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The interaction of syntax, prosody, and discourse in licensing French *wh-in-situ* questions☆

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Abstract

The current experiment addresses the proposal by Cheng and Rooryk (2000) that *wh-in-situ* questions in French are marked by an obligatory rising contour, which is the result of an intonation morpheme [Q:] in C. Twelve native French speakers participated in a production study in which they produced the target interrogatives, along with a range of similar sentences. While most participants were perceived to assign *wh-in-situ* questions a sentence-final rise, a minority was not. Moreover, the rise associated with *wh-in-situ* was smaller than the rise exhibited in *yes–no* questions, which C&R claim to be licensed by the same morpheme. Given that these two results are unexpected under C&R's account, we conducted a further acoustic analysis of the productions, which revealed that for sentences lacking a sentence-final rise, the *in situ wh*-word had an elevated high pitch accent. A statistical analysis shows a negative correlation between the height of the pitch accent assigned to the *wh*-word and the presence and height of the sentence-final rise, indicating that instead of the sentence-final rise for *wh-in-situ* questions being *optional*, it may instead be variable and predictable by focus placed on the *wh*-word, for discourse reasons. We discuss three possibilities for the status of the intonation morpheme concerning *yes–no* and *wh*-questions and the role of information structure in French *wh-in-situ* questions.

Keywords: French; Syntax; Interrogatives; Intonation; Prosody; *wh-in-situ*

1. Introduction

Although the parametric landscape of *wh*-question formation is well known, the motivation for why *wh*-questions terms are displaced in some languages or stay *in situ* in others still remains a puzzle. While approximately 240 languages found in the World Atlas of Language Structures (WALS) display obligatory displacement of interrogative phrases to the initial position of the sentence, approximately 540 do not require interrogative phrases to be sentence-initial (Dryer, 2008). In a generative framework, such variation among languages is accounted for by positing features that are encoded in the morphosyntax, which either trigger movement or not (*cf.* Chomsky, 1995).

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While this type of account explains a cross-linguistic difference between two sorts of languages—those that largely require movement and those that do not—the existence of the 20-some languages in WALS, such as French and Chicheŵa (and even English), which allow for optional movement forces a reevaluation of the range of factors governing this linguistic variation. A growing number of recent studies have sought to identify the prosodic and pragmatic factors governing the variation in *wh*-questions (Cheng and Rooryk, 2000; Kučerová, 2007; Pesetsky, 2000; Richards, 2006, 2010; Wagner, 2005, 2006). The conclusion arising from this work is that it is likely that a host of factors play a role in licensing this variability both within and across languages. It is therefore of great interest to identify these factors and arrive at a principled explanation of how they interact.

The present work investigates the relationship between prosody and syntax, and the extent to which it is mediated by other aspects of the discourse, such as information structure. We target French as a case study for two main reasons. First, there is substantial variability in *wh*-question formation within this language, which makes it an excellent testing ground for such an investigation. Second, Cheng and Rooryk (2000) presented a clear and testable model for how such variation is licensed in French, appealing to the role of pragmatic presupposition and to intonation as it is encoded in morphosyntactic features. Here we report the results of an experimental study of the intonation of French interrogatives, focusing specifically on the licensing of *wh-in-situ* questions in a language that otherwise has widespread movement. We show that an account incorporating the role of information structure and prosody goes a long way toward both accounting for and predicting the range of inter- and intraspeaker variability. Furthermore, our results raise broader questions about the grammatical features licensing *wh-in-situ* itself and the nature of the relationship between prosody and syntax.

The structure of the paper is as follows. In section 2, we present background on interrogatives in French, with a focus on *wh-in-situ* questions. We then transition into a summary of the specific details of Cheng and Rooryk (2000)'s proposal in section 3, outlining the predictions this proposal makes for the prosodic realization for *wh-in-situ* questions in French. In section 4, we briefly review the previous experimental work that has been appealed to in the objections to C&R's account, which has made claims relevant to the intonation contour of these questions. We show that the choice of experimental methodology makes reliance on these studies as support for the apparent optionality of a rising contour of *wh-in-situ* questions problematic at best. In section 5, we present a production experiment involving native French speakers, which directly investigates the prosody of French *wh-in-situ* questions. To preview our results, we show that in lieu of an optional rise, we find inter- and intraspeaker variability in the presence and height of the rise, which appears to be governed by both syntactic and discourse factors. Finally, in section 6, we discuss the implications of our findings for Cheng and Rooryk's (2000) original proposal and for future research on the licensing of interrogatives and the relationship between syntax, prosody, and the discourse context.

2. French *wh-in-situ* questions

French manifests a variety of question strategies, as illustrated in (1). Here, we present just a subset of the many surface forms available to express the same *wh-question* ''Where are you going?'' (See also Mathieu, 2009.)

(1) Multiple surface forms for ''Where are you going?''

a. Où est-ce que tu vas?
where QUES you go
'Where are you going?'

b. Où vas-tu?
where go-you

c. Où tu vas?
where you go

d. Tu vas où?
you go where

As this example makes clear, French allows both moved (1a)–(1c) and *in situ* (1d) strategies for the same question. It thus presents us with a unique empirical testing ground for an investigation of the factors governing variation among interrogatives within a language.

Wh-in-situ questions such as (1d) are true information-seeking questions and do not have the force of an echo question, which are identical on the surface. However, both seem to be licensed by distinct aspects of the discourse. It has been argued that echo questions must be entailed by previous discourse (Artstein, 2002) while *wh-in-situ* content questions are most felicitous when they appear as part of a presupposed context, in which the speaker and hearer share relevant information as part of their common ground (Boeckx, 2000; Chang, 1997; Cheng and Rooryk, 2000). For example, (1d) may be most natural when uttered in the course of a conversation about plans for the evening or a summer vacation, or when a 'going out' event is clear from the context and the only information that remains unknown is the destination.

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Now, while moved *wh*-questions by definition encode a surface-level cue to their question status (in the form of the moved *wh*-word), which may be accompanied by the *est-ce que* question marker (1a) or subject-auxiliary inversion (1b), in *wh-in-situ* questions, the *wh*-word remains in its base position. Following an idea by Wachowicz (1978) that languages all have overt cues for marking *wh*-questions (*e.g.*, in the form of a moved word or a question marker), Cheng and Rooryk (2000) (hereafter, C&R) proposed that French *wh-in-situ* content questions do in fact encode a surface-level cue to question status, in the form of a sentence-final rising intonation contour. They further claim that this rising contour is identical to the one exhibited in polar *yes–no* questions.

Thus, a *wh-in-situ* content question, such as (2), should rise at the end, similar to *yes–no* questions such as the one in (3), but unlike moved *wh*-questions such as (4), which are claimed to have no such obligatory rising contour.

(2) Elle a mis **quel élément** au milieu?
she has placed which shape in.the middle
'She placed which shape in the middle?'

(3) Est-ce qu' elle a mis **cet élément** au milieu?
QUES.PRT she has placed this shape in.the middle
'Did she place this shape in the middle?'

(4) **Quel élément** est-ce qu' elle a mis au milieu?
which shape QUES.PRT she has placed in.the middle
'Which shape did she place in the middle?'

This characteristic rising intonation, they claim, is dictated by a special interrogative morpheme, merged in C, which is implicated in both *yes–no* questions such as (3) and *wh-in-situ* questions. C&R further claim that these questions require contexts with strong presuppositions, observing that a negative response to such questions is infelicitous: it should be somewhat odd if a speaker were to respond to (1d) by saying, ''Nowhere'' or to (2) by saying that there wasn't any shape to which that description applied.

C&R's model offers an attractively simple formalization of the conditions under which *wh-in-situ* are cross-linguistically allowed. On their view, *wh-in-situ* questions are licensed in essentially the same way in all languages: by a complementizer that leaves a prosodic stamp at the surface level, signaling the interrogative nature of these sentences without resorting to overt *wh*-movement or a lexical question marker. Because it accounts for both the variability of interrogative formation in French, as well as both the phonetic realization and discourse relevance of *wh-in-situ* questions, C&R's proposal has since gained much notice in the syntactic literature. In spite of the elegance of their proposal, however, objections to their proposal have been raised on two grounds.

First, a number of researchers (*e.g.*, Adli, 2004; Baunaz, 2011; Baunaz and Patin, 2011; Hamlaoui, 2008, 2010; Starke, 2001; Vergnaud and Zubizarreta, 2001; Zubizarreta, 2001) have questioned C&R's claims about the discourse status of *wh-in-situ* questions, pointing out that negative responses *are* allowed in certain contexts and that *wh-in-situ* questions are licensed in certain syntactic environments that C&R would predict would not be possible.[1] Second, some researchers (*e.g.*, Adli, 2004; Hamlaoui, 2008, 2010; Zubizarreta, 2001) have also called into question the idea that *wh-in-situ* questions are required to have a rising intonation contour. Though there is much to say on the pragmatics of *wh-in-situ* questions, we set discussion of this matter aside in this paper, and address this issue in a separate paper (Déprez et al., in press). Here, we focus on the second objection and experimentally investigate the nature of the rising intonation contour and its supposed obligatory status. In doing so, it will become necessary to reference the role of the discourse context—specifically, information structure—but we keep that discussion brief in the interest of space.

3. Summary of Cheng and Rooryk (2000)'s proposal

C&R begin by assuming, as have others (Bošcović, 1998; Boeckx, 2000; Déprez, 1994) that French questions are characterized by the presence of a strong Q-feature in C^0. C&R argue that this Q-feature can be spelled out morphologically as the question marker *est-ce que* or remain null. As (3) and (4) illustrate, *est-ce que* can appear with both *yes–no* and moved *wh*-questions. Based on this observation C&R argue that this underspecified instantiation of the Q-feature can be checked and semantically specified in two different ways. In *wh*-questions, the *wh*-phrase moves overtly

[1] Some of the objections to C&R's account also apply to Bošković (1998) and Chang (1997).

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to spec, CP to check the Q feature, endowing C with [+wh]. In *yes–no* questions, a null intonation morpheme [Q:] (with *yes–no* intonation) is merged in spec, CP and checks the Q feature, specifying the question as *yes–no*.

However, French can also have questions without an *est-ce que* question marker, as illustrated by the moved *wh*-questions in (1b-c) above, the *wh-in-situ* questions in (1d) and (2) (repeated here), and the *yes–no* question in (5), which is identical to (3) above, without the question marker.

(2) Elle a mis **quel élément** au milieu?
she has placed which shape in.the middle
'She placed which shape in the middle?'

(5) Elle a mis **cet élément** au milieu?
she has placed this shape in.the middle
'Did she place this shape in the middle?'

In these cases, C&R claim, the strong Q feature in C^0 is not instantiated as an overt question marker and can be checked at Spell-Out in two different ways. It can be checked through overt *wh*-movement to Spec, CP as in (1b-c) or *via* the insertion (Merge, *cf.* Chomsky, 1995) of the null intonation morpheme ([Q:]) in the head of C.[2] This intonation morpheme is claimed to carry a rising *yes–no* contour by default. As a result, every question in which it is implicated (*yes–no* questions with and without *est-ce que* and *wh-in-situ* questions) is predicted to have the same rising intonational contour. Since no such intonation morpheme is involved in moved *wh*-questions, these interrogatives are not predicted to require any specific contour.[3]

Now, like *est-ce que*, the null Q-morpheme [Q:] is also semantically underspecified, and is thus also compatible with both *yes–no* and *wh*-questions. C&R claim that if there is nothing for the underspecified morpheme to attract, then it will be interpreted as [Q: y/n] by default, and at Spell Out, the underspecified intonation morpheme will be realized in the form of yes/no intonation. However, if there is a *wh*-feature in the array, the underspecified morpheme can trigger covert movement of the *wh*-feature to C^0 at LF to allow for semantic specification. This movement then sets the value of [Q:] to [Q: wh]. (In cases of overt *wh*- movement, the purpose of the movement is both to check the Q feature and specify C^0 as [+wh], but in the case of covert movement, in which the null intonation morpheme checks the Q feature, the purpose of covert *wh*-movement is only to semantically specify [Q:] as [Q: wh].) In this case, because the intonation morpheme is in C^0, the question will have a rising *yes–no* intonation; however, because the intonation morpheme has been specified as [Q: wh] by covert movement of the *wh*-feature, the form of the question is *wh-in-situ*. Moreover, by arguing that merger of the rising intonation morpheme is driven by the need to check the strong Q feature of C, C&R predict that *in situ* questions without such intonation should be ungrammatical, and hence unattested.

In sum, the system proposed in C&R distinguishes between five separate cases:

(a) An overt instantiation of the Q feature spelled as the underspecified *est-ce que* in C, which is checked and specified as [+wh] at Spell Out through overt *wh*-movement (*cf.* (4))
(b) The same *est-ce que* in C as in (a) checked at Spell Out through the insertion/Merge of the intonation morpheme in Spec, CP, and specified at LF as [+y/n] by the default semantic value of the intonation morpheme (*cf.* (3))
(c) A covert instantiation of the strong Q feature in C, checked and specified at Spell Out with overt *wh*-movement (*cf.* (1c))
(d) The covert Q feature in C as in (c), checked at Spell Out *via* the insertion/merger of the intonation morpheme, which is specified at LF as [Q: y/n] *via* the default semantic value of the morpheme (*cf.* (5))
(e) The same null C as in (c) and (d), checked *via* the insertion of the intonation morpheme in C, which is specified at LF as [Q: wh] *via* covert *wh*- movement (*cf.* (2))[4]

[2] C&R do not provide an account of the role of inversion in their model, and so do not explicitly distinguish between 1(b) and (1c). If *wh*-movement is sufficient to check the strong Q feature of C, the question of why inversion should ever arise, and of why it can apparently be optional as in (1b) *vs* (1c) remains unanswered. For our purpose, however, it is sufficient to note that the null intonation morpheme is never involved for the licensing of moved *wh*-questions. These questions are thus not predicted to involve any obligatory final rise contour.

[3] See Di Cristo (1998), Di Cristo and Hirst (1993) and Vion and Colas (2006) for discussion of the intonation of *yes–no* questions in French.

[4] A reviewer raised a question about two further cases: (f) instantiation of the Q feature as *est-ce que* accompanied by *wh-in-situ* and (g) the covert Q feature accompanied by overt *wh*-movement and rising intonation. Although C&R do not appear to explicitly rule out such cases, we take it that their system implicitly rules out such possibilities—and these cases appear to be unattested. With regards to (f), *est-ce que* is claimed to be underspecified, so it needs to be both checked and specified. If there were no *wh*-movement to perform these functions, then the intonation morpheme would need to be merged in Spec, CP, to check the feature. However, this would also result in specifying the question as [+y/n] under C&R's system, and there should therefore be no *wh-in-situ*. With regards to (g), if there is no overt Q marker, then either the intonation morpheme checks the feature, and is then further specified, or *wh*-movement checked the feature. If the former, there is no motivation for *wh*-movement. If the latter, then the marker will be valued as [+wh], and since the intonation morpheme was never implicated, there should be no rising contour.

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The last case (e) corresponds to the *wh-in-situ* question, which is the focus of this paper.

C&R's proposal about the integral role that prosody plays in the syntactic licensing of *wh-in-situ* questions makes specific predictions about the phonetic realization of these questions: Cases (b), (d) and (e) above should all have a sentence-final rising contour equal to that of *yes–no* questions, since all implicate the same morpheme, and this contour should be obligatory, because in all of these cases, the intonation morpheme serves to check the strong Q feature of C, an operation whose absence leads to derivational crash and ungrammaticality.

The supposedly obligatory character of the rising contour of French *wh-in-situ* questions has been questioned in the literature. Objections to this aspect of C&R's proposal often appeal to either informal intuitive judgment data or to previous studies on French interrogatives. In the next section, we review a core set of studies generally cited in these rebuttals. While we grant that these studies may show that French *wh-in-situ* questions may be produced without the acute rising contour of a *yes–no* question, a range of flaws or gaps in the experimental designs lead us to call into question conclusions based on such results. The fact that experimental research directly addressing C&R's claims is lacking thus provides motivation for our research on this topic.

4. Previous research on the prosody of French *wh-in-situ* questions

A number of researchers have argued that although a final rise is evident across many realizations of French *wh-in-situ* questions, findings from a small set of previous studies on French interrogatives should lead us to doubt the status of this contour as a hallmark characteristic of this question type. Indeed, based on this previous research, Hamlaoui (2008) refers to evidence from notes that there is ''no obligatory rising intonation associated'' with these questions and therefore that there is ''no serious empirical reason to posit the existence of an intonation morpheme'' (p. 11). However, when we revisit the experimental evidence on French interrogatives that is said to provide evidence for an optional rising contour for these sentences (most notably Adli, 2004, 2006; Beyssade et al., 2007; Delattre, 1966; Wunderli, 1983, 1984, among few others), we believe conclusions about the prosody of *wh-in-situ* questions based on them to be on shaky ground.

To begin, Delattre (1966) did not directly gather data of *wh-in-situ* questions, and was instead interested in describing the variety of intonational contours observed across a range of sentences, which included declaratives as well as various types of questions. Likewise, while Beyssade et al. (2007) analyzed the prosody of a number of *wh*-questions, they did not appear to have analyzed the prosody of *wh-in-situ* questions in particular. Furthermore, while Wunderli (1983, 1984) recorded speakers producing a range of sentences, among them *wh-in-situ* questions, these sentences were apparently read with no previous discourse context. The absence of such a context may have had two consequences. First, speakers might not have read the sentences as they would be naturally delivered in context, if they were read one after another. Second, the questions could have been interpreted as echo questions, in which case they would not necessarily need to be accompanied by a rising contour. Third, all of the *wh*-phrases appear to have been sentence-final, which could have conflated pitch accent of the *wh*-word with that of the end of the utterance.

In experimental work directly addressing C&R's proposal, Adli (2004, 2006) reported the results of ''une approche qualitative d'interview semi-directif'' (a qualitative interview) with 20 native French speakers. Adli (2004, 2006) argued that his data called into question both the restrictions on the syntactic environments in which these questions can appear as well as the necessary rising contour. Leaving the first objection aside, we focus on the evidence bearing on the necessity of rising contour.

Two subsets of these speakers (a group of three and a group of five) were asked to produce and describe the intonation contour for a *yes–no* question without *est-ce que* and an *wh-in-situ* question (in which the *wh*-phrase was sentence-final). Each group received one pair of sentences, which was different for each group. The contours of these sentences were sketched on a paper ''in order to help subjects to give more accurate verbal descriptions'' (p. 183). Each of the speakers reported that the *yes–no* questions obligatorily ended with a rising contour, but that the *wh-in-situ* questions could have either a rising or falling contour. Based on this pattern of results, Adli (2006) concluded that *yes–no* and *wh-in-situ* questions have different intonational contours, and that there is therefore a lack of evidence in support of C&R's proposal. However, this study does not offer definitive conclusions about the intonation of *wh-in-situ* questions in French, given the small number of items and participants, the structure of these sentences, the absence of a discourse context, and a methodological approach that was not designed to tap into what participants do, but rather to elicit their metalinguistic judgments about what they do.

Indeed, it is difficult to see how the combined set of previous studies (both those described here and others occasionally cited in the relevant literature) present us with a clear picture of the intonation of French *wh-in-situ* questions. Thus, there remains a lack of evidence addressing this particular aspect of C&R's proposal. By overcoming the problems of these previous studies and taking into account the pragmatic felicity conditions of these sentences, our research demonstrates that rather than apparent *optionality* of a sentence-final rise, there is principled syntactic- and discourse-governed *variability* in both the presence and extent of such a rise. We therefore obtain what we see as nuanced support for C&R's claims, accompanied by questions that we hope will drive further research in this area.

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5. Current study

5.1. Method

5.1.1. Stimuli

Our stimuli consisted of sentences representing seven conditions: (1) declaratives, (2) *yes–no* questions with *est-ce que*, (3) *yes–no* questions without *est-ce que*, (4) *wh-in-situ* content questions, (5) *wh-in-situ* echo questions, (6) moved *wh*-questions with *est-ce que*, and (7) moved *wh*-questions with subject-auxiliary inversion. The sentences were structured so as to be minimally different in order to provide the cleanest comparison across conditions. The first three conditions were intended to establish a baseline for cases in which the intonational contour was predictable and uncontroversial in neutral contexts. The fourth condition was our main target. The last three conditions were included to complete the paradigm and to allow for additional comparison among similar sentences. In the explication of our analysis, we focus on the comparison between the first four conditions, referring to the last three as they may provide additional perspective on participants' intonational contours.

The full list of target sentences, with annotated intervals indicated, is provided in Appendix A. In order to prevent pitch perturbation by obstruents, we used words consisting of sonorants as much as possible in target sentences, although it was not possible to avoid certain stops, such as the [k] in *quel* or *est-ce que*. All target sentences had a subject pronoun: *il* (he) or *elle* (she). In order to prevent sentence-final rises from merging with potential pitch accents of *wh*-words, the *wh*-words were never sentence-final; all sentences had an NP complement and/or post-VP adjunct. Each of the sentences was annotated using Praat (Boersma, 2001; Boersma and Weenink, 1999–2011), segmenting the subject NP and auxiliary, main V, object NP, question word or corresponding determiner, and VP adjunct.

All sentences were preceded by a two- to three-sentence discourse context, which involved a 'choice scenario'. This feature was intended to satisfy the pragmatic felicity conditions of the target questions and to prevent participants from reading the sentences with a list intonation. There were five unique discourse contexts, each with seven corresponding types of syntactic environments, for a total of 35 items. An example of one such discourse context and the seven target sentence types is included in Appendix B.

The 35 test items were presented one at a time on a computer screen, each separated from the next by a blank screen. Sentences were divided into three distinct blocks, with a short intervening break. Participants were randomly assigned to one of three block orders in a Latin-square type format. Similar sentence types (*e.g.*, both types of *yes–no* questions; both types of *wh-in-situ* questions; declaratives and *yes–no* questions without *est-ce que*, *etc.*) were separated by blocks. The order of the sentences was randomized within each block per participant.

5.1.2. Participants

12 French native speakers (5 F, 7 M) participated. All participants were compensated $8 for their time. Ten of the speakers were from France, and two were from Switzerland. None of the participants reported a previous history of or showed any signs of having a speech disorder. *Post hoc* comparison of the data and demographic information indicated no apparent correlation in performance with age, geographic region, or amount of time spent in the US.

5.1.3. Recording procedure

Participants were recorded in a sound-attenuated recording booth using a high quality microphone (AT 4040 Cardioid Capacitor) with a pop filter. Their speech was amplified through an ART TubeMP microphone pre-amplifier (JVC RX 554V) and was digitized with 44.1 k sampling rate upon recording using Audacity. The participants were told that they would see a series of sentences appear on the screen and were instructed to first read the sentences silently in their head and then to read them aloud as they were recorded. Participants were also told that if they made an error while recording, they should re-read the sentence, starting from the beginning. The entire recording sessions took approximately 30 min.

5.1.4. Analysis

All 35 sentences for each of the 12 speakers were isolated from the entire recording session using Audacity. These sound files were examined for naturalness using two measures. First, pitch accenting on lexical items within the sentence was examined to ensure, for example, that speakers assigned pitch accents to appropriate lexical items, that not every lexical item was accented (*cf.* Beyssade et al., 2007; Hamlaoui, 2008). Second, four native French speakers (who were living in France and were blind to the experiment) listened to each of the 420 files and coded them as 'natural' or not. 79% of the files were coded as 'natural' by three or four of the four coders. Only 11 of the 420 files were not coded as natural by any of the four coders. There was no discernible pattern of naturalness with respect to speaker or sentence type, although one speaker did obtain higher 'non-natural' scores than the others. We kept this outlier participant in mind in our subsequent analysis. Two types of data relevant to the intonation contour were collected for analysis: perception of sentence-final rise or fall and an acoustic analysis of the contour.

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5.1.4.1. Perception of sentence-final rise or fall. As a first pass, three research assistants familiar with the project were randomly assigned to three subsets of the files to review them for possible sentence-final rise or fall. This process allowed us to ensure that no tokens or participants presented problems in terms of perceptibility of final intonation contours. The sound files were then submitted to two coders with little to no knowledge of French and no knowledge of the research project for a more stringent coding of sentence-final rise or fall. Agreement between these double-blind coders was 90%.[5] All disagreements were then resolved by discussion between the two coders while listening to the target files and good exemplars of falls or rises produced by the same participant. The dependent measure of average sentence-final rise was then calculated for each speaker and each sentence type.

5.1.4.2. Acoustic analysis of contour. To quantitatively assess the intonation contour of our target sentences and to compare the intonation contour for *yes–no* and *wh-in-situ* content questions, we performed an acoustic analysis of F0 (fundamental frequency). Using our annotations, we targeted a region in each sentence from the onset of the *wh*-word or corresponding determiner (*e.g.*, *quel* or *cet*) to the end of the sentence. We then divided this region into 40 evenly spaced windows of approximately 19–20 ms each and calculated the average *F*0 value within each window to track the *F*0 movement. We then calculated the average *F*0 across the five tokens for each sentence type for each participant. This acoustic analysis process allowed us to make a comparison among sentence types and among speakers. All statistical analyses were performed using R (R Development Core Team, 1993–2011).

5.2. Predictions

We predicted that *yes–no* questions with *est-ce que* and *yes–no* questions without *est-ce que* should both be perceived to have and should acoustically exhibit, a final rise. By contrast, declarative sentences should not. Based on C&R's claims about *wh-in-situ* questions, we predicted that *wh-in-situ* content questions should pattern with the *yes–no* questions and exhibit a final rise. Predictions for the *wh-in-situ* echo questions were less clear, but there have been suggestions by Adli (2004), following Di Cristo (1998), that *wh-in-situ* content and echo questions would have the same contour. Indeed, if speakers were interpreting the *wh-in-situ* content questions as echo questions, we would expect no difference between the two. While it was also not clear what to predict for the moved *wh*-cases, however, we expected the strong possibility of a falling contour for moved *wh*-questions, given the absence of the intonation morpheme in these sentences and corpus results by Beyssade et al. (2007), which revealed a robust tendency for *wh*-questions to have a falling contour.

5.3. Results

5.3.1. Perception of sentence-final rise or fall

Among our seven sentence types, the key comparison is between the two types of *yes–no* questions and the *wh-in-situ* content questions, which C&R predict to exhibit a similar percentage of sentence-final rise—near ceiling in all three cases. In Fig. 1, we present the percentage of perceived final rise for these sentences. We also include the percentage of final rise for declaratives, which were not predicted to exhibit a sentence-final rise, as an additional baseline.

As predicted, declaratives showed little to no sentence-final rise, while the *yes–no* questions (both with and without *est-ce que*) displayed a sentence-final rise in nearly every instance: both of these percentages significantly deviate from chance by binominal tests both at the $p < .001$ level. At first glance, the above-chance ($p < .001$) percentage of sentence-final rise with *wh-in-situ* questions appears to support C&R's proposal. However, the differences between this sentence-type and each of the two *yes–no* sentences are significant by proportional tests at the $p < .001$ level. Cases in which *wh-in-situ* sentences did not display a sentence-final rise led us to take a closer look at the data. Indeed, upon further examination, we noticed the emergence of two groups of participants, as captured in Fig. 2.

While the majority of participants (nine of the twelve) assigned a final rise to the target *wh-in-situ* content questions, a small subset of participants (three) did not. The difference in the percentage of sentence-final rise for these two groups was significant (by a proportional test, $p < .001$). Closer inspection of the *wh-in-situ* items revealed an outlier, which received much lower rise scores than the other four. Excluding this outlier, the distinction between the two groups becomes slightly amplified: the three participants in Group 1 were perceived to assign a sentence-final rise 25% of the time, while eight of the nine participants in Group 2 were perceived to assign a rise 100% of the time, and one 75% of the time. (We note in passing here that the outlier participant receiving higher-than-average non-natural ratings was in Group 1.)

On the whole, these results therefore provide tentative support for C&R's claims about the required rising intonation of *wh-in-situ* content questions, at least for nine of the 12 participants recorded. However, we still seek an explanation for the

[5] There was no correlation between disagreements on coding and naturalness rating (by a Spearman correlation test, $\rho = -0.005$, *n.s.*).

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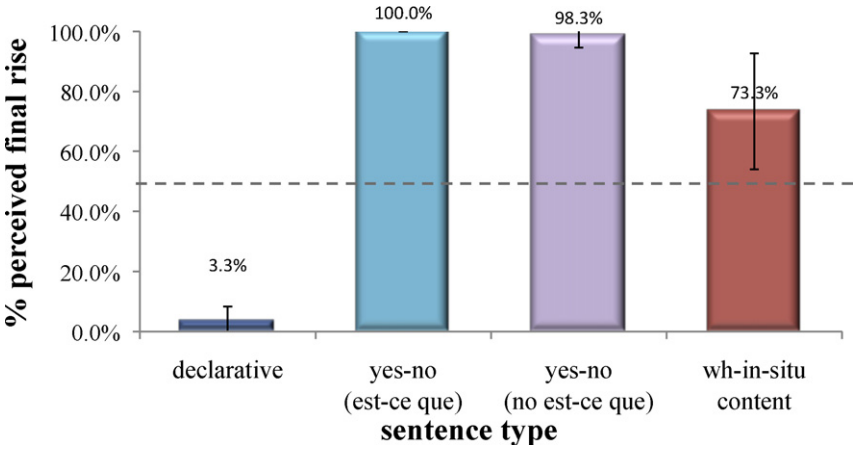

Fig. 1. Percentage of perceived sentence-final rise for three baseline sentences and the target *wh-in-situ* content questions (bar on far right). Error bars represent standard errors.

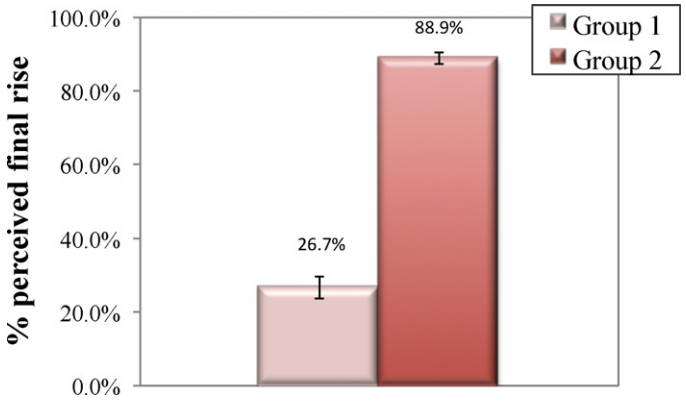

Fig. 2. Percentage final rise for the *wh-in-situ* content sentences in two groups of participants. The error bars represent standard error.

performance of the participants in Group 1 and the difference between the *wh-in-situ* and the *yes–no* questions (which are both unexpected from the point of view of C&R). While a categorical perceived rise/fall distinction allowed us to begin to address C&R's proposal, we expected that a more fine-grained analysis of the intonation contour would shed light on this pattern of results. We turn to this analysis in the next section.

5.3.2. Acoustic analysis of contour

Our second analysis focused on the intonation contour (or *F*0) of our target *wh-in-situ* sentences as compared with a subset of other sentences: the two baseline sentences (both types of *yes–no* questions and declaratives), along with *wh-in-situ* echo questions. Recall that C&R would predict a falling contour for the declaratives in contrast to a rising contour that is either identical or at the very least highly similar for *yes–no* and *wh-in-situ* content questions. We include echo questions here to address the possibility that *wh-in-situ* content questions are simply produced as echo questions. The fact that these five sentences types are also the same verbatim on the surface with the exception of the *wh*-word or the determiner makes for a clean comparison across these conditions. Recall that we chose to analyze a window from the onset of the *wh*-word or determiner to the end of the sentence, as noted in the figures.

While the first analysis generally supported C&R's claim, a second, more quantitative, analysis reveals a more nuanced picture. The results are presented in Fig. 3, with Group 1 (on the left: the subset of participants who were generally not perceived to assign our target *wh-in-situ* sentences a sentence-final rise) and Group 2 (on the right: the majority of participants who were generally perceived to assign these sentences a rise).

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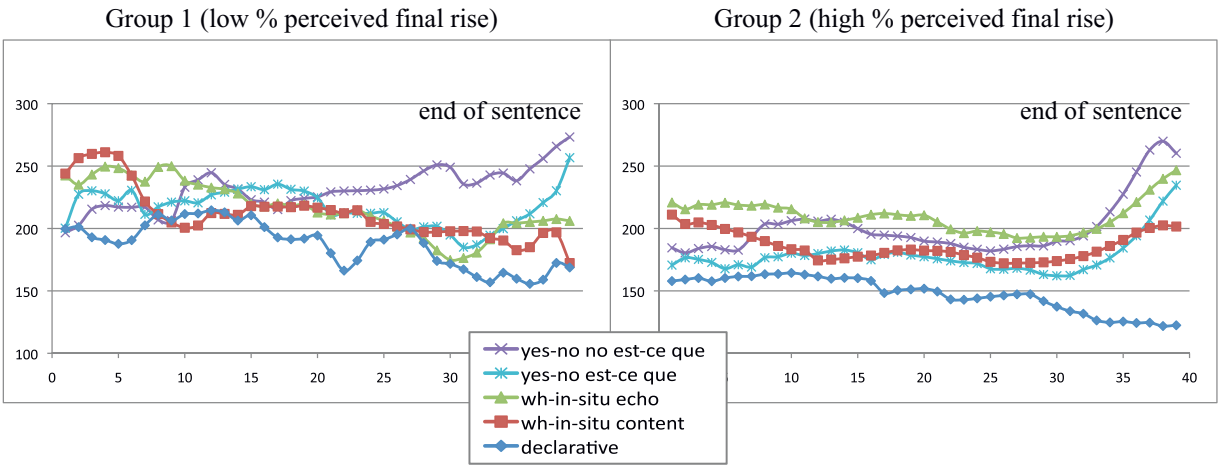

Fig. 3. Sentence-final intonation contours for five sentence types for the two groups of speakers identified in the analysis of perceived sentence-final rise/fall.

We are able to make a series of observations about the contours captured in these graphs. First, for both groups, the declarative sentences have the predicted falling contour (although Group 1 appears to have a higher starting pitch for these sentences). Second, for both groups, the two types of *yes–no* questions have the predicted rising intonation contour. Thus, as in the previous analysis, both groups pattern similarly with respect to the baseline sentences.

Next we turn our attention to the sentence-final contour of the *wh-in-situ* content questions.[6] The contour observed for each group is consistent with the results from the previous analysis: the contour for Group 1 (left) is falling, while the contour for Group 2 is rising. However, the picture we obtain through this analysis allows us to see much more than a coarse rise/fall distinction. First, while Group 1 did not assign these sentences a rising contour, the falling contour of the *wh-in-situ* sentences nevertheless appears to be distinct from that of the declaratives. Second, for Group 2, the rise for these sentences is not nearly as sharp as for the two types of *yes–no* questions. This difference is perhaps curious if indeed the same intonation morpheme licenses all three question types, as C&R claimed. However, the contour for these sentences does not simply mirror the contour for the echo questions in this group.

One final difference between these groups lies in the height of the *H** accent assigned to the *wh*-word (*cf.* Pierrehumbert, 1980; Pierrehumbert and Beckman, 1986). The average peak for Group 1 (left) is above 250 Hz, while for Group 2 (right), it is just over 200 Hz. Given the difference between the two groups with respect to the presence of a sentence-final rise, this difference in the prominence of the *wh*-word may not be inconsequential. The presence of a prominent pitch accent on *wh*-words in *wh-in-situ* questions is consistent with a number of other studies, which have obtained a similar finding. For example, Wunderli (1983) noted the presence of ''un accent très accusé'' on the *wh*-words in many of the *wh-in-situ* questions produced by speakers in that study, and that in many cases, this accent was accompanied by a falling contour. Beyssade et al. (2007) observed that when *wh*-questions in their study (not restricted to *in situ* questions) were accompanied by a falling contour, the *wh*-word was assigned a high tone, followed by a low pitch accent on a subsequent syllable. By contrast, when the contour of a *wh*-question was rising, the *wh*-word was frequently assigned a low tone. Likewise, Baunaz and Patin (2011) noted that *wh*-words produced by speakers in their study of *wh-in-situ* questions were also frequently assigned a high pitch accent under certain presuppositional conditions, and further that there was interspeaker variability on the placement of this accent.

It is therefore perhaps not entirely surprising to observe either high prominence surface on the *wh*-word or variability among speakers with respect to its presence. Here, however, we wish to make a novel observation concerning its correlation with the sentence-final intonation contour associated with *wh-in-situ* sentences: a high pitch accent on the *wh*-word is negatively correlated with a sentence-final rising intonation contour. This correlation is captured in a comparison of one item produced by a speaker in Group 1 and a speaker in Group 2. (See Fig. 4.) While the speaker on the left assigns a

[6] While we recognize that a French-style ToBI transcription (Di Cristo, 1998; Di Cristo and Hirst, 1993; Jun and Fougeron, 1995, 2000, 2002; Post, 2000) might present additional information and perhaps more fine-grained details concerning these intonational contours, we feel that our combined perceptual and phonetic approach captures both interesting and robust trends concerning a rise/fall contrast and patterns of pitch accenting that are directly relevant to C&R's (2000) theoretical proposal.

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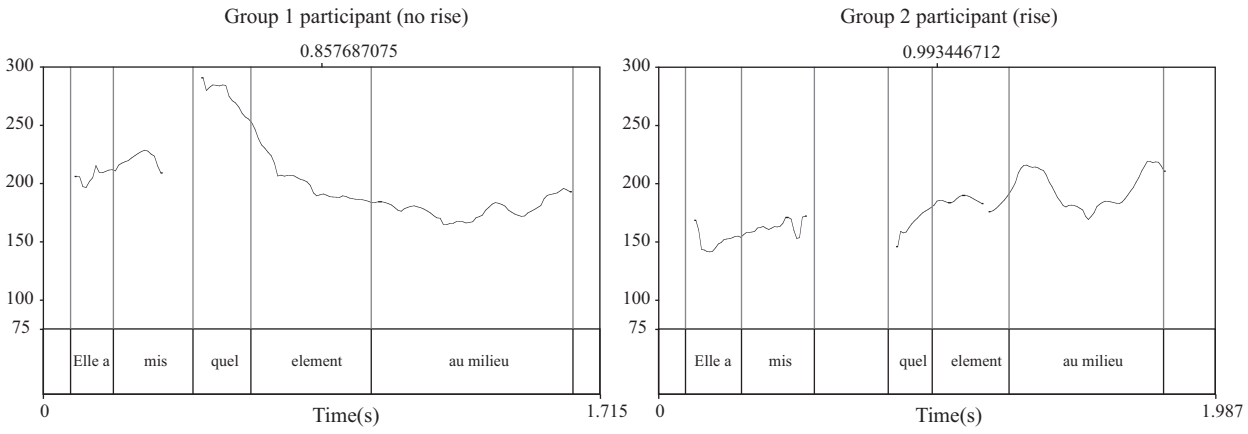

Fig. 4. Example of the intonation contour from two participants (one from Group 1 and one from Group 2) for the *wh-in-situ* sentence *Elle a mis quel élément au milieu?*

high pitch accent to the *wh*-word (*quel*), the speaker on the right does not. By contrast, while the speaker on the left is not perceived to assign this sentence a rise, the speaker on the right is.[7]

Seeking a more stringent measure of this pattern across participants, we performed a systematic comparison of the *wh*-region and the sentence-final region for each item for each speaker. We first identified the maximum *F*0 value in the first 10 intervals after the onset of the *wh*-word, then found the minimum *F*0 value in the following 10 intervals, and calculated the difference in *F*0 between the two points. We refer to this value as ''Initial Max–Initial Min.'' We then found the maximum *F*0 value in the last 5 intervals of the sentence, and calculated the difference between the first maximum *F*0 point and this value. We refer to this difference as ''Initial Max–Final Max.''

We predicted that a large initial difference would be positively correlated with a large difference between the initial and final maximum values, result from high pitch accenting on the *wh*-word followed by a depressed rise, a plateau, or even a fall. Likewise, we predicted that a smaller or negative difference in the *wh*-region would be correlated with a small or a negative difference between the two maxima, indicating the presence of a rise. Combined, this pattern would indicate that an elevated peak on the *wh*-word is negatively correlated with a sentence-final rise.[8] Indeed we find a strong correlation between the two measures: the greater the Initial Max–Initial Min difference, the greater the Initial Max–Final Max difference (Pearson correlation test, $r = 0.75$, $r^2 = .56$, $p < .001$). A scatterplot capturing this correlation is presented in Fig. 5.

Before moving on to the discussion, we would like to entertain one further possibility about speakers' productions. One might wonder why we should not just simply expect to see a rising intonation whenever a question is asked. That is, more generally, are all *wh*-questions accompanied by a rising intonation? This pattern would be problematic for C&R, since only *wh-in-situ* questions are licensed by the intonation morpheme that carries with it a rising intonation; moved *wh*-questions are checked *via* overt movement of the *wh*-word and not *via* the merging of this morpheme: they should therefore not exhibit the same systematic sentence-final rise.

In Fig. 6 we compare the intonation contour of the moved *wh*-questions to our target *wh-in-situ* questions for both groups of participants. For participants in Group 1, not surprisingly, all *wh*-questions exhibit a falling contour. For participants in Group 2, however, there is a definite difference between the falling contour exhibited by the moved *wh*-questions and the rising contour exhibited by the *wh-in-situ* questions. To substantiate this difference, we calculated the trendlines from the point where the three contours intersect (at the y intercept of approximately 180 Hz), and found that the slopes of the least square regression lines are quantitatively different. For the two moved *wh*-questions, it is clearly negative, reflecting a falling contour (moved *est-ce que*: -0.70 ± 0.28 margin of error, moved inversion: -1.21 ± 0.29),

[7] A reviewer commented on the rise observed on the last syllable of *élement*, which may indicate the possibility of an intermediary rise implicating an intonational copy mechanism (Delais-Roussarie et al., 2002; Rialland et al., 2002). In fact, when we examined the sound files for this speaker and others, we found that the same peak often occurred on this word in the declarative sentences, which very clearly have a falling contour. The peak may therefore be an artifact of the pronunciation of that word (due to its prominent final syllable). However, it is also possible that for speakers exhibiting such a peak, it reflects a continuation rise. Either way, the contrast between the two sentences with respect to the pitch accent on the *wh*-word and the contour should be clear.

[8] An alternative would have been to take the size of sentence-final rise. We did not take this approach because not all sentences exhibit final rises, and also because it was difficult to find an objective reference L point to quantify the size of a rise, if it existed at all.

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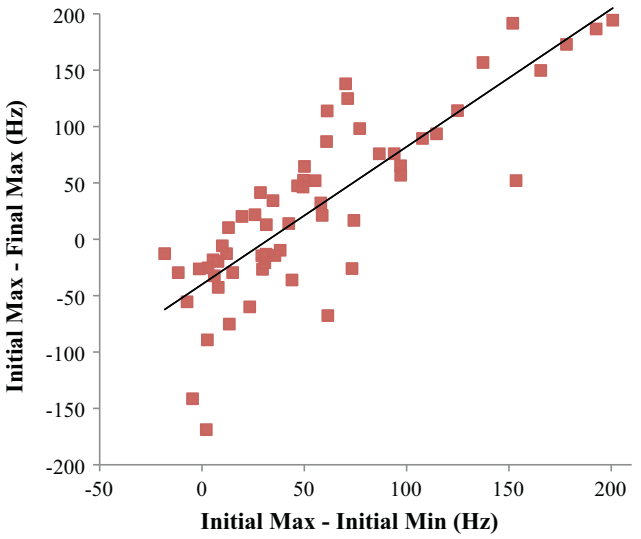

Fig. 5. Scatterplot capturing the correlation between two values in the sentence-final region of the target *wh-in-situ* sentences: the difference between the initial maximum value and the final maximum value (within 10 intervals), and the difference between the initial maximum value and a minimum value in the following 10 intervals.

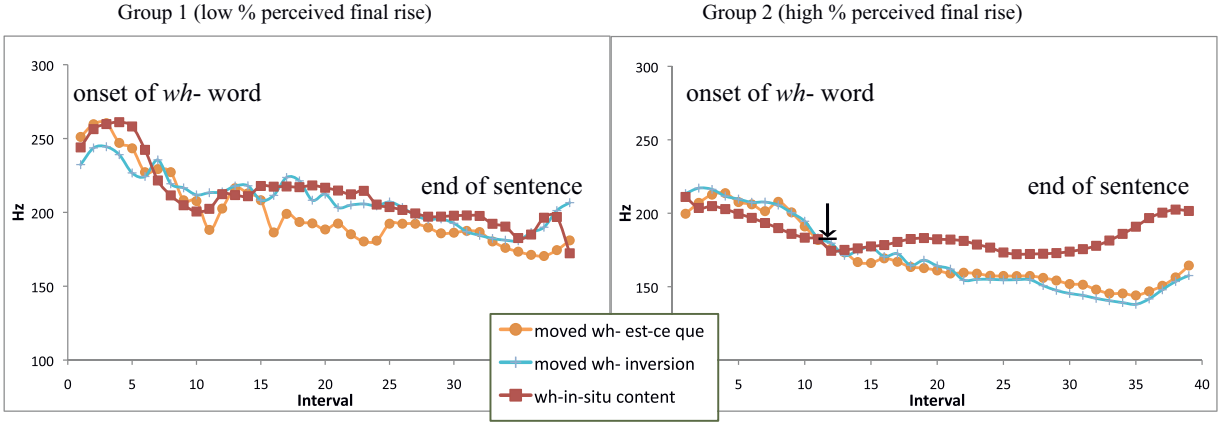

Fig. 6. Sentence-final intonation contours for moved *wh-* and *wh-in-situ* questions for the two groups of speakers identified in the analysis of perceived sentence-final rise/fall.

while for the *wh-in-situ* questions, it reflects a fairly steady rise (0.79 ± 0.37). These comparisons underscore the difference between the moved- and *in situ wh*-questions for this group of speakers.

One commonality does appear to hold across all *wh*-questions for both groups. In all cases, there appears to be deaccenting or pitch compression of the lexical material following the *wh*-word. For both groups, following the *wh*-word in the two moved *wh*-questions, the pitch is compressed approximately 50 Hz and never regains its initial frequency at the peak of the *wh*-word. For the *wh-in-situ* questions, there also appears to be pitch compression following the *wh*-word. For Group 1, this compression is followed by a falling contour, while for Group 2, it is followed by a slow and steady rise through the end of the sentence.[9]

[9] An analysis of the lexical material preceding the onset of the *wh*-word revealed that both groups (with the exception of our outlier participant) displayed flat intonation or a compressed pitch accent in this region of the sentence. Thus, the real difference between the two groups lies in what they did following the onset of the *wh*-word.

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6. Discussion

We began with a broad interest in the relation between syntax, prosody, and the discourse context in licensing interrogatives, choosing as our case study French *wh-in-situ* questions and a claim by Cheng and Rooryk (2000) that these questions are obligatorily associated with a sentence-final rising intonation contour. Under their proposal, the same null intonation morpheme, implicated in both *yes–no* and *wh-in-situ* questions, carries rising *yes–no* intonation by default, regardless of whether it is associated with a *yes–no* or a *wh*-question. Thus, a clear prediction arising from such a proposal is that both types of questions should be realized with the same intonational contour. We sought to pursue this prediction experimentally with a production study involving native French speakers, analyzing their productions for sentence-final rise/fall and the shape of the *F*0 contour.

Our results provide nuanced support for C&R's proposal, along with a more fine-grained understanding of the connection between prosody and syntax in French *wh-in-situ* questions. For the majority of speakers in our experiment, the target *wh-in-situ* questions—unlike the moved *wh*-questions—were perceived to have and were shown to exhibit a sentence-final rising intonation contour. However, this rise, when present, was not identical to the rising contour exhibited by two types of *yes–no* questions. This difference is unexpected, given C&R's proposal that the same intonation morpheme with default *yes–no* intonation is associated with both *yes–no* and *wh-in-situ* questions.

Further analysis of these questions revealed that the height of the pitch accent assigned to the *wh*-word was negatively correlated with the presence and height of the sentence-final rise. This connection may indicate that instead of the rise simply being optional, as reported by some researchers, its presence and shape may instead be connected to the focus placed on the *wh*-word. Given the picture that emerges from our experimental investigation, we return to C&R's original proposal and raise three possibilities concerning the status of the intonation morpheme associated with *wh-in-situ* questions in French and how we can best account for our pattern of results. Each of these possibilities allows us to both maintain some version of C&R's proposal and account for the variability in the realization of the contour for *wh-in-situ* content sentences.

The first possibility is that the intonation morpheme calls for a sentence-final rising contour, as stated by C&R. Because *wh-in-situ* questions are most felicitous in contexts that carry some level of presupposition, and because we specifically manipulated information structure in our experimental contexts, we would predict, following others, that the *wh*-word in the target sentences would receive narrow focus (*cf.* Beyssade et al., 2007; Hamlaoui, 2008), and that the given information would be deaccented (*e.g.*, Ladd, 2008, pp. 231–236; Kučerová, 2007; Schwarzschild, 1999; Selkirk, 1984; Wagner, 2005, 2006). Pitch compression following the *wh*-word (and other focused items in general) has been observed in French (Beyssade et al., 2007; Jun and Fougeron, 2000, 2002; Wunderli, 1983) as well as in other languages (*e.g.*, Mandarin Chinese: Liu and Xu, 2005; Xu, 1999; Japanese: Deguchi and Kitagawa, 2002; Ishihara, 2003; Korean: Jun, 2002) (see also Flemming, 2008 for a recent review). It is also a key aspect of Richards' (2006, 2010) proposal about the formation of *wh*-domains.

The difference between the two groups could be accounted for by a difference in the height of the pitch realized on the *wh*-word and the level of deaccenting of the surrounding lexical material. The post-focal depression following the *H** on the *wh*-word would then mitigate any would-be rise dictated by the intonation morpheme. For the small number of participants in the first group, who generally exhibited a markedly high accent on the *wh*-word, this compression was completely maintained, resulting in a plateau or a falling contour. For the participants in the second group, there was some recovery at the end of the sentence of a rising contour after the depression following the focused *wh*-element, but the contour never achieved the height of a prototypical *yes–no* rise. Because *yes–no* questions do not contain a focused *wh*-word contrasted with given information from the discourse, the H carried by the intonation morpheme is realized as predicted, as a typical *yes–no* sentence-final rise.[10]

The second possibility encodes this ''either–or'' relationship directly into the grammar, rather than arguing that the absence of a rise is a consequence of focus-induced elevated *F*0 of the *wh*-element. Under this account, the intonation morpheme, rather than specifically calling for a sentence-final rise, instead encodes an H tone, whose docking site is lexically underspecified. This H could be realized as an H* hosted by a syllable receiving prominence (*i.e.*, the narrowly focused monosyllabic French *wh*-words in our sentences) or as a sentence-final H% boundary tone. The observation that the same tone can dock on different locations for different speakers is not unprecedented. Kawahara and Shinya (2008) showed that in multiple-clause constructions, Japanese shows an utterance-final H tone, which speakers either dock on a phrase-final case particle or a pitch accent within the penultimate phonological phrase. Phrase accents in question

[10] This is not to say that yes–no questions are not focus-insensitive. Indeed, an empirical prediction from our line of work is that *yes–no* questions with an intermediate focused element might also exhibit a depressed final rising contour, thereby reflecting a similar negative correlation between the pitch accent on the focused element and the extent of the final rise. The experimental stimuli in this task were not designed to test this prediction. We thank the editors for helping us to clarify this point.

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intonation in Eastern European languages are claimed to show a similar pattern. In Standard Greek, for example, the docking site of the H accent followed by a L% in interrogatives is said to covary with the position of the nuclear accent (Grice et al., 2000).

In our experiment, the difference between the two groups could be accounted for by a difference in the docking site and the specification of the H. (This possibility might work toward addressing one of Adli (2004)'s concerns about the position of the morpheme and its prosodic realization at the end of the phrase.) For Group 1, the H tone is largely realized as an accentual H* on the *wh*-word, while for the second group, the H is largely realized as a boundary H% tone and a rising contour. In short, both groups of speakers would have an H tone licensing the *wh-in-situ* question (deriving from C&R's proposed intonation morpheme), but they would differ in how they associated it.

This difference would explain the negative correlation between the size of the pitch accent on the *wh*-word and the sentence-final rise, since the H tone assigned by the morpheme would be located in one of these two places. As noted above, we would predict that in any case, the pitch accent of the *wh*-word would be elevated from the surrounding lexical material. For those speakers that realize the H tone as an H* on an already F-marked *wh*-word receiving narrow focus (*e.g.*, Bartels and Kingston, 1994; Deguchi and Kitagawa, 2002; Ishihara, 2003; Schwarzschild, 1999; Selkirk, 1984, 2002), the docking of H on a syllable already having H* might have an additive effect, boosting the peak on this syllable (Kawahara and Shinya, 2008). This possibility would still allow for both intra- and interspeaker variability, provided the H is not encoded in a speaker's grammar as one option or the other. The choice of docking site could be conceived of as being motivated by the goals of the conversation: a speaker either docks the H on a syllable in the *wh*-word, giving the listener a cue about information structure, or at the end of the sentence, highlighting the status of the sentence as a question.

A third possibility is that the intonation morpheme for *yes–no* questions and *wh-in-situ* questions is simply different, and that C&R were simply wrong in suggesting that they were the same. This alternative might explain the difference in the contour exhibited by the two sorts of questions. However, this possibility does not systematically account for the range of data we obtained in our study in the way that either of the other two accounts can. In particular, the interesting negative correlation between the H* on the *wh*-word and a rising contour that we discovered would remain unexplained. At this point, we see no reason to abandon C&R's proposal. We are intrigued by the possible accounts entertained here and hope that they motivate further empirical investigations on this topic.

Appendix A

List of target sentences, with annotated boundaries. Translations and glosses are provided for the declaratives.

declaratives
Elle a | mis | cet | élément | au milieu.
she has | put | this | shape | in.the middle
'She has placed this shape in the middle'.

Il a | éliminé | une | ligne | en haut.
he has | marked.off | a | line | at.the.top
'He has marked off a line at the top'.

Elle l'a | emmené | là | la nuit.
she her has | brought | there | that night
'She brought her there last night.'

Elle est | allée | à Lille | il y a un mois.
she has | gone | to Lille | a.month.ago
'She went to Lille a month ago.'

Il a | envoyé | les | menus | à un ami.
he has | sent | the | menus | to a friend
'He sent the menus to a friend.'

***yes–no* questions with and without *est-ce que* (QUES)**
(Est-ce qu' |) elle a | mis | cet élément | au milieu?
(Est-ce qu' |) il a | éliminé | une ligne | en haut?
(Est-ce qu' |) elle l'a | emmené là | la nuit?
(Est-ce qu' |) elle est | allée à Lille | il y a un mois?
(Est-ce qu' |) il a | envoyé | les menus | à un ami?

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***wh-in-situ* content and echo questions**
Elle a | mis | quel | élément | au milieu?
Il a | éliminé | quelle | ligne | en haut?
Elle l'a | emmené | où | la nuit?
Elle est | allée | où | il y a un mois?
Il a | envoyé | quel | menu | à un ami?

Wh*-moved questions with *est-ce que
Quel | élément | est-ce qu' | elle a | mis | au milieu?
Quelle | ligne | est-ce qu' | il a | éliminé | en haut?
Où | est-ce qu' | elle l'a | emmenée | la nuit?
Où | est-ce qu' | elle est | allée | il y a un mois?
Quel menu | est-ce qu' | il a | envoyé | à un ami?

***Wh*-moved questions with subject-auxiliary inversion**
Quel | élément | a-t-elle | mis | au milieu?
Quelle | ligne | a-t-il | éliminé | en haut?
Où | l'a-t-elle | emmené | la nuit?
Où | est-t-elle | allée | il y a un mois?
Quel menu | a-t-il | envoyé | à un ami?

Appendix B

Seven sentences corresponding to one context type.

Pour participer à un test de psychologie, Emma devait/doit placer
to participate in a test of psychology, Emma had/has.to place
un rond, un carré ou un triangle sur un tableau.
a circle, a square or a triangle on a board.
'In order to participate in a psychology experiment, Emma had/has to place
a circle, a square or a triangle on a board'.

sentence	continuation of context (if applicable) and target (underlined)
(1) declarative	Emma a pris le rond dans sa main et l'a placé sur le Emma AUX took the circle in her hand and it.AUX placed on the tableau. *Elle a mis cet élément au milieu*. board. she AUX placed that shape in.the middle 'Emma took the circle in her hand and placed it on the board. *She placed that shape in the middle*'.
yes–no question	Emma a pris le rond dans sa main et l'a placé au
(2) with est-ce que	Emma AUX took the circle in her hand and it.AUX placed in.the
(3) without est-ce que	milieu. Le psychologue a demandé: middle. the psychologist AUX asked ''*Est-ce qu'elle a mis cet élément au milieu?*''/ QUES she AUX placed that shape in.the middle ''*Elle a mis cet élément au milieu?*'' she AUX placed that shape in.the middle 'Emma took the circle in her hand and placed it in the middle. The psychologist asked, ''*Did she place that shape in the middle?*''/ ''*She placed that shape in the middle?*'''
(4) *wh-in-situ* content question	Le psychologue a demandé: ''Elle a mis quel élément au the psychologist AUX asked: ''she AUX placed which shape in.the milieu?'' middle 'The psychologist asked, ''She placed which shape in the middle?'''

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(5) *wh-in-situ* echo question

Emma a pris le rond dans sa main et l'a placé sur le
Emma AUX took the circle in her hand and it.AUX placed on the
tableau. L' assistant a dit au psychologue:
board. the assistant AUX said to.the psychologist:
Elle a mis le rond au milieu.
she AUX placed the circle in.the middle
Mais lui qui n'avait rien entendu a redemandé:
But he who NEG.had nothing heard AUX re-asked
''Elle a mis quel élément au milieu?''
she AUX placed which shape in.the middle
'Emma took the circle in her hand and placed it on the board.
The assistant said to the psychologist, ''She placed the circle in the middle.''
But he who hadn't heard anything asked, ''She placed which shape
in the middle?'''

moved wh-question
(6) with est-ce que
(7) with inversion

Le psychologue a demandé:
the psychologist AUX asked:
''Quel élément est-ce qu'elle a mis au milieu?''/
which shape QUES she AUX placed in.the middle
''Quel élément a-t-elle mis au milieu?''
which shape AUX. she placed in.the middle
'The psychologist asked, ''Which shape did she place in the middle?'''

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