

## On-line grammaticality judgments in French children and adults: a crosslinguistic perspective\*

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### ABSTRACT

This study examined the on-line processing of French sentences in a grammaticality judgment experiment. Three age groups of French children (mean age: 6;8, 8;6 and 10;10 years) and a group of adults were asked to detect grammatical violations as quickly as possible. Three factors were studied: the violation type: agreement violations (number and gender) vs. word order violations; the violation position: early vs. late in the sentence; the target type of the violations: intra vs. interphrasal. An example of an early interphrasal verbal agreement violation follows: ‘Chaque semaine la voisine remplissent le frigo après avoir fait les courses au marché’ (Every week the neighbour fill the fridge after shopping at the market). The main developmental results were the following: not surprisingly, children were always slower than adults in the detection of grammatical violations. At each age level, morphological violations were more rapidly detected than word order violations. Each age group was faster at judging sentences with later occurring violations and the position effect was especially strong in the youngest groups. Finally, intraphrasal violations were more rapidly detected than interphrasal ones, this effect being observed only in the oldest groups (i.e. 10;10 years and adults). The results were compared to previous on-line data obtained in modern Greek (Kail & Diakogiorgi, 1998) showing strong similarities, even though Greek is a very rich morphological language. These results are discussed within the framework of the Competition Model, outlining the necessity to incorporate new processing constraints into the model.

### INTRODUCTION

To become fluent speakers in their native language, children must learn to process language efficiently and rapidly. Studies devoted to on-line sentence

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processing in children are still uncommon. The present study on French was conducted to provide more developmental data on the on-line integration of two basic types of grammatical constraints, word order configurations and morphological agreements. Real-time language processing requires that the listener (or reader) integrates linguistic cues into the ongoing sentence representation. During the past 20 years, considerable attention has been directed towards the information used by the human parser to guide decisions and the timing of information use. The main controversy revolves around the following question: is structural information processed autonomously during an initial phase, while lexical-semantic information is processed later, when the parser's first analyses have failed? Or, on the contrary, is the parser immediately able to integrate all the available linguistic information?

This study is an extension of research conducted by Bates, MacWhinney and colleagues working within the Competition Model, a model which assumes that semantic and syntactic information are integrated from the start.

The Competition Model (MacWhinney & Bates, 1989) is an integrative-activation framework proposed to account for quantitative as well qualitative variations in performance across a wide range of languages. The basic tenets of the Competition Model have been extensively presented in Bates & MacWhinney (1982; 1987; 1989) as well as in many articles and chapters. In this model, the mapping of form to function is stated as directly as possible. This principle of direct mapping emphasizes that the language processor can use compound input cues that work across linguistic boundaries – e.g. prosody, morphology, lexicon, syntax – and that the different sources of information are processed *via* a common set of perceptual, representational and retrieval mechanisms. As mentioned above, this conception contrasts with modular theories in which different linguistic data types are computed by separate processors.

In some cases, the parallel activation of the formal and functional levels leads to competition between the different sources of information for role assignment. In these instances, a co-evaluation of sources becomes necessary and is directly determined by the relative validity of these cues in a given language.

The notion of cue validity is the central predictive construct of the model, representing the informative value of a given source of information (for example, the preverbal position) for the assignment of a particular function (for example, the semantic function of agent). Cue validity is defined by two properties, availability and reliability. If a cue is there whenever needed, it is high in availability. If a cue is never ambiguous and always leads to the correct interpretation, it is maximally high in reliability. An example of a very valid cue in English is preverbal position which is both available and

reliable for agent assignment, contrary to what happens in Italian or in Spanish. Another fundamental notion is cue strength. Whereas cue validity is an objective property of the stimulus, measured in samples of inputs given to the language learner, cue strength is a subjective property of the language user. According to the processing hypotheses proposed by the model, cue strength depends on cue validity in a given language. In adults, cue strength and cue validity are isomorphic when form–function mappings are optimally ‘adjusted’. In children, the main hypothesis is that the order in which cues for sentence comprehension emerge in a language is largely a function of the relative validity of cues in that language.

A substantial body of sentence comprehension studies summarized in MacWhinney & Bates (1989) and more recently in Kail (1999) have provided strong evidence for the importance of cue validity as a predictor of cue strength in more than twenty languages. The results also supported the assumption that children acquire sentence comprehension strategies in a sequence that is predictable from the cue validity of the grammatical devices in the adult language.

However, a number of exceptions to developmental predictions based on cue validity have been found in some language, Chinese (Li, Bates & MacWhinney, 1993), Serbo-Croatian (Mimica, Sullivan & Smith, 1994) and French (Kail & Charvillat, 1986; Kail, 1987). Young French children initially base their sentence interpretation on word order like English children. Later, from 6;0 upwards, they rely on the animacy contrast of the nouns like French adults and like Italian children and adults. In order to explain the incompatibility of such results with the model’s developmental predictions, we added the notion of cue cost (Kail, 1989) to the Competition Model. This notion refers to the perceptual and mnemonic limitations of the processing system. In line with earlier proposal by Ammon & Slobin (1979), we suggested (Kail & Charvillat, 1988) that cues are distributed on a continuum according to their processing type: from local (an interpretation can be computed as soon as the cue is encountered) to topological processing (the interpretation is delayed until the distributed information is stored and compared).

To study the microstructure of on-line sentence processing, different experimental methods have been used successfully in adults and children from six years of age upwards. These techniques have provided reliable new data on processing times as a function of cue configuration (convergence or competition) and cue integration in various languages (Kail, 1989; Charvillat & Kail, 1991; Wulfeck, Bates & Capasso, 1991; Li *et al.*, 1993; Mimica *et al.*, 1994; Kail & Bassano, 1997).

For the most part, results are compatible with these specific predictions about reaction times: sentences with cue convergence lead to shorter reaction times while sentences with cue competition result in longer reaction

times. Nevertheless, some interesting exceptions have been found. For example, in Spanish (Kail & Charvillat, 1988; Kail, 1989), sentences with cue convergence do not lead to faster reaction times compared to sentences in which the very strong cue – accusative preposition *a* – acts alone (the ‘enough is enough’ principle). In French, Kail (1989) showed that both clitics and subject–verb agreement markers tend to slow down listeners in NVN (SVO) configurations. In contrast, they can speed up reaction times in non-canonical orders (NNV and VNN). Hence, the contribution of cues interacts with what we called ‘canonicity’.

One of the most productive paradigms used with children is real-time grammaticality judgments which gives information not only on whether a child makes a correct judgment but also on the kind of information the decisions use and how they are affected by contextual constraints. The capacity to perform grammaticality judgments has been studied within the framework of the development of metalinguistic abilities in children. The main question addressed by this type of study is when children become able to abstract themselves from the normal use of language such as communication in order to reflect upon and manipulate the structural features of spoken language. Based on an accumulating body of research, there is an emerging consensus that it is not until middle childhood that this capacity is acquired (Pratt, Tunmer & Bowey, 1984; Tunmer & Grieve, 1984; Gombert, 1990). The high dependence of young children on content and consequently their tendency to base their judgments more on semantic and pragmatic considerations than on grammatical ones explains why little research has focused on the development of grammaticality judgments although attempts to elicit acceptability judgments from very young children were reported up to 20 years ago (de Villiers & de Villiers, 1972; Gleitman, Gleitman & Shipley, 1972; Clark, 1978; Hakes, 1980; Sutter & Johnson, 1990). In short, the most important finding of these studies is a developmental progression: young children seemed be more receptive to the semantic content and the plausibility of events while older ones showed an increase sensitivity to morphosyntactic aspects of language.

Within the Competition Model, the study of Wulfeck (1993) was one of the first to examine real-time grammaticality judgments in school-age English children from 7;0 to 9;0. Following previous results from college students (Wulfeck *et al.*, 1991) it was expected that if children showed greater sensitivity to word order compared to agreement violations, there might be a processing speed advantage as well. The results were more complex: on the one hand, there was no significant difference in overall processing times between the two violation types and on the other hand, there was a significant interaction of position of the violation in the sentence (early vs. late) and violation type. Children produced faster detection times for late occurring word order violations compared to agreement violations,

but no detection time advantage for early word order violations. Such on-line data for English children partly followed the predictions based on cue validity, according to which stronger cues (e.g. word order) will lead to faster detection times and weaker cues (e.g. agreement) will be associated with slower times.

In this research, we investigate whether French yields a different developmental pattern.

#### SELECTED CHARACTERISTICS OF FRENCH

##### *Word order*

The canonical word order in French is SVO. The first NP in a sentence is most frequently the agent. Despite its pre-eminence, the canonical SVO order occurs along with other orders imposed by syntactic, pragmatic or contextual constraints. OVS. order can be found in relativized object constructions, for example

- (4a) *La femme que connaît Paul enseigne le droit.* 'The woman that Paul knows teaches law' and the OSV stylistic variant  
 (4b) *La femme que Paul connaît enseigne le droit.*

which means the same thing and more closely resembles the object relative construction in English.

A major exception to SVO order is the use of SOV order. SOV order in French is primarily due to the existence of a double series of clitic pronouns: preverbal direct object (*le, la, les*) and preverbal indirect object (*lui, leur*) pronouns. From the sentence

- (5a) *Le soldat montre la flèche à l'indien.* 'The soldier is showing the arrow to the Indian', all the following may be derived  
 (5b) *Le soldat la montre à l'indien.* 'The soldier it is showing to the Indian.'  
 (5c) *Le soldat lui montre la flèche.* 'The soldier to him is showing the arrow.'  
 (5d) *Le soldat la lui montre.* 'The soldier it to him is showing.'

Although direct object clitics are marked both for gender and number, these forms are identical to the definite articles (*le, la, les*). This potential ambiguity between clitics and articles raises problems for left-to-right parsing in French as we have shown for children (Weissenborn, Kail & Friederici, 1990; Charvillat & Kail, 1991) and aphasic subjects (Friederici, Weissenborn & Kail, 1991).

The other exceptions to SVO order are fairly rare. VSO order is found in the interrogative form *Prend-il le train ce soir?* 'Is taking he the train this evening?', a form which is infrequent in spoken French. Finally, VOS

is a very low frequency construction observed in two cases: right topicalization as in spoken sentences *Il prend beaucoup d'argent, mon fils* 'He takes a lot of money, my son'. Combinations of left and right topicalizations and cliticization are responsible for extending the range of possible orders found in French.

Nonetheless, this variability clearly operates within definite limits. French does not allow subject ellipsis, and tends to conserve canonical SVO in many constructions.

#### *Verbal and nominal agreement*

Verbal agreement in French (Béchade, 1989) is determined by the number of the subject and, in some constructions, by its gender. Gender is expressed only in complex verbal forms composed of the auxiliary *être* (be) and a past participle with a masculine, feminine, or plural marking:

- (1a) *Les cerises sont ramassées au printemps.* 'The cherries are gathered in spring.'  
 (1b) *Le cerisier est chargé de fruits.* 'The cherry tree is laden with fruits.'

When the subject is composed of a quantifier or a collective noun, plural or singular agreement depends to some extent on the intentions of the speaker; this possibility results in high variability of agreement. For example, if the speaker wants to highlight the idea of totality expressed by a collective singular noun, the verb is in the singular form:

- (2a) *Tout cet ensemble de choses indicibles a été la cause véritable de la rupture.* 'This set of indescribable things was the real cause of a rupture.'

In the opposite case, if the speaker wants to focus on the plurality of the complement, semantic agreement can replace grammatical agreement and the verb is expressed in plural form:

- (2b) *Une troupe de cavaliers traversèrent au galop le village désert.* 'A group of horsemen galloped through the deserted village.'

When the subject is composed of several coordinated or juxtaposed nouns, the verb takes the plural marking:

- (2c) *L'un comme l'autre étaient pour moi des exemples difficiles.* 'One like the other were difficult examples for me.'

In the oral code, French has a large degree of ambiguity in its inflectional system, particularly with the verbs of the 1st conjugation (ending in *-er-* in the infinitive form, like *chanter*).

- (3a) *je chante* (1st sg)  
 (3b) *tu chantes* (2nd sg)  
 (3c) *il chante* (3rd sg)  
 (3d) *ils chantent* (3rd pl)

The various written inflections (*s* and *nt*) are inaudible because for all these items the pronunciation is the same. In the absence of contextual information, *il chante* can be confounded with *ils chantent*.

As a general rule (Mauger, 1968) nominal agreement concerns gender and number agreement of various units such as articles, adjectives, possessive and demonstrative pronouns. In the French lexicon, 60% of the nouns have exclusive gender, masculine being more frequent than feminine (Tucker, Lambert & Rigault, 1977), and the phonological information of the last syllable of the noun often has a high predictive value for gender assignment. Gender agreement is frequently realized through the addition of *-e-* to the masculine form (*fort* vs. *forte*, *grand* vs. *grande* ...). Such gender inflections are audible, contrary to number inflections such as *-s-* or *-x-* for plurals which are inaudible (*homme* vs. *hommes*; *la grande fille* vs. *les grandes filles*). In a small set of nouns which constitute an exception, number is expressed by an audible contrastive flexion (*le journal* vs. *les journaux*).

We know from our French off-line studies that sentence interpretation strategies change during late stages of language development, showing from 6;0 a substantial increase in the use of agreement cues (local cues) and a corresponding decrease in reliance on word order cues (topological cues). However, we know nothing about the on-line integration of these different types of cues during language development in French. The aim of the current research is to explore real-time language processing in French school children and adults using an on-line error detection task. We have previously used this experimental paradigm to study verbal agreement processing in French adults (Kail & Bassano, 1997; Lambert & Kail, 2001) and to examine the on-line integration of case morphological cues in Greek children and adults (Kail & Diakogiorgi, 1998). Our predictions are the following:

1. Based on our previous off-line processing data, we expect French children and adults will be able to make on-line grammaticality judgments, detecting agreement violations more rapidly than word order violations. We also expect young children to be slower and less accurate than adults as has been found in other languages (Wulfeck, 1993 for English; Kail & Diakogiorgi, 1998 for Modern Greek).
2. One very strong finding has emerged from crosslinguistic research on on-line sentence processing which uses this paradigm of error detection: violations that occur late in the sentence are more rapidly detected than

those that occur earlier. This difference has been shown for children aged six and older, normal adults and aphasics. This phenomenon provides information regarding the temporal components underlying detection processes. One prediction of the study is that we will be able to confirm this effect in French and also determine its developmental course.

3. Finally, very few studies have examined the role of the sentence structural constraints: error detection times should be sensitive to the hierarchical relations between the sentence elements affected by the violation. Elements belonging to the same constituent (for example, gender agreements within NP) will be detected more rapidly than elements belonging to different main constituents (for example, verbal agreement). Such a prediction is based on the assumption that the processing system tries to assign cues to meanings as soon as possible, integrating each piece of linguistic information into larger structures compatible with the information obtained up to that point. In this processing view, attachments between units that can be made locally place less load on the processor.

## METHOD

### *Subjects*

Forty eight French-speaking children participated in this study, divided into three age groups: sixteen six-to-seven-year-olds (mean age 6;8), sixteen eight-to-nine-year-olds (mean age 8;6), sixteen ten-to-eleven-year-olds (mean age 10;10). In addition, sixteen university students were tested as adult controls. All participants were native speakers of French, living and attending school/university in Paris.

### *Linguistic material*

A total of 360 sentences were constructed consisting of 40 grammatical sentences and 320 ungrammatical sentences with the same contents as the grammatical ones.

There were five different sentences at each level of a  $2 \times 2 \times 2$  design, representing orthogonal combinations of 2 types of violations (word order vs. agreement), 2 positions (early vs. late) and 2 structural types of target (intraphrasal vs. interphrasal). 8 lists of 40 grammatical and 40 ungrammatical sentences were constructed. For a given semantic content, each list contained a different violation and the corresponding grammatical sentence. Each subject was assigned to one list and received 80 sentences. In addition, 32 fillers were presented (16 grammatical and 16 ungrammatical sentences). An example of one of the lists is given in Appendix.



Stimuli were declarative sentences with an animate subject, a verb, a direct object and an adverbial transitive complement which can easily be shifted (e.g. placed before or after the subject noun). In all sentences, the main verb was chosen from the 2nd or 3rd verb group which mark number agreement by an audible change in the suffix of the verb (contrary to the 1st verb group). Half of the sentences had a masculine subject, half a feminine one; the gender of each noun is audible: *voisin* vs. *voisine*, ‘neighbour’; *acteur* vs. *actrice*, ‘actor vs. actress’. The overall length of each sentence was controlled (20–21 syllables).

### *Violation types*

*Agreement violations.* Violation of nominal gender agreement was created between the article and the following noun: *la* (fem) *voisin* (mas) instead of *la* (fem) *voisine* (fem) or *le* (mas) *voisin* (mas). Violation of verb agreement between the subject and the verb: *la voisine* (sing) *remplissent* (plural) instead of *la voisine* (sing) *remplit* (sing), ‘the neighbour fill’ instead of ‘the neighbour fills.’

*Word order violations.* Word order violations were constructed by altering the position of contiguous elements *voisine la* instead of *la voisine*, ‘neighbour the’ instead of ‘the neighbour’ or *remplit la voisine le frigo* instead of *la voisine remplit le frigo*, ‘fills the neighbour’ instead of ‘the neighbour fills.’

### *Violation position (early vs. late)*

The position of the violation in relation to the rest of the words in the sentence varied. For example, the two versions of the sentence below vary in that the verb agreement violation for the first version occurs early in the sentence (6 syllables), while it comes later in the second version (16 syllables).

- (6a) *Chaque semaine, la voisine remplissent le frigo après avoir fait les courses au marché.* ‘Every week, the neighbour fill the fridge after going shopping at the market.’
- (6b) *Chaque semaine, après avoir fait les courses au marché, la voisine remplissent le frigo.* ‘Every week, after going shopping at the market, the neighbour fill the fridge.’

### *Target type (intra vs. interphrasal)*

Each type of violation could have as target a nominal phrase (gender agreement between the article and the noun or word order modification between the article and the noun (*cf.* 7a)) or two phrases (number agreement

between the subject and the verb or word order modification between the subject and the verb (*cf.* 7b)).

- (7a) *A 8 heures, vendeuse la prévient les clients avant de fermer le magasin.*  
(intra)  
'At 8 o'clock, saleswoman the warns the shoppers before closing the shop.'
- (7b) *A 8 heures, prévient la vendeuse les clients avant de fermer le magasin.*  
(inter)  
'At 8 o'clock, warns the saleswoman the shoppers before closing the shop.'

### *Experimental apparatus*

Subjects' grammaticality judgments and decision times in error detections were recorded using an experimental system developed at Carnegie Mellon University: PsyScope (Cohen, MacWhinney, Flatt & Provost, 1993).

The stimuli were read by a native French speaker with the most appropriate intonational contour, tape recorded, and digitally stored in a microcomputer. The speech signals corresponding to each sentence were equalized for duration using Sound Edit Pro. The mean duration was 5620 ms for grammatical sentences and 5710 ms for ungrammatical sentences. In the ungrammatical sentences, a timer was started by a pulse on a second channel (marked by (!) in the example below), placed at the offset of the word that made the sentence ungrammatical. In other words, a violation time was taken from that place in the sentence after which no legal completion could render the sentence grammatical.

- (8) *Chaque semaine, la voisine remplissent! le frigo après avoir fait les courses au marché.* 'Every week, the neighbour fill! the fridge after going shopping at the market.'

Subjects were tested individually during a session of approximately 20 minutes; two short breaks were proposed. Subjects listened to 8 training items and afterwards the 112 experimental sentences (80 test sentences and 32 fillers) were presented in a random order at intervals of two seconds. No sentence was followed immediately by its grammatical or ungrammatical counterpart. Subjects were asked to decide whether each sentence was grammatical ('has good grammar') and indicate their choice *via* a button box, pressing a red button for ungrammatical sentences and a green one for grammatical sentences. In other words, children and adults were asked to accept grammatical sentences and reject ungrammatical ones. Children were instructed to listen carefully because they would hear each sentence only once, and to respond as quickly as possible in particular for ungrammatical

sentences as soon as they could detect the violation. By pressing the button, the subject stopped the timer started at the offset of the violation and the time needed to detect the violation was computed.

## RESULTS

### *Grammaticality judgments – error analysis*

In this on-line judgment task, adults performed with high accuracy. They failed to detect violations 3.7% of the time. Children's errors were false alarms (incorrectly accepting an ungrammatical sentence) analysed through analysis of variance: (3) age group  $\times$  (2) location  $\times$  (2) violation type  $\times$  (2) target type with subjects as a random variable, age group as a between subjects variable and location, violation type and target type as repeated measures. The error data (25.3% at 6;8; 19.9% at 8;6; 17.9% at 10;10) were transformed for the ANOVA. Data for the error rate analysis are absolute frequencies which were first transformed into relative frequencies. Secondly we did an angular transformation (found by Fisher) to avoid variance dependence on mean. The resulting variable has a nearly normal distribution. The transformation is an arc sin transformation, according to the following formula:  $y = 2 \arcsin \sqrt{p}$ , where  $y$  is the new variable and  $p$  the relative frequency (proportion). In the following ANOVA analyses,  $F_1$  represents the subject analysis and  $F_2$  represents the item analysis.

From 6;8 years on, children showed good sensitivity to grammatical violations, displaying a judgment accuracy above-chance. The error rates in each group showed a main effect of age  $F_1(2, 45) = 4.09$ ,  $p < 0.002$  and  $F_2(2, 117) = 9.17$ ,  $p < 0.002$ .

The following results were obtained in age group comparisons: 6;8 years vs. 8;6 years ( $F_1(1, 30) = 7.52$ ,  $p < 0.009$  and  $F_2(1, 78) = 13.11$ ,  $p < 0.0006$ ); 6;8 years vs. 10;10 years ( $F_1(1, 30) = 3.18$ ,  $p < 0.08$  and  $F_2(1, 78) = 8.62$ ,  $p < 0.004$ ). The main developmental changes take place between 6;8 years and 8;6 whereas there was no difference between 8;6 years and 10;10 years.

A significant main effect for target type was obtained ( $F_1(1, 45) = 26.61$ ,  $p < 0.0001$  and  $F_2(1, 117) = 2.91$ ,  $p < 0.08$ ) with greater sensitivity for intraphrasal violations involving nouns and articles compared to interphrasal violations involving subject–verb relations (agreement or word order configurations). The interaction between groups and target type was also significant ( $F_1(2, 45) = 3.71$ ,  $p < 0.03$  and  $F_2(2, 117) = 10.86$ ,  $p < 0.00001$ ). For the youngest groups (6;8 and 8;6) intraphrasal violations were easier to detect than interphrasal ones (respectively:  $F_1(1, 15) = 22.62$ ,  $p < 0.0002$  and  $F_2(1, 39) = 28.22$ ,  $p < 0.00001$ ;  $F_1(1, 15) = 8.44$ ,  $p < 0.01$  and  $F_2(1, 39) = 6.68$ ,  $p < 0.01$  whereas this difference disappeared in the oldest group.

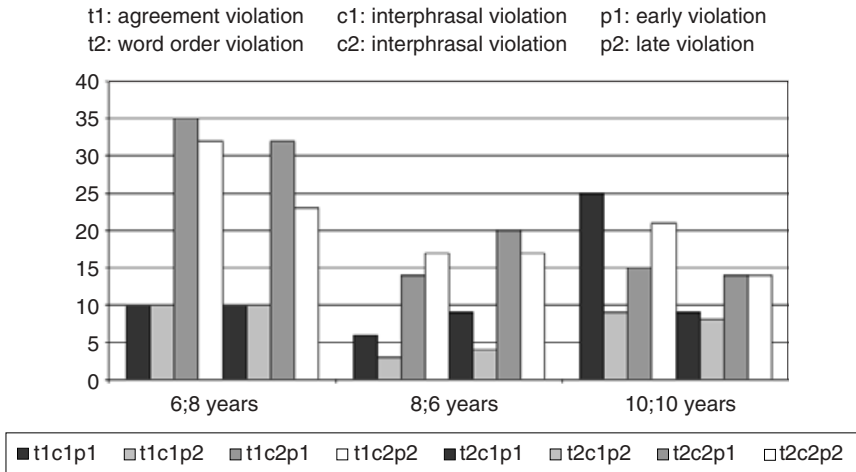


Fig. 1. Number of errors as a function of age and structure type.

There was no main effect of violation type: children did not make more errors for agreement violations than for word order alterations.

In accordance with previous results (Wulfeck, 1993) the main effect of location type did not reach significance. Children did not show a better sensitivity to violations coming late in the sentence. A qualitative analysis of errors as a function of each sentence structure type – 8 types corresponding to violation type  $T(2) \times$  target type  $C(2) \times$  position  $P(2)$  – shows consistent patterns across ages.

As can be seen on Figure 1, at all ages, four structures elicit many more errors than the others:  $t1c2p1$ ;  $t1c2p2$ ;  $t2c2p1$ ;  $t2c2p2$ . In other words, any structure including an interphrasal violation ( $c2$ ) elicits a lot of errors with no interaction with the other factors which, as previously mentioned, do not reach significance.

### Detection times

Not surprisingly, children were slower than adults in their detection of grammatical violations. The overall analysis showed a significant main effect of age on detection times,  $F_1(3, 60) = 29.78$ ,  $p < 0.0001$  and  $F_2(3, 156) = 613.41$ ,  $p < 0.0001$ . Each of the children's age group differed from the adult group: 6;8 years vs. adults  $F_1(1, 30) = 124.76$ ,  $p < 0.0001$  and  $F_2(1, 78) = 1697.85$ ,  $p < 0.0001$ ; 8;6 years vs. adults  $F_1(1, 30) = 22.20$ ,  $p < 0.0001$  and  $F_2(1, 78) = 750.18$ ,  $p < 0.0001$ ; 10;10 years vs. adults  $F_1(1, 30) = 11.01$ ,  $p < 0.002$  and  $F_2(1, 78) = 92.35$ ,  $p < 0.0001$ .

The age effect was monotonic: (detection times averaged 2573 ms at 6;8 years; 2017 ms at 8;6 years; 1123 ms at 10;10 years and 790 ms in adults.) and we tested for a linear trend across the four age levels: linear trend  $F_1(1,60)=87.25$ ,  $p<0.0001$  and  $F_2(1,156)=1793.96$ ,  $p<0.0001$ . The sum of squares for the linear trend accounted for 97% of the sum of squares between age groups (both for subject and item analyses).

Interaction of age and violation type was not significant,  $F_1(3,60)=1.07$ , and  $F_2(3,156)=8.39$ ,  $p<0.0001$ ; interaction of age and violation position was significant,  $F_1(3,60)=20.73$ ,  $p<0.0001$  and  $F_2(3,156)=47.55$ ,  $p<0.0001$  and finally interaction of age and target type was also significant,  $F_1(3,60)=2.64$ ,  $p<0.05$  and  $F_2(3,156)=4.59$ ,  $p<0.004$ .

#### *Violation type: agreement vs. word order violations*

On the basis of off-line French results (Kail & Charvillat, 1988; Kail, 1989) it was predicted that agreement violations will be detected more rapidly than word order violations, above all in the oldest groups reflecting a developmental change in cue cost in French.

The detection times obtained in this on-line experiment confirmed this prediction: agreement violations were more rapidly detected than word order violations,  $F_1(1,60)=143.88$ ,  $p<0.0001$  and  $F_2(1,156)=195.52$ ,  $p<0.0001$ , at each age level. At 6;8 years,  $F_1(1,15)=27.38$ ,  $p<0.0001$  and  $F_2(1,39)=77.75$ ,  $p<0.0001$ ; at 8;6 years,  $F_1(1,15)=16.317$ ,  $p<0.01$  and  $F_2(1,39)=6.74$ ,  $p<0.02$ ; at 10;10 years,  $F_1(1,15)=58.83$ ,  $p<0.0001$  and  $F_2(1,39)=55.58$ ,  $p<0.0001$  and in adults,  $F_1(1,15)=121.87$ ,  $p<0.0001$  and  $F_2(1,39)=147.3$ ,  $p<0.0001$ . Since agreement violations were always detected more rapidly than word order violations through age groups, there was no interaction between age and violation type as stated before.

As can be seen in Figure 2, agreement violations are detected even more rapidly in the oldest groups (10;10 years and adults). These results indicate that local violations can be resolved more quickly than topological ones, and are compatible with data obtained with English-speaking adults (Blackwell, Bates & Fisher, 1996).

#### *Violation position: early vs. late violation*

As predicted, late violations are detected more rapidly than early ones:  $F_1(1,60)=99.03$ ,  $p<0.0001$  and  $F_2(1,156)=251.51$ ,  $p<0.0001$ . This position effect is especially strong in the youngest groups (6;8 years and 8;6 years) and tends to decrease with age, as the age  $\times$  position interaction showed ( $F_1(3,60)=20.73$   $p<0.0001$  and  $F_2(3,156)=45.55$ ,  $p<0.0001$ ).

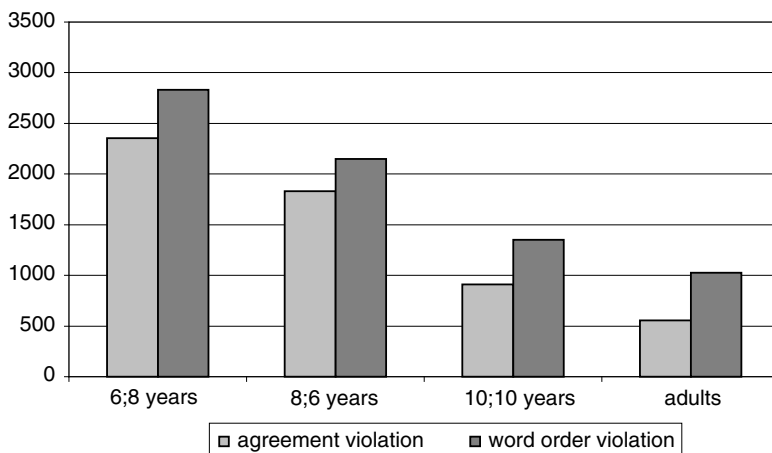


Fig. 2. Mean detection times (ms) as a function of violation type and age.

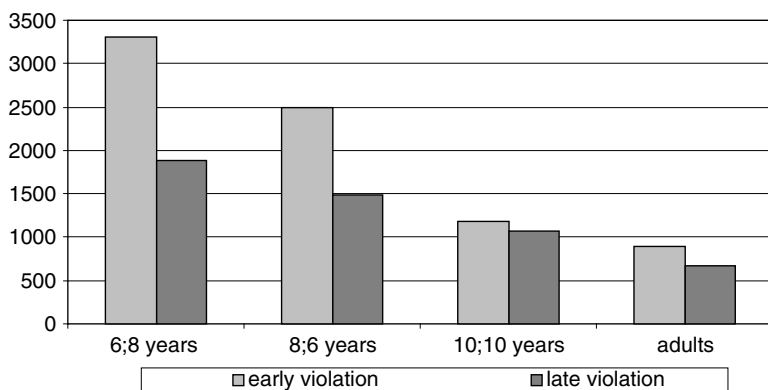


Fig. 3. Mean detection times (ms) as a function of position and age.

Each age group was faster at judging sentences with later occurring violations: at 6;8 years, ( $F_{1(1, 15)}=87.07$ ,  $p<0.0001$  and  $F_{2(1, 39)}=197.1$ ,  $p<0.0001$ ); at 8;6 years ( $F_{1(1, 15)}=20.27$ ,  $p<0.0004$  and  $F_{2(1, 39)}=67$ ,  $p<0.0001$ ); at 10;10 years ( $F_{1(1, 15)}=5.3$ ,  $p<0.05$  and  $F_{2(1, 39)}=7.64$ ,  $p<0.008$ ) and in adults  $F_{1(1, 15)}=16.79$ ,  $p<0.0001$  and  $F_{2(1, 39)}=22.06$ ,  $p<0.0001$ .

The overall interaction age  $\times$  position  $\times$  violation type is significant ( $F_{1(3, 60)}=3.51$ ,  $p<0.03$  and  $F_{2(3, 156)}=3.78$ ,  $p<0.02$ ). The only significant position  $\times$  violation type interaction observed concerned the youngest group, ( $F_{1(1, 15)}=12.72$ ,  $p<0.02$  and  $F_{2(1, 39)}=9.10$ ,  $p<0.01$ ). For early

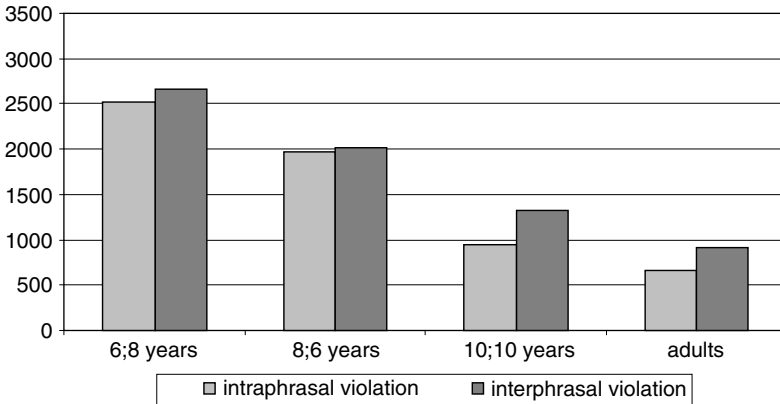


Fig. 4. Mean detection times (ms) as a function of violation target type and age.

violations, there is no effect of the violation type while for late violations, agreement violations are detected more rapidly (1466 ms) than word order ones (2272 ms).

#### *Target type: intra vs. interphrasal violations*

On the basis of Wulfeck's data (1993) in English, we predicted that intraphrasal violations would be more rapidly detected than interphrasal ones. As previously mentioned, the global analysis confirmed this prediction.  $F_{1(1, 60)} = 21.74$ ,  $p < 0.00001$  and  $F_{2(1, 156)} = 23.99$ ,  $p < 0.00001$ . The age  $\times$  target type interaction was significant ( $F_{1(3, 60)} = 2.65$ ,  $p < 0.05$  and  $F_{2(3, 156)} = 4.60$ ,  $p < 0.004$ ), indicating that this effect cannot be found at each age. In the two youngest groups (6;8 and 8;6 years) no significant effect of target type was obtained.

In contrast, a strong effect was found at 10;10 years  $F_{1(1, 15)} = 37.38$ ,  $p < 0.0001$  and  $F_{2(1, 39)} = 8.79$ ,  $p < 0.001$  and in adults  $F_{1(1, 15)} = 34.66$ ,  $p < 0.001$  and  $F_{2(1, 39)} = 30.2$ ,  $p < 0.0001$ .

The age  $\times$  target type  $\times$  position interaction is not significant. Although the target type  $\times$  position interaction was significant at 10;10 years, ( $F_{1(1, 15)} = 6.97$ ,  $p < 0.01$  and  $F_{2(1, 34)} = 3.39$  ns). Interphrasal violations were more rapidly detected when they occurred late (1234 ms) than early in the sentence (1434 ms) whereas intraphrasal violations were not affected by the position (early = 940 ms and late = 922 ms).

The age  $\times$  target type  $\times$  violation type interaction was not significant. Although the target type  $\times$  violation type interaction was significant in the adult group, significant  $F_{1(1, 15)} = 9.89$ ,  $p < 0.01$  and  $F_{2(1, 39)} = 13.21$ ,  $p < 0.01$ . For agreement violations there was no effect of target type

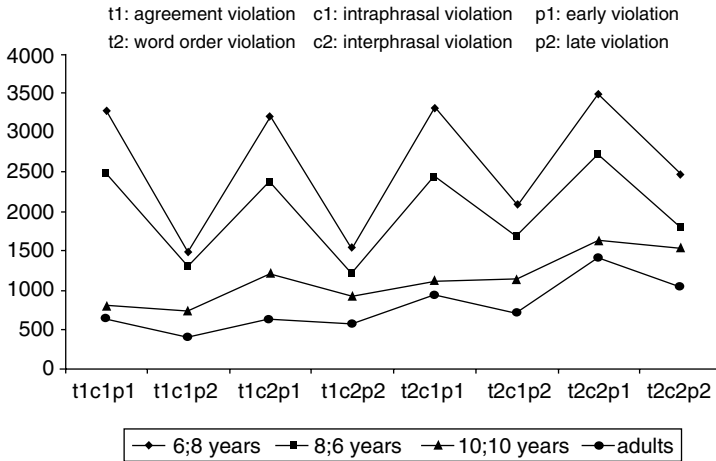


Fig. 5. Mean detection times (ms) as a function of age and structure type.

(intraphrasal = 514 ms and interphrasal = 595 ms) while for word order violations, intraphrasal violations were more rapidly detected (832 ms) than interphrasal ones (1228 ms).

A comparative age analysis of the eight structures involving violations indicates very robust results (Fig. 5)

At each age level, an intraphrasal agreement violation occurring late in the sentence (t1c1p2 = 968 ms, as global mean) is the most rapidly detected; in contrast, an interphrasal word order violation occurring early in the sentence is the most slowly detected (t2c2p1 = 2306 ms, as global mean). It is worth noting that this last type of violation was also the one which elicits more errors in the three groups of children. These findings suggest that, to some extent, children are developing essentially the same on-line types of analyses of the input as adults. Nevertheless, the data also indicate some important developmental changes concerning the respective weight of the various cues children and adults rely on during on-line sentence processing.

At 6;8 years, the most important cue is the position of the violation in the sentence which elicits a large difference: early violations take 3306 ms to be detected, while late ones take 1881 ms. The second cue is the violation type: agreement violations are detected more quickly (2356 ms) than word order violations (2831 ms). Finally, the structural cue, intra vs. interphrasal violations has no effect in this age group.

At 8;6 years, the same hierarchical pattern for cues is obtained. The dominant cue is the violation position (early = 2495 ms and late = 1488 ms) followed by the violation type (agreement = 1832 ms and word order = 2150 ms). As in the youngest group, the target cue has no effect. In both age



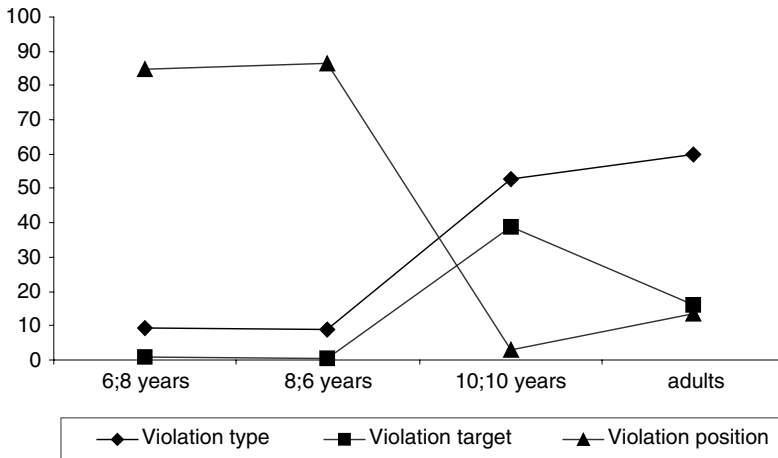


Fig. 6. Detection times: percentage of variance resulting from main effects in each age group.

groups, the eight violation patterns are exactly ranked in the same order for the relative accessibility of the violation.

At 10;10 years, decision times decrease a lot and the cue hierarchy changes. The dominant cue becomes the violation type: agreement violations are more rapidly detected (911 ms) than word order ones (1350 ms) and the structural cue is now taken into account by these children: intraphrasal violations are detected faster (943 ms) than interphrasal ones (1319 ms). Contrary to the youngest groups, the position of the violation has no significant effect.

Among the adults, the cue hierarchy is the same: the violation type remains the dominant cue (agreement = 555 ms vs. word order = 1026 ms), followed by the structural cue (intraphrasal = 669 ms vs. interphrasal = 912 ms). The position of the violation is also an important cue for adults (early = 902 ms and late = 678 ms).

This developmental course is captured in a separate ANOVA. For each age group, we have estimated percentages of variance as  $S_{\text{effect}}/S_{\text{total}}$ , the latter including all interactions. Results of this analysis are illustrated in Figure 6 which shows the clear developmental change between 8;6 and 10;10 years mentioned previously.

In the youngest groups, the largest contribution to detection times comes from the main effect of violation position. For these children, the prevalence of position effect seems to indicate that during this period, on-line processing is characterized by its dependence on linguistic context. With age, children become more sensitive to the intrinsic value of linguistic cues

whatever the context. This tendency is compatible with the lack of sensitivity of young children to the structural properties of violations.

#### DISCUSSION

The purpose of this study was to explore on-line sentence processing in French children and adults. More precisely, investigations were conducted into how two basic types of grammatical constraints, like word order configurations and morphological agreements determine the ongoing analysis of subjects engaged in an on-line error detection task.

Three main findings were observed which supported the hypotheses formulated within the Competition Model framework. First, as predicted, violations of agreement cues which are the most valid ones in French, were more rapidly detected than word order cues at each age level. Second, violation position which reflects the temporal components underlying detection processes had a great influence on sentence processing, mainly in the youngest groups. Violations which occur late in the sentence were more rapidly detected than earlier ones. Third, although children were able to make on-line grammaticality judgments, results revealed that some structural constraints of the target were not accessible under the pressure of on-line processing until 10;0.

The first finding highlights the strong convergence between our previous off-line sentence processing data in French, showing the strength of local cues such as verbal agreement and the present results showing the children's capacity to detect accurately and rapidly violations of such cues.

In previous studies (Kail & Charvillat, 1986, 1988; Kail, 1989) it was shown that, for French adults, semantic (animacy contrasts) and morphological cues (verbal agreement and clitic pronouns) were much more important than word order for sentence interpretation. In other words, French is functionally more similar to Italian than to English. Nevertheless, it was also found that young children (from 3;0 to 6;0) have an order-based strategy very like their English counterparts. Somewhere between 6;0 and adulthood, French children must go through a radical reorganization of their comprehension system, switching from word order dominance to a primary reliance on morphology and semantics. Children have to reset their internal linguistic system to favour those cues which win in conflict situations. This developmental shift illustrated a move from overall validity to conflict validity.

The present on-line results are compatible with previous ones (Charvillat & Kail, 1991) obtained in a word monitoring task showing that word order is not a crucial factor either for adults or for children (from 6;6 to 10;6) especially when sentences contained clitic pronouns. The present study provides on-line sentence processing data at a developmental phase when

children have changed their off-line dominant strategy from word order to morphological agreement cues. An interesting question could be the following: What kind of on-line results could be expected at an earlier phase (around 5;0)? Unfortunately, it has not been possible to obtain reliable on-line grammaticality judgments before the age of 6;0 but it is worth noting that some on-line methods have been tested with success in younger children.

For example, Trueswell, Sekerina, Hill & Logrip (1999) present a new method for studying young children's on-line sentence processing in which a head-mounted eye-tracking system was used. Participant's eye movement abilities were monitored as they responded to spoken instructions to move objects about on a table. The results revealed systematic differences in how children (five-year-olds) and adults process sentences with syntactic ambiguities. Despite the limitations on the five-year-olds' ability to deal with local syntactic ambiguity, the findings indicate a highly incremental processing system at this age. Other studies on children on-line processing using eye tracking have now been reported (Hurewitz, Brown-Schmidt, Thorpe, Gleitman & Trueswell, 2000; Arnold, Novick, Brown-Schmidt, Eisenband & Trueswell, 2001).

The access to the on-line sentence processing of young children is particularly crucial in a language such as French to evaluate the on-line impact of cue reliability. At 5;0 agreement cues are not yet the most reliable ones in off-line sentence interpretation since children show a great reliance on word order cues. The impact of cue reliability on adults' on-line sentence processing has been clearly established in Kempe & MacWhinney's cross-linguistic study (1999). Two languages such as Russian and German that have a parallel set of morphological cues can differ in the immediacy of processing case markers. The results suggest that 'the higher the availability of a cue (Russian), the larger the processing benefits associated with the presence of this cue and the smaller the impact of other converging information' (p. 129).

Even though the present study focused on the differential sensitivity of French subjects to basic linguistic constraints, our general framework is an integrative one. For example, the importance of word order for the on-line processing of morphological cues was underscored in a previous research done with Greek adults and children over 6;0. In a task which required the interpretation of sentences with varied word order (NVN, NNV, VNN) and case morphology, Kail & Diakogiorgi (1994) found that the decision times for agent assignment were shorter in NNV sentences where the initial information on nouns concerned the most valid cue in Greek, case morphology. Analogous results were recently reported in Italian (Devescovi D'Amico & Gentile, 1999). Italian subjects processed VNN sequences faster than NVN or NNV because of the immediate access to the most

valid cue, verbal agreement. It is interesting to remark that in Italian, VNN is not the dominant word-order ((S) VO is dominant), just as NNV is not the dominant word order in Greek. In fact, it seems that the constraints of on-line processing in languages with relatively rich morphology result in the mediation of agreement by word order.

The second finding of the present study was the strong effect of the position of the violation to be detected. Violations occurring in late position were consistently detected more quickly than earlier violations, for both word order and agreement violations at each age level. This set of results suggests that the facilitation effect of late position presents a high degree of systematicity. It is consistent with results obtained in other languages such as English as well as Italian (Wulfeck *et al.*, 1991). This effect has been interpreted as an indication that listeners are using their grammatical knowledge to build up expectations over the course of the sentence. It could also be considered as reflecting the proper inertia of the listener's processing system: when the violation occurs at the beginning of the sentence, the detection process lacks time to work at its optimal level. By contrast, when the violation is located at the end of the sentence, its occurrence probability increases and consequently the detection cost decreases. If we adopt a broader perspective, when speakers process language on-line in a conversation, they integrate information in a cumulative way. Early in a sentence, the addressee might expect that the speaker could correct it at any moment. But as the intonation indicates the speaker is approaching the end, it is much clearer that the speaker is not going to repair what happened, and this may be why late violations are detected faster.

In the youngest group of the present study, the interaction of position and violation type was significant. Detection time results indicated that young children's greater sensitivity to agreement violations seemed to enhance their ability to take advantage of context across the sentence. That is, children produced faster detection times for late occurring agreement violations compared to word order violations. Wulfeck (1993) reported similar results: English children produced faster detection times for late occurring word order violations compared to agreement violations. To summarize, in both languages, the more reliable the cue, the more efficient the context. When children become older, these contextual effects tend to decrease.

Kail & Diakogiorgi (1998) have studied the on-line integration of the morphological properties of the sentential context. This was investigated by using a task of detection of case agreement violations between articles and nouns in preverbal and postverbal NPs with Greek children (six-to-seven-year-olds) and adults. At all ages, postverbal violations were more quickly detected than preverbal violations. These findings indicated that both children and adults were capable of processing the morphosyntactic

information made available by context, and could rapidly integrate this information in the course of sentence processing. Consequently, they were able to formulate precise expectations with respect to subsequent information in the sentence. Results suggested the existence of activation resources which were highly developed even in young children, that allowed for both the rapid activation of representational elements of the sentence and the maintenance of this activation for subsequent use in the course of sentence processing. However, the effect of context was not always the same: in high perceptible case substitutions, context facilitated the detection of case violations. When the violation was slightly perceptible, the strong anticipation of the correct form inhibited the rapid activation of the perceived form and this considerably slowed its detection. The effect of context thus depended both on the perceptibility of the violation and the frequency of case substitute suffixes.

The third factor examined the role of the sentence structural constraints. The prediction according to which violations within the same constituent should be easier to detect than violations concerning elements belonging to different sentence constituents was supported by the oldest children group (10;10 years) and by the adults.

On the one hand, such a late mastery could be interpreted in terms of a limited working memory capacity in young children. In interphrasal violations, the listener encountered difficulties in decoding the surface form information, attachments between units cannot be made locally and placed more load on the processor.

On the other hand, with respect to agreement violations, a potential explanation may be found within the two violation types used in the experiment. Intraphrasal violations were gender nominal agreements between the article and the noun. On the contrary, interphrasal violations were number verbal agreement between the noun and the verb. In a recent study conducted with French children (11;0) and adults, Lambert & Kail (2001) have shown that nominal agreement violations including adjective–noun were detected more rapidly than subject–verb agreement violations.

Some previous results obtained by Wulfeck (1993) provide evidence that English children show greater sensitivity to word order violations as compared to morphological ones, but no processing speed advantage, contrary to expectations based on cue validity. In contrast, in the present study focusing on French as well as in previous studies focusing on Greek (Kail & Diakogiorgi, 1998), at each age level, we obtained decision times that were in accordance with cue validity in the corresponding language.

A challenge for these crosslinguistic studies is to determine more precisely how the developmental increase in on-line processing capacities interacts with cue validity.

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APPENDIX

UNGRAMMATICAL SENTENCES: AN EXAMPLE OF LIST

- A1. Chaque semaine, après avoir fait les courses au marché, le voisin remplit le frigo.
- A2. En hiver, dans la salle de gymnastique, la fillette suspendent les cerceaux.
- A3. Certaines fois, maîtresse la punit les élèves pour obtenir le silence dans la classe.
- A4. Chaque jeudi, écrit la banquière des factures pour tous les commerçants de la ville.
- A5. Aujourd'hui, pour fêter la réussite du concert, chanteuse la reçoit un bouquet.
- A6. Tous les soirs, jusqu'à la tombée complète de la nuit, relit la comtesse des poèmes.
- A7. Quelques fois, le championne vomit le repas par peur de perdre la compétition.
- A8. A midi, la serveuse choisissent des gâteaux dans la meilleure pâtisserie de la ville.
- B1. Chaque été, avec du sable et des coquillages, la garçon construit des châteaux.
- B2. Sur la piste, pendant la dernière partie de la course, le coureur ressentent des douleurs.
- B3. Sur l'île noire, bandit le enfouit le trésor après avoir coulé le bateau.
- B4. Tous les ans, obtient le nageur une médaille pour l'exécution du meilleur plongeur.
- B5. A Noël, avant de décorer le magasin, patron le garnit le sapin.
- B6. Tous les mois, afin de gagner beaucoup d'argent, revend le voleur des bijoux.
- B7. Dans le stade, la sportif franchit les obstacles en courant le plus rapidement possible.
- B8. De nos jours, le docteur guérissent les malades grâce aux progrès des recherches médicales.
- C1. Le matin, avant de s'envoler dans les airs, le sorcière saisit un balai.
- C2. Chaque dimanche, avant de recevoir des invités, la princesse fleurissent le château.
- C3. Le mardi, marchande la fournit du poisson à tous les habitants du village.
- C4. Chaque week-end, salit la danseuse un tutu en faisant des exercices au sol.
- C5. Très souvent, sur un petit carnet personnel, cliente la inscrit les achats.
- C6. Chaque année, très haut dans les montagnes du pays, conduit la bergère les moutons.



APPENDIX (*cont.*)

- C7. Pour dîner, le cousin farcit le poulet après avoir préparé les entrées.
- C8. Le lundi, la lingère blanchissent les mouchoirs en utilisant un nouveau produit.
- D1. Fréquemment, en racontant de très longues histoires, la papy endort les enfants.
- D2. Au village, grâce à l'aide de tous les ouvriers, le maçon bâtissent des maisons.
- D3. Depuis hier, facteur le transmet le courrier au volant d'une fourgonnette jaune.
- D4. A l'église, bénit le curé les mariés après avoir célébré la messe.
- D5. Aux frontières, après avoir vérifié les passeports, douanier le défait les valises.
- D6. Jusqu'au soir, en passant par différentes pistes, descend le skieur la montagne.
- D7. Sans pitié, la chasseur abat le gibier avec une grande carabine à plombs.
- D8. Dans la rue, le gendarme poursuivent les bandits pour récupérer l'argent volé.
- E1. Dans le pré, après avoir nettoyé la roulotte, le gitane étend les tapis.
- E2. De bonne heure, après avoir récolté de l'avoine, la fermière nourrit les chevaux.
- E3. Au salon, coiffeuse la noircit les cheveux avec des shampooings provenant de Chine.
- E4. Vers 7 heures, prévient la vendeuse les clients avant de fermer le magasin.
- E5. Sous la tente, après avoir lu les plans de bataille guerrier le éteint la lumière.
- E6. En montagne, après avoir marché de longues heures, atteint le grimpeur le sommet.
- E7. En été, la pêcheur rejoint le rivage une fois le bateau rempli de poissons.
- E8. A Paris, le boxeur surprennent le public en gagnant contre le champion du monde.