the processing of a wh-filler without a grammatical function and/or a semantic role until the parser finds the corresponding gap position. In contrast, what is ambiguous about Japanese wh-elements is their interrogative scope until they are linked with their corresponding Q-particles. Thus for both wh-movement and wh-in-situ languages, the parser must hold a wh-word with missing information for some time, but the type of information that is missing differs. It is syntactic for a displaced wh-phrase (namely, the appropriate grammatical function and semantic role—although the latter is also partially semantic) but logico-semantic for a wh-phrase in situ (interrogative scope). The computation of syntactic vs. logico-semantic properties could involve different neural generators and may well have contributed to the left- vs. right-lateralization differences found in the present study. However, although scope ambiguity seems to be the driving force for wh-Q dependencies, to the best of our knowledge there is no independent evidence to link logico-semantic processes to right-lateralization, as logical or mathematical processes have been linked to phasic or sustained posterior/parietal negativities in terms of ERPs (Ruchkin et al., 1991; Martín-Loeches et al., 2006), left hemisphere activation in terms of MEG (Yoshida et al., 1998), and inferior parietal and lateral frontal activation in terms of PET and fMRI (cf. Feh et al., 2007). Thus the “missing information type” account of the lateralization differences remains tenuous.

A somewhat related alternative explanation is an implicit prosody effect. Although stimulus sentences were presented visually in the present study, there have been reports of the influence of implicit prosody in ambiguity resolution with self-paced reading times (Bader, 1998; Hirose, 1999; Fodor, 2002). Participants may have been saying sentences to themselves silently or imagining corresponding prosody while reading sentences (more likely with an appropriate presentation rate
for doing so; see Section 5.1.3), and this could cause a tacit prosody effect. In fact, there is a well-known correlation between prosody and the scope of wh-questions in different dialects of Japanese. In Tokyo dialect this manifests as a high pitch on the wh-element itself followed by a sustained de-accented low pitch on all words within its scope (i.e., the lexically specified pitch accents of all the words within the interrogative scope are significantly attenuated) usually up to the corresponding Q-particle position (e.g., Ishihara, 2002; Deguchi and Kitagawa, 2002; Hirotani, 2003). A pitch analysis of a spoken version of our sample stimuli (Ueno, 2003) suggests that our wh-questions follow this pattern as well, while there was no such pitch reduction in the yes/no-question counterparts. A number of studies report that the right hemisphere predominates in interpreting prosodic cues (e.g., Zatorre et al., 1992; Meyer et al., 2002), and there have been several reports of phasic ERAN/RAN effects for prosody mismatch both in terms of music (e.g., Patel et al., 1998; Koelsch et al., 2000; Koelsch and Jentschke, 2008) and sentential contour (e.g., Eckstein and Friederici, 2005, 2006). Thus we could link the right lateralization of the negativity in our data to an implicit prosody effect, in that participants may have been imagining the pitch contour specific to Japanese wh-questions within the domain of their scope. This may have caused more involvement of the right hemisphere and the subsequent right-lateralization of anterior negativity effects in response to our stimulus materials.\(^{17}\)

However, one could just as well claim that participants were imagining a lower pitch in the scope of a wh-element because they had not yet located the required Q-particle in the sentence string. In this sense, an effect of implicit prosody could be subsumed under the effect of the wh-Q dependency as part of the same scope disambiguation process.

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\(^{17}\) This must remain a speculation on our part, because it is impossible to infer source generators from the scalp distribution of ERP effects, and we were unable to perform current source density analyses given the limited number of electrodes used in this experiment. We feel that this speculation is nonetheless warranted, however, given prior research indicating left hemisphere sources for LAN and verbal working memory effects in general (Ruchkin et al., 1990, 1992). We merely assume that the additional influence of prosodic processing in these experiments may have skewed the scalp distribution of the anterior negativity to the right.
4.2 Wh-scope disambiguation

Given the present data, we propose that the scope of a Japanese wh-element is disambiguated in the following way. Upon recognizing a wh-element (with missing scope information), the parser registers the wh-element in a “scopeless-wh” buffer, holds off on assigning scope to this wh-element, and keeps it in the buffer until the corresponding Q-particle is located later in the sentence. This process causes an increase in working memory load between the wh-element and the Q-particle, similar to the working memory load postulated between a wh-filler and its gap in English or German, and results in sustained anterior negativity. However, this anterior negativity is right- instead of left-lateralized, possibly because participants implicitly imagine the prosodic contour of Japanese wh-questions, which in fact mirrors the interrogative scope. At the scope-marking Q-particle position, the parser associates the wh-phrase and the Q-particle (in other words, completes the wh-Q dependency), thus determining the interrogative scope of the question. However, in contrast to wh-movement languages, this interpretive process does not elicit any additional phasic RAN or P600 effects at the Q-position, most likely because it does not involve either the retrieval or syntactic integration of a displaced wh-filler (see Ueno and Kluender, 2003, Hagiwara et al., 2007, and Ueno and Garnsey, 2008, for late positivity effects in Japanese scrambling and relative clauses, where actual displacement of a filler is involved). Instead, the only necessary operation would be a linkage of the Japanese wh-element with its Q-particle in terms of interrogative scope (cf. Nishigauchi, 1990; Cheng, 1991). This process does not seem to elicit any discernible local effects, consistent with a previous reading-time study (Miyamoto and Takahashi, 2002) that reported no local slowdown at the corresponding verb-Q positions of embedded and main clause wh-questions.

From the above, one could argue that the scope of wh-in-situ is disambiguated by the incremental formation of a long-distance dependency with a corresponding Q-particle, rather than
by a local disambiguation operation that occurs only once the verb-Q position is encountered. If RAN really indexes working memory load as suggested in Section 4.1, the parser would prefer a shorter dependency for minimizing the working memory load. If this view is taken, the results of the present study are then also consistent with previous studies of the processing of Japanese wh-questions (Miyamoto and Takahashi, 2002; Aoshima et al., 2004) which suggest that the parser expects and actively seeks out a Q-particle following the appearance of a Japanese wh-element well before the actual Q-particle position. In a broader scheme, this view is not only compatible with a variety of processing models pertaining to filler-gap dependencies, including the first-resort over last-resort strategy (Fodor, 1978; Garnsey et al., 1989), the active filler strategy (Frazier and Clifton, 1989), and the minimal chain principle (de Vincenzi, 1991), in which the parser actively tries to associate an extracted wh-element with the first possible gap position, but with incremental (e.g., Inoue and Fodor, 1995) rather than with head-driven (e.g., Pritchett, 1992) models of language processing as well.

One may wonder whether these negative slow potentials are actually a variety of contingent negative variation (CNV), which has been related to anticipation and/or preparation for an impending event (McCallum, 1993). However, Ruchkin et al. (1995) showed that retention (i.e., working-memory-related) and preparation (i.e., CNV-like) operations result in slow waves that differ clearly from each other in terms of amplitude, distribution, and sensitivity to memory load (i.e., no effect of load for CNV), thus separating memory-related slow waves from anticipation/preparation-related CNV. Fiebach et al. (2001; 2002) reported that the amplitude of LAN increased as the length of wh-dependencies increased in German (but see Phillips et al., 2005 for a different result in English). Similarly, recall that in the present study, RAN appeared earlier for bi-clausal wh-questions with potentially longer wh-Q dependencies than for mono-clausal wh-questions, suggesting that the effect was sensitive to (potential) memory load (see Kluender and
Münte, 1998 for related effects in German). Thus both LAN and RAN waves seem to be memory-rather than anticipation/preparation-related, and therefore unlikely to be a type of CNV. Then the parser’s preference for shortening wh-dependencies in both wh-movement and wh-in-situ languages would reflect an attempt to minimize working memory load rather than the anticipation of the upcoming gap/Q-particle.

4.3 Summary and conclusions

This study investigated the processing of Japanese wh-in-situ questions using ERPs. Both mono-clausal and bi-clausal Japanese wh-questions elicited right-lateralized anterior negativity (RAN) between wh-words and corresponding Q-particles, relative to structurally equivalent yes/no-question control conditions. These results suggest a reliable neural processing correlate of the dependency between wh-elements and Q-particles in Japanese, similar to the ERP effects seen between wh-fillers and gaps in English and German, but with a right- rather than left-lateralized distribution. This result along with other behavioral studies (Miyamoto and Takahashi, 2002; Aoshima et al., 2004) suggests that the interrogative scope of a wh-element in a Japanese wh-question is disambiguated by the incremental formation of a long-distance dependency with its corresponding Q-particle, causing a working memory load for keeping track of the scopeless wh-element. The difference between right and left lateralization of the anterior negativity is possibly due to an implicit prosody effect related to specific pitch contours of Japanese wh-questions, which coincide with the domain of their interrogative scope. Future studies are planned to scrutinize the exact driving forces behind the right-lateralization of this anterior negativity by investigating the processing of different types of syntactic dependencies in Japanese.
5. Experimental procedures

5.1 Experiment 1

5.1.1 Participants

Twenty (11 female) native speakers of Japanese between 19 and 29 years of age (mean: 25) were included in the study. They were residents of the San Diego area and had been living outside Japan for less than two years. Participants had normal or corrected-to-normal vision, were right-handed, and had no neurological or reading disorders. Participants were reimbursed for their time.

5.1.2 Materials

Stimuli consisted of four versions of 200 mono-clausal questions, namely, (a) wh-in-situ questions, (b) yes/no-in-situ questions, (c) scrambled wh-questions (with the object displaced in front of the subject), and (d) scrambled yes/no-questions, as shown in Table 1 in Section 2. Scrambled conditions were included to increase the distance between wh-elements and Q-particles and to form the basis of another experimental manipulation, as reported in Ueno and Kluender (2003). 150 filler items consisted of four separate question types, namely, (a) ditransitives in canonical word order, (b) ditransitives with accusative-marked demonstrative objects scrambled within the verb phrase, preceding the dative objects, (c) ditransitives with accusative-marked demonstrative objects scrambled within the clause, preceding the nominative subjects, and (d) bi-clausal embedded clause wh-questions with wh-subjects. The 200 sets of stimulus sentences instantiating the four experimental conditions were placed in a Latin square design to create four parallel lists of 200 stimulus sentences, such that no one participant saw more than one sentence from each set. The 200 filler sentences were added to each list, and then each list was pseudo-randomized. The materials were divided into 20 sets of 20 sentences each.

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18 The total number of participants actually run was 27. However, due to experimenter error, four participants saw stimuli at a different presentation rate from the others, and their data had to be discarded. Three additional participants were excluded, one who exhibited excessive muscle tension that interfered with the EEG recording, and two who never returned for their second session.
5.1.3 Procedure

Participants were run in two sessions lasting about 2.5 hours each. Participants were seated in a reclining chair facing a computer monitor in a sound-attenuated chamber and wore an elastic cap mounted with tin electrodes. An illuminated rectangular border appeared uninterruptedly in the middle of the screen during presentation of experimental sentences for purposes of fixation. Stimuli were presented in Japanese characters basically one *bunsetsu* at a time with 650 ms duration and 650 ms stimulus onset asynchrony. A *bunsetsu* consists of one free morpheme (lexical word or pronoun) and the bound morpheme(s) associated with it (particles modifying the noun/verb), and is referred to as a “word” elsewhere in the present paper. The presentation rate of 650 ms per word is slower than rates used in many English studies, but was deemed optimal after consulting three native speakers of Japanese. (Given both the visual complexity of Chinese characters often used in Japanese and the fact that many of the Japanese *bunsetsu* translate as multiple English words, it is not surprising that readers needed more time per *bunsetsu*.) There was no interstimulus blank interval between *bunsetsu* for this experiment. The interstimulus interval between sentences was three seconds, and participants were given as much rest as they wished between sets of sentences. In order to engage participants’ attention, they were asked to answer a comprehension question regarding the immediately preceding sentence after every five sentences on average but at semi-random intervals.

5.1.4 Electrophysiological recording

The electroencephalogram (EEG) was recorded from 19 positions, including all standard positions of the international 10/20 system, using tin electrodes mounted in an elastic cap. Reference electrodes were positioned on the two mastoid processes, and the EEG was algebraically referenced off-line to the mean of the electrical activity recorded at these two electrodes. To detect blinks and lateral eye-movements for later correction, additional electrodes were placed beneath the
right eye and at the outer canthi of the two eyes. Impedances were kept below 5KΩ. The EEG was amplified with a bandpass of 0.01 to 100 Hz, digitized at 250 Hz, and stored on hard disk for off-line analysis. Data with excessive blinks were corrected using a spatial filter algorithm (Dale, 1994), and a band-pass filter set from 0.2 to 15 Hz was used on all the data prior to running analyses to reduce high frequency noise.

5.1.5 Data analysis

Measurements were taken of single-word averages to look for transient effects, as well as of four-word averages mid-sentence in the scrambled wh- and scrambled yes/no conditions to look for longer-lasting effects. Single-word averages consisted of 1000 ms epochs, including a 100 ms prestimulus baseline, while four-word averages consisted of 2700 ms epochs (4 x 650 ms SOA plus a 100 ms prestimulus baseline).

The statistical analyses were done separately on midline (Fz, Cz, and Pz), parasagittal (Fp1/2, F3/4, C3/4, P3/4, O1/2), and temporal (F7/8, T3/4, T5/6) electrodes. All analyses consisted of repeated measures ANOVAs run on mean amplitudes of specified latency intervals (P200: 200-300 ms; N400: 300-500 ms; phasic RAN: 300-600 ms; P600: 500-800 ms) unless otherwise noted. Midline analyses included two within-group factors, including two levels of experimental condition type and three levels of anterior/posterior sites. Parasagittal analyses included three within-group factors, including two levels of condition type, five levels of anterior/posterior sites, and two levels of hemisphere. Temporal analyses included three within-group factors, including two levels of condition type, three levels of anterior/posterior sites, and two levels of hemisphere. In addition, trend analyses were performed to investigate P200 and N350 effects (see Section 2.1.1). An alpha level of .05 was used for all statistical tests, with a p-value up to .10 considered marginally significant. The Huynh-Feld correction for lack of sphericity was applied whenever applicable.
(Huynh and Feldt, 1976). Original degrees of freedom are reported with the corrected probability level.

5.2 Experiment 2

5.2.1 Participants

Twenty (13 female) native speakers of Japanese between 19 and 29 years of age (mean: 23) were included in the study. They were residents of the San Diego area who had been living outside Japan for less than two years, but were a different group of Japanese speakers from those who participated in Experiment 1. Participants had normal or corrected-to-normal vision, were right-handed, and had no neurological or reading disorders. Participants were reimbursed for their time.

5.2.2 Materials

Stimuli consisted of four types of bi-clausal questions, namely, (a) embedded clause wh-questions, (b) main clause wh-questions, (c) embedded clause yes/no-questions, and (d) main clause yes/no-questions, as shown in Table 3 in Section 3. Recall that the stimuli in Experiment 1 elicited lexical effects in response to wh-words, namely a larger amplitude P200 related to stroke count, and an earlier and larger N350 component related to word length (Section 2.1.1). This made it impossible to use this sentence position for purposes of baselining subsequent averages in Experiment 1. In order to avoid eliciting N350 effects in Experiment 2, all wh- and non-wh-modifiers in the embedded object noun phrases were matched for word length. As shown in Table 6, half of the stimulus sets contained wh/non-wh adjective pairs with *donna* (どんな) ‘what.kind.of’ as the wh-modifier, and an adjective such as *atarashii* (新しい) ‘new’ as the non-wh counterpart. The members of each wh/non-wh pair had equal numbers of characters, but different ratios of

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19 The total number of participants actually run was 22. However, one participant showed low comprehension scores, and there was an equipment malfunction during the session of another participant. Thus their data were discarded.
Chinese characters (kanji) to phonemic characters (kana) (e.g., donna どんな ‘what.kind.of’ consists entirely of kana, while atarashii 新しい ‘new’ consists of one kanji and two kana segments), such that these stimulus pairs differed in total stroke count. This made it virtually impossible to avoid P200 effects related to graphic complexity in Experiment 2. The other half of the stimulus sets contained numeral classifier pairs, such as nan-bai-no (何杯の) ‘what-cup-of (how many cups of)’ as the wh-modifier, and ni-hai-no (二杯の) ‘2-cup-of’ as the non-wh counterpart, always written with three characters. Although the numeral classifier pairs had the same kanji ratio for each pair and were better controlled for stroke count than the adjective pairs, there remained moderate stroke count differences across wh/non-wh pairs. Wh- and non-wh-classifiers differed in one character out of three, e.g., nan (何) ‘what’ (seven strokes) vs. ni ‘2’ (二) (two strokes). Main clause verbs for (a) and (c) (‘say’ verbs) and for (b) and (d) (‘ask’ verbs) were matched for word length and kanji ratio. The token frequency (based on Amano and Kondo 2000) of the two groups of the verbs did not differ significantly.

--Table 6--

200 sets of sentences containing these four conditions were constructed. 150 filler items consisted of four types of declarative sentences or questions: (a) bi-clausal declaratives, (b) monoclausal ditransitive declaratives, (c) mono-clausal ditransitive yes/no-questions, and (d) mono-clausal ditransitive wh-questions. The 200 sets of stimulus sentences were placed in a Latin square design to create four parallel lists of 200 stimulus sentences such that no one participant saw more than one sentence from each set. The 150 filler sentences were added to each list, and then each list was pseudorandomized. The materials were divided into 10 sets of 35 sentences each.
5.2.3 Procedure

The procedure was the same as in Experiment 1 except for the following: participants were run in only one session lasting about 2.5 hours each; stimuli were again presented one word (or \textit{bunsetsu}) at a time with a stimulus onset asynchrony of 650 ms but with a duration of 450 ms; comprehension questions were this time inserted in the stimuli every seven sentences on average but at semi-random intervals. Following a modified Bonferroni procedure (Keppel, 1982) that allows up to [number of conditions -1] contrasts to maintain the same alpha level, an alpha level of .05 was also used for planned pairwise comparisons.\footnote{As specific comparisons were preplanned in the present study, we did not run omnibus ANOVAs, a choice justified by statisticians such as G. Keppel: When “tests designed to shed light on these particular questions are planned before the start of an experiment, ...a researcher is not interested in the omnibus F test—this test is more appropriate in the absence of specific hypotheses...analytical comparisons can be conducted directly on a set of data without reference to the significance or non-significance of the omnibus F test.” (Keppel, 1982: 106)}
Acknowledgements

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Note

The experiments were undertaken with the understanding and written consent of each subject.
References


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Table 1

Sample stimuli for Experiment 1

<table>
<thead>
<tr>
<th>a. Object wh-in-situ questions (wh-in-situ questions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;According to the local newspaper, what did that reckless adventurer finally discover?&quot;</td>
</tr>
<tr>
<td>Ano jimotono shinbun-ni yoruto</td>
</tr>
<tr>
<td>the local newspaper-to according</td>
</tr>
</tbody>
</table>
| その 命知らずの 冒険家が とうとう 何を 見つけたんですか。
sono inochishirazuno bokenka-ga toto nani-o mitsuketa-ndesu-ka. |
| the/that reckless adventurer-NOM finally what-ACC discovered- POL- Q |

<table>
<thead>
<tr>
<th>b. Yes/no-questions with demonstrative objects in situ (yes/no-in-situ questions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;According to the local newspaper, did that reckless adventurer finally discover that?&quot;</td>
</tr>
<tr>
<td>Ano jimotono shinbun-ni yoruto</td>
</tr>
<tr>
<td>the local newspaper-to according</td>
</tr>
</tbody>
</table>
| その 命知らずの 冒険家が とうとう それを 見つけたんですか。
sono inochishirazuno bokenka-ga toto sore-o mitsuketa-ndesu-ka.                  |
| the/that reckless adventurer-NOM finally that-ACC discovered- POL- Q             |

<table>
<thead>
<tr>
<th>c. Scrambled object wh-questions (scrambled wh-questions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;According to the local newspaper, what did that reckless adventurer finally discover?&quot;</td>
</tr>
<tr>
<td>Ano jimotono shinbun-ni yoruto</td>
</tr>
<tr>
<td>the local newspaper-to according</td>
</tr>
</tbody>
</table>
| 何を その 命知らずの 冒険家が とうとう 見つけたんですか。
nani-o sono inochishirazuno bokenka-ga toto mitsuketa-ndesu-ka. |
| what-ACC the/that reckless adventurer-NOM finally discovered- POL- Q |

<table>
<thead>
<tr>
<th>d. Yes/no-questions with scrambled demonstrative objects (scrambled yes/no-questions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;According to the local newspaper, did that reckless adventurer finally discover that?&quot;</td>
</tr>
<tr>
<td>Ano jimotono shinbun-ni yoruto</td>
</tr>
<tr>
<td>the local newspaper-to according</td>
</tr>
</tbody>
</table>
| それを その 命知らずの 冒険家が とうとう 見つけたんですか。
sore-o sono inochishirazuno bokenka-ga toto mitsuketa-ndesu-ka.                   |
| that-ACC the/that reckless adventurer-NOM finally discovered- POL- Q               |
Table 2

F values for the ANOVAs for wh vs. non-wh word comparisons in Experiment 1

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Effect (df)</th>
<th>P200</th>
<th>N350</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean Amp.</td>
<td>Peak Latency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>200-300 ms</td>
<td>250-450 ms</td>
</tr>
<tr>
<td>Midline</td>
<td>C (1,19)</td>
<td>4.28*</td>
<td>5.67**</td>
</tr>
<tr>
<td></td>
<td>C x A (2,38)</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Parasagittal</td>
<td>C (1,19)</td>
<td>4.01*</td>
<td>3.86*</td>
</tr>
<tr>
<td></td>
<td>C x H (1,19)</td>
<td>5.64**</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>C x A (4,76)</td>
<td>ns</td>
<td>2.37*</td>
</tr>
<tr>
<td></td>
<td>C x H x A (4,76)</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Temporal</td>
<td>C (1,19)</td>
<td>3.43*</td>
<td>6.84**</td>
</tr>
<tr>
<td></td>
<td>C x H (1,19)</td>
<td>20.03***</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>C x A (2,38)</td>
<td>7.87***</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>C x H x A (2,38)</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

C: Condition, A: Anteriority, H: Hemisphere

*p < .10
**p < .05
***p < .01
Table 3

Sample stimuli for Experiment 2

a. Embedded clause wh-questions

専務が どんなパソコンを買ったか 経理の係長が聞きましたか。
[senmu-ga donna pasokon-o katta-ka] keiri-no kakaricho-ga__kikimashita-ka.
director-N what.kind.of computer-A bought-Q accounting-of manager-N asked.POL-Q

‘Did the accounting manager ask what kind of computer the director bought?’

b. Main clause wh-questions

専務がどんなパソコンを買ったと経理の係長が言いましたか。
[senmu-ga donna pasokon-o katta-to] keiri-no kakaricho-ga__iimashita-ka.
director-N what.kind.of computer-A bought-that accounting-of manager-N said.POL-Q

‘What kind of computer did the accounting manager say the director bought?’

c. Embedded clause yes/no-questions

専務が新しいパソコンを買ったか経理の係長が聞きましたか。
[senmu-ga atarashii pasokon-o katta-ka] keiri-no kakaricho-ga__kikimashita-ka.
director-N new computer-A bought-Q accounting-of manager-N asked.POL-Q

‘Did the accounting manager ask if the director bought a new computer?’

d. Main clause yes/no-questions

専務が新しいパソコンを買ったと経理の係長が言いましたか。
[senmu-ga atarashii pasokon-o katta-to] keiri-no kakaricho-ga__iimashita-ka.
director-N new computer-A bought-that accounting-of manager-N said.POL-Q

‘Did the accounting manager say the director bought a new computer?’
Table 4

Points of comparisons and ERP effects

a. All wh

(AN to all wh, (AN to all wh) (RAN to main clause wh, (R)AN to main clause wh) (N400 to main y/n) N400 to all y/n) N400 to embedded y/n

Fig 4       Fig 5       Fig 6/7a       Fig 8       Fig 7b

[Director-NOM what.kind.of computer-ACC bought-Q/that] accounting-of manager-NOM asked/said-Q

b. All yes/no

[Director-NOM new computer-ACC bought-Q/that] accounting-of manager-NOM asked/said-Q

embedded verb-Q main verb-Q

‘Did the accounting manager ask what kind of computer the director bought?’
‘What kind of computer did the accounting manager say the director bought?’
‘Did the accounting manager ask if the director bought a new computer?’
‘Did the accounting manager say that the director bought a new computer?’
Table 5

F values for the ANOVAs for wh vs. non-wh modifier comparisons in Experiment 2

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Effect (df)</th>
<th>All Wh vs. All Yes/No</th>
<th>Adjective Pairs (どんな ‘what.kind.of’ vs. 新しい ‘new’)</th>
<th>Numeral Classifier Pairs (何杯の ‘what-cup-of’ vs. 二杯の ‘2-cup-of’)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>300-500 ms 500-700 ms</td>
<td>200-300 ms 300-500 ms 500-700 ms</td>
<td>200-300 ms 300-500 ms 500-700 ms</td>
</tr>
<tr>
<td>Midline</td>
<td>C (1,19)</td>
<td>ns ns</td>
<td>5.26** ns ns</td>
<td>3.81* ns ns</td>
</tr>
<tr>
<td></td>
<td>C x A (2,38)</td>
<td>3.40* ns</td>
<td>ns 5.28** ns ns</td>
<td>ns ns ns</td>
</tr>
<tr>
<td>Parasagittal</td>
<td>C (1,19)</td>
<td>ns 5.63**</td>
<td>8.20*** ns ns</td>
<td>4.26* ns ns</td>
</tr>
<tr>
<td></td>
<td>C x H (1,19)</td>
<td>ns ns</td>
<td>ns ns ns ns</td>
<td>ns ns ns</td>
</tr>
<tr>
<td></td>
<td>C x A (4,76)</td>
<td>6.97*** ns</td>
<td>3.76** 11.07*** 2.85* ns ns</td>
<td>ns ns ns</td>
</tr>
<tr>
<td></td>
<td>C x H x A (4,76)</td>
<td>ns ns</td>
<td>ns ns ns ns</td>
<td>ns ns ns</td>
</tr>
<tr>
<td>Temporal</td>
<td>C (1,19)</td>
<td>ns 10.02*** 6.80** ns 5.99**</td>
<td>4.18* ns ns</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C x H (1,19)</td>
<td>ns ns</td>
<td>ns ns ns ns</td>
<td>4.87** ns ns</td>
</tr>
<tr>
<td></td>
<td>C x A (2,38)</td>
<td>11.58*** 2.9* 10.51*** 21.35*** 3.53* ns ns</td>
<td>ns ns ns</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C x H x A (2,38)</td>
<td>ns ns</td>
<td>ns ns ns 2.48* ns ns</td>
<td>ns ns ns</td>
</tr>
</tbody>
</table>

C: Condition, A: Anteriority, H: Hemisphere

*p < .10
**p < .05
***p < .01
Table 6
Types in modifiers to the embedded object noun phrase

<table>
<thead>
<tr>
<th></th>
<th>Wh-modifiers</th>
<th>Non-wh-modifiers</th>
<th>Number of stimulus sets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjective pairs</td>
<td><em>donnna</em> ‘what.kind.of’</td>
<td>adjectives (e.g. ‘new’)</td>
<td>100</td>
</tr>
<tr>
<td>Numeral classifier pairs</td>
<td>wh-classifiers (e.g., ‘what-cup-of (how many cups of)’)</td>
<td>non-wh-classifiers (e.g., ‘2-cup-of’)</td>
<td>100</td>
</tr>
</tbody>
</table>
Figure Captions

**Figure 1.** (a) ERPs (n = 20) for all electrodes to wh-words and demonstratives, collapsed across sentence positions. (b) ERPs (n = 20) at Pz to four types of pronominal elements, collapsed across sentence positions.

**Figure 2.** ERPs (n = 20) for all electrodes relative to a 100 ms prestimulus baseline. Shown are the ERPs to the final verb-Q position (‘discovered-Q’) of wh-in-situ vs. yes/no-in-situ-questions. The isovoltage map is based on the mean difference calculated as the wh-in-situ minus yes/no-in-situ conditions for the 300-600 ms interval.

**Figure 3.** ERPs (n = 20) for all electrodes relative to a 100 ms prestimulus baseline following wh-words up to and including the verb-question particle complex. Shown are the ERPs covering the adjective, participant noun, adverbial, and verb-question-particle positions (‘reckless adventurer-NOM finally discovered-Q’) of scrambled wh- vs. yes/no-questions. The isovoltage map is based on the mean difference calculated as the scrambled wh minus scrambled yes/no conditions for the 950-2600 ms interval.

**Figure 4.** ERPs (n = 20) recorded from all electrodes relative to a 100 ms prestimulus baseline. Shown are the ERPs to all wh- vs. non-wh-modifiers.

**Figure 5.** ERPs (n = 20) recorded from all electrodes relative to a 100 ms prestimulus baseline. Shown are the ERPs to the embedded object noun phrase position (‘what.kind.of/new computer-ACC’ in Tables 3 and 4) of all wh- vs. yes/no-questions. The isovoltage maps are based on the mean difference calculated as the all wh minus all yes/no conditions for the 500-1250 ms, 500-700 ms, and 950-1250 ms intervals.

**Figure 6.** ERPs (n = 20) recorded from all electrodes relative to a 100 ms prestimulus baseline. Shown are the ERPs to the embedded verb position (‘bought-Q/that’) of main clause wh, embedded clause wh, and main clause yes/no conditions. The isovoltage maps are based on the mean
difference calculated as the main-wh minus embedded-wh conditions (above) and the main-wh minus main-yes/no conditions (below) for the 300-900 ms interval.

Figure 7. (a) ERPs (n=20) recorded from C4 relative to a 100 ms prestimulus baseline. Shown are the ERPs to the embedded verb position (‘bought-Q’) of embedded clause wh and embedded clause yes/no conditions. (b) ERPs (n=20) recorded from C4 relative to a 100 ms prestimulus baseline. Shown are the ERPs to the main verb position (‘said-Q’) of main clause wh and main clause yes/no conditions.

Figure 8. ERPs (n=20) recorded from all electrodes relative to a 100 ms prestimulus baseline. Shown are the ERPs to the region from the embedded to the main clause verb position (‘bought-Q/that accounting-of manager-NOM asked-Q’ in Tables 3 and 4) of main clause wh, embedded clause wh, and main clause yes/no conditions. The isovoltage maps are based on the mean difference calculated as the main-wh minus embedded-wh conditions (above) and the main-wh minus main-yes/no conditions (below) for the 300-2600 ms, 300-1950 ms, and 2250-2450 ms intervals.
Figure 1

(a) 

(b) 

---

who-ACC

what-ACC

that-person-ACC

that-ACC

---

N350

P200

---

what-ACC/who-ACC 何を/誰を

that-ACC/that-person-ACC それを/あのを

---

who-ACC 誰を (18 strokes)

what-ACC 何を (10 strokes)

that-person-ACC あのを (9 strokes)

that-ACC それを (6 strokes)
その命知らずの冒険家がとうとう何を見つけたんですか。

Yes/No-in-Situ:  ..that reckless adventurer-NOM finally what-ACC discovered-Q。

その命知らずの冒険家がとうとうそれを見つけたんですか。

Yes/No-in-Situ:  ..that reckless adventurer-NOM finally that-ACC discovered-Q。
Figure 3

Scrambled Wh: ...what-ACC that reckless adventurer-NOM finally discovered-Q.

Scrambled Yes/No: ...that-ACC that reckless adventurer-NOM finally discovered-Q.
Figure 4

---------- All Wh  what.kind.of/what-cup-of  どんな/何杯の

------- All Non-Wh  new/2-cup-of  新しい/二杯の
Figure 5

500-1250ms 500-700ms 950-1250ms

ΔΔΔΔ ΔΔΔΔ ΔΔΔΔ

μV

------------ All Yes/No

専務がどんなパソコンを買ったかと経理の係長が聞き言いましたか。
[Director-NOM what.kind.of computer-ACC bought-Q/that] accounting-of manager-NOM __ asked/said-Q.

専務が新しいパソコンを買ったかと経理の係長が聞き言いましたか。
[Director-NOM new computer-ACC bought-Q/that] accounting-of manager-NOM __ asked/said-Q.
専務がどんなパソコンを買ったと経理の係長が言いましたか。

[Director-NOM what.kind.of computer-ACC bought-that accounting-of manager-NOM __ said-Q.

専務がどんなパソコンを買ったか経理の係長が聞きましたか。

[Director-NOM what.kind.of computer-ACC bought-Q]    accounting-of manager-NOM __ asked-Q.

専務が新しいパソコンを買ったと経理の係長が言いましたか。

[Director-NOM new computer-ACC bought-that accounting-of manager-NOM __ said-Q.]
Figure 7

a. C4

N400

............ Embedded Wh

_____ Embedded Yes/No

b. C4

N400

............ Main Wh

_____ Main Yes/No
Figure 8

Main Wh-Embedded Wh

Main Wh-Main YN

300-2600ms

300-1950ms

2250-2450ms

-3.50

-3.15

-2.80

-2.45

-2.10

-1.75

-1.40

-1.05

-0.70

-0.35

0.00

0.35

0.70

1.05

1.40

1.75

2.10

2.45

2.80

3.15

3.50

μV

5 μV

0 1500 3000 ms

(R)AN

N400

(R)AN

N400

(R)AN

N400

(R)AN

N400

Main Wh

専務が どんなパソコンを買ったと経理の係長が言いましたか。
[Director-NOM  what.kind.of computer-ACC bought-that] accounting-of manager-NOM __ said-Q.

Embedded Wh

専務が どんなパソコンを買ったか経理の係長が聞きましたか。
[Director-NOM  what.kind.of computer-ACC bought-Q] accounting-of manager-NOM __ asked-Q.

Main Yes/No

専務が 新しいパソコンを買ったと経理の係長が言いましたか。
[Director-NOM new computer-ACC bought-that] accounting-of manager-NOM __ said-Q.