Background/Study Context: A goal of language and aging research is to determine the nature of change in language-processing skills. In this study the authors examine the role of age and use of cues (e.g., word order, verbal agreement, sentence structure) on online sentence processing.

Methods: French young and older adults were asked to detect grammatical violations in sentences as quickly as possible. Detection times were analyzed as a function of participants' age and sentence characteristics (i.e., violation type, span, and position).

Results: Above and beyond main effects of participant's age and linguistic features, results showed age-related differences in effects of linguistic cues on sentence processing and important individual differences during aging in hierarchies of cue strength.

Conclusion: Young and older adults use similar linguistic cues in the online process, but loss of cognitive resources with age shows a cost of cue use and a greater use of context.

The goal of research on language and aging is to understand how language-processing skills change with age during adulthood. The present research contributes to this enterprise by examining the role
of age on online sentence processing. We investigate online grammaticality judgments so as to determine how young and older adults integrate two basic types of grammatical constraints during language comprehension, namely word order configurations and morphological agreements. The theoretical basis of this experiment is one particular psycholinguistic model of language processing, namely the Competition Model (CM). This model was first proposed by MacWhinney and Bates (1989). We base the present empirical work on the CM because it has provided definitions of linguistic factors that guided a wide variety of studies, ranging from cross-linguistic, developmental, and clinical investigations of language processing and performance. Also, it has not been used in aging studies, though it enables specific predictions in the context of older adults’ sentence processing. In particular, CM offers the possibility to detect age differences in strategies that participants use to process language material and link these strategy variations with features of linguistic materials. Finally, such models may help understand why some language functions decline during aging (e.g., complex syntactic processing) whereas others are well preserved or are less affected in older adults (e.g., semantic processing at lexical and discourse levels). Before outlining the logic of the present work, we briefly review previous findings on aging and language processing and provide an overview of the main assumptions within CM that guided the present work.

**Aging Effects in Language Comprehension**

Research on aging effects in language processing concerns not only how performance changes with age (Do young and older adults have similar versus different performance? At what age does performance change if it changes and under which conditions do we see age-related changes?), but also how processes change or remain stable with age (Do young and older adults use the same versus different processes in language production and comprehension? How do older adults compensate age-related deficits in cognitive resources during processing language tasks?). Effects of age on language-processing skills have often been studied with offline methods in which participants are asked to answer questions after a sentence (or a text) has been presented. Most of these studies have found age-related declines in performance, such that, for example, older participants tend to have poorer comprehension scores, poorer memory of language material, and more problems with retrieving lexical information from memory or with understanding or remembering complex sentences or text material (e.g., Kemper & Summer, 2001; Van der Linden et al.,
Aging effects on language comprehension have also been investigated with online methods, in which participants are asked to read or hear language materials and asked to perform a variety of tasks (e.g., grammaticality, word/nonword judgment). Above and beyond general age-related declines found in studies with offline methods, investigations of online measures of performance revealed some specific effects that are fruitful to understand how young and older adults differ in language processing. For example, in sentence processing, the main focus of the present study, Stine-Morrow and colleagues have found smaller wrap-up effects (i.e., they allocate less time at the end of sentences than young adults), in older adults at both intra- and intersentence boundaries (e.g., Stine, Cheung, & Henderson, 1995; Stine-Miller, Miller, & Nevin, 1999; Stine-Morrow, Ryan, & Leonard, 2000).

Several hypotheses have been proposed to account for age-related changes in language-processing skills. These hypotheses range from specific psycholinguistic hypotheses like weakened connections among representational units and deficits in transmission between connected representations (e.g., Burke & Mackay, 1997; MacKay & James, 2004) to more general cognitive hypotheses like decreased general processing resources, such as working memory (e.g., Waters & Caplan, 2001, 2004), inhibition (e.g., Hasher, Lustig, & Zacks, 2007), or processing speed (e.g., Kail & Salthouse, 1994). One issue that previous studies did not address and that we address in the present work concerns how young and older participants integrate grammatical constraints during language comprehension.

Sentence Processing in the Competition Model

The present study was theoretically guided by the Competition Model, a computational model of language processing proposed by MacWhinney and colleagues (MacWhinney, 1987; Bates & MacWhinney, 1989). Although this is not the only model of language processing that could serve as a framework for aging research, the Competition Model was chosen because it makes several assumptions that are crucial for the present work. First, it assumes that the parser is able to immediately integrate all available linguistic information. Second, the informational value of linguistic forms in a given language plays a probabilistic role in mapping surface forms to their underlying functions as directly as possible. Third, the Competition Model assumes parallel processing such that linguistic cues can be processed in parallel via a common set of perceptual, representational,
and retrieval mechanisms. Fourth, the language processor can use compound input cues that work across linguistic boundaries (e.g., prosody, morphology, lexicon, and syntax). Fifth, language comprehension is achieved via different cues cooperating and competing with each other. When different cues compete, the coevaluation of different linguistic sources becomes necessary and is directly determined by the validity and the costs of these cues in a given language. Cue validity includes “cue availability” (how often a cue is there when needed) and “cue reliability” (how often an available cue leads to the right interpretation). Cue validity, availability, and reliability are properties of linguistic inputs. Validity can be measured directly in samples of spoken or written language. For example, to assign the agent function, word order has a higher validity value in English than animacy or morphological agreement, whereas the opposite pattern characterizes Italian or French. Thus, English speakers rely more on word order in sentence comprehension, whereas Italian and French speakers rely more on animacy and morphology. According to the processing hypotheses proposed by the CM, cue strength in a given language (i.e., the probability assigned by children or adults to a specific linguistic form in order to assign a specific function) is determined by cue validity (see Kail, 1999, for a review). The last important assumption within the CM concerns cue cost. Cue cost refers to the amount and type of processing required for the activation of a given form when cue validity is held constant. In line with an earlier proposal by Ammon and Slobin (1979), Kail and Charvillat (1988) proposed that cues are distributed along a processing-type continuum that ranges from local (an interpretation can be computed as soon as the cue is encountered) to topological (the interpretation is delayed until all information is stored and compared) processing. Local processing is characterized by low cost. In some languages such as French (Kail & Charvillat, 1988), Italian (Devescovi, D’Amico, & Gentile, 1999), or German (Lindner, 2003), cue validity and cue cost interact during development. The two issues addressed in the present work concern whether cue strength changes with adults’ age and whether costs of linguistics cues change with aging. Addressing these two issues was expected to help further our understanding of age-related changes in online sentence processing.

**Online Sentence Processing and Grammaticality Judgments**

Different experimental methods have been successfully used to investigate online sentence processing such as self-paced listening or reading (Booth, MacWhinney, & Harasaki, 2000), cross-modal priming
(Mckee, Niccol, & Daniel, 1993), or eye-tracking (Trueswell, Skerina, Hill, & Logrip, 1999). One of the most productive methods is real-time grammaticality judgment. In grammaticality judgment tasks, participants are shown sentences that violate or not grammatical rules and have to say as soon as possible when they detect an error in ungrammatical sentences. We base this work on previous findings showing that different violation types affect grammaticality judgment performance. This grammaticality judgment method has been used with a wide variety of population, ranging from normal adults and children (e.g., Kail & Bassano, 1997; Lambert & Kail, 2001) to clinical research with aphasics (e.g., Wulfeck, Bates, & Capasso, 1991). It has been successfully used to examine online integration of linguistic cues during development in various languages (Modern Greek: Kail & Diakogiorgi, 1998; French: Kail, 2004; Portuguese: Kail, Costa, & Hub Faria, 2010; Swedish: Kail, Kihlstedt, & Bonnet, 2012). It is used here for the first time to understand how young and older adults use linguistic information during language comprehension.

Previous works with young adults and children found that participants were faster at detecting word agreement violations than word order violations (e.g., Kail, 1989; Kail & Charvillat, 1988; Kail & Diakogiorgi, 1998; Wulfeck, Bates, Krupa-Kwiatowski, & Saltzman, 2004). They were faster at detecting errors in sentences like “The neighbor fill the fridge” than in sentences like “Fills the neighbor the fridge.” The present work tested whether older adults would show the same or a different pattern. One prediction was that older adults would show larger difference between word agreement and word order violations than young adults, suggesting that morphology is becoming an increasingly strong cue with age. Alternatively, older adults might show the same pattern as young adults, showing stability with age of cue cost of morphology during sentence comprehension.

Also, previous studies found that participants were slower at detecting syntactic violations when these violations are at the beginning of a sentence (e.g., Every week, the neighbor fill the fridge after shopping at the market) as compared to when they are at the end (e.g., Every week, after shopping at the market the neighbor fill the fridge). Kail (2004) showed that this early-late difference tends to decrease with increasing age in children. This violation position has been interpreted as resulting from listeners’ using their grammatical knowledge to build up expectations over the course of the sentence. The two alternative predictions under test here were that older adults would show a larger early-late difference than young adults, or no difference. The former would be an indication of older adults’ relying
more on their grammatical knowledge to build up expectations, possibly as a way to maximize efficiency at language comprehension. The latter would suggest that young and older adults differ in how they use grammatical knowledge to build up expectation, such that older adults would use this knowledge to a lesser extent than young adults. Such a possibility would suggest difficulties in older adults to use their grammatical knowledge to build up expectations. Such an outcome is possible given increased limited processing resources with aging. This latter result would have implications for the CM, as the model does not assume such a sentence processing strategy.

Finally, one previous result that is relevant to the present work is consistent with one important assumption within the CM. According to the CM, the processing system tries to assign cues to meaning as soon as possible, integrating each piece of linguistic information into larger structures compatible with the information obtained up to that point. This assumption predicts that participants should be faster to judge sentences with intraphrasal violations than to judge sentences with interphrasal violations. Intraphrasal violations are found in sentences with violations of elements belonging to the same constituent (e.g., word order violation in the nominal phrase), whereas interphrasal violations are found in sentences with violations of elements belonging to different main constituents (e.g., word order violation across two constituents). Previous studies in languages such as English (Wulfeck, 1993), French (Lambert & Kail, 2001; Kail, 2004), Portuguese (Kail, Costa, & Hub Faria, 2010), or Swedish (Kail, Kihlstedt, & Bonnet, 2012) found exactly this pattern. Participants were slower at detecting interphrasal violations (e.g., At 8 o’clock, warns the saleswoman the shoppers before closing the shop) than intraphrasal violations (e.g., At 8 o’clock, saleswoman the warns the shoppers before closing the shop). Such an effect of violation span was interpreted as resulting from demands of the working-memory system to detect interphrasal violations. In interphrasal violations, attachments between units place load on the processor, as these attachments cannot be made locally. Given the previously mentioned decreased working-memory resources with age, we tested the possibility that this effect of violation span (i.e., interphrasal-intraphrasal difference) would increase with age.

In sum, in the present experiment, young and older participants were asked to accomplish a grammaticality judgment task in which half the sentences were correct and half had a syntactic violation. Participants had to detect violations as soon as possible when sentences with violations were presented. Syntactic violations could concern word order or word agreement, and they could be placed early
versus late in the sentence. Syntactic violations could concern elements belonging to the same constituent or to different constituents (intra- vs. interphrasal violations). We tested two sets of predictions in this experiment. First, the hypothesis that cue strength changes with age predicts interactions between age and violation type, violation span, or violation position. That is, compared to young adults, older adults were expected to show larger difference between word order and word agreement violations, and would be more influenced by violation position (early vs. late errors in the sentence) and by violation span (intra- vs. interphrasal errors). Second, the hypothesis that changes of costs of linguistic cues with age predicts that the weight of each type of linguistic cues on grammaticality judgment times should be different in young and older adults.

METHODS

Participants

Sixty-four adults, French native speakers voluntarily participated in the study. They were divided into two age groups. The first group included 32 young adults (16 females; mean age = 23 years, SD = 1.8; range 20–27) who were students at the University of Provence, Marseille (France); they had 14 years of formal education. The second group of 32 older adults (23 females; mean age = 77 years, SD = 5.8; range 65–88) had a comparable level education. All older participants reported no history of neurological or psychiatric disease, lived autonomously at home, and had almost perfect performance at the Mini-Mental State Examination (mean = 29.48, SD = 0.72; range = 28–30). Both age groups had comparable performance at the Mill-Hill Vocabulary test. Means were 24.8 (SD = 4.3; range = 14–31) and 26.6 (SD = 4.1; range = 20–34) for young and older adults, respectively.

Linguistic Material

Stimuli were sentences with an animate subject, a verb, a direct object, and an adverbial transitive complement that can easily be shifted (i.e., placed before or after the subject noun). In the experiment, we used 2nd and 3rd conjugations in which the plural inflection is audible (e.g., la femme remplit vs. les femmes remplissent, “The woman fills” vs. “The women fill”). The overall length of each sentence was controlled (21 to 25 syllables).
A total of 360 sentences were constructed consisting of 40 grammatical sentences and 320 ungrammatical sentences with the same contents as the grammatical sentences. There were five different sentences in each 2 Violation Positions (early vs. late) × 2 Violation Spans (intraphrasal vs. interphrasal) × 2 Violation Types (word order vs. agreement) condition. For each participant, this yielded 40 grammatical and 40 ungrammatical sentences to judge. To avoid semantic repetitions across violations, eight lists of 40 grammatical and 40 ungrammatical sentences were generated. For a given semantic content, each list contained a different violation and the corresponding grammatical sentence. Each participant was assigned to one list and processed 80 sentences. The linguistic material was that used in Kail’s study (2004). An example is given in Appendix 1.

**Experimental Apparatus**

Participants’ grammaticality judgments and error detection times were recorded using E-Prime. The stimuli were read by a native 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. In the ungrammatical sentences, a timer was started by a pulse on a second channel, 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, marked with ! as in the following example:

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"Every week, fills the neighbor ! the fridge after going shopping at the market."
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Participants were individually tested during a session of approximately 20 min. They listened to eight training items. Following this training session, 80 test sentences were presented in a random order, with a 2-s interval in-between each sentence. No sentence was followed immediately by its grammatical or ungrammatical counterpart. Participants were asked to decide whether each sentence was grammatical (“has good grammar”) and indicate their choice via the Carnegie Mellon University button box, pressing a red button for ungrammatical sentences and a green one for grammatical sentences. Participants 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 participant stopped the timer that started at the offset of the violation. Therefore, grammaticality judgment times were the times between offset of violations and participants’ responses. In order to maintain participants’ attention and to make sure both young and older participants remember instructions all throughout the experiment, the experimenter repeated instructions several times before and during the experiment. When the experiment started in earnest, no participants had difficulties with the procedure and the task.

**RESULTS**

Age-Related Differences in Grammaticality Judgment Performance

**Accuracy**

Four old participants have been excluded from analyses because they were unable to perform the task. Participants included in analyses correctly performed the task even though older participants showed a higher percentage of undetected violations than young ones (10.4% vs. 1.6%). Concerning accuracy of online judgments, young and older adults’ undetected violations consisted of overacceptance (i.e., incorrectly accepting an ungrammatical sentence). What can be called “errors” have to be analyzed before examining the main dependent variable, detection times for correctly rejected ungrammatical sentences.

A within-participants analysis of variance (ANOVA) was carried out in the older group on mean percent errors, with a 2 (violation position) × 2 (violation span) × 2 (violation type) design. Significant effects were found for violation position, $F(1, 30) = 4.68, p < .05$, and violation span, $F(1, 30) = 5.06, p < .05$. These effects showed older adults’ greater sensitivity for late (12.2%) than for early (8.6%) violations, and for interphrasal (13%) than for intraphrasal (7.8%) violations. The main effect of violation type was not significant, nor were any interactions among violation position, span, or type ($F$s < 1.51).

**Detection Times**

Two sets of analyses on detection times were run to address the two main issues of the present project. First, analyses of times to detect ungrammatical sentences enabled us to determine whether cue strength changes with age or whether both young and older adults’
language comprehension systems are sensitive to linguistic cues such as word order, verbal agreement, as well as sentence structures. Second, changes of costs of linguistic cues were examined by determining their relative contributions to detection times so as to know whether variances of young and older adults’ detection times accounted for by each type of linguistic cues were different.

To determine whether cue strength changes with age, a mixed-design ANOVA on mean detection times (see means and SDs in Table 1) for correctly rejected ungrammatical sentences was carried out with a 2 (participants’ age) × 2 (violation position) × 2 (violation span) × 2 (violation type) design in which participants’ age was the only between-participants factor. ANOVAs were run with participants (F1) or sentences as a random factor (F2). Unless otherwise noted, all significant effects were significant to at least p < .05. The same analyses were run on mean detection times and on standardized (z-scores) latencies. Both analyses showed the same effects. Therefore, we report analyses on mean detection times.

Not surprisingly, older adults were much slower (1850 ms) than young adults (924 ms) in detecting grammatical violations, $F(1, 62) = 39.05$, $F(2, 78) = 416.85$. Moreover, the main effects of violation position ($F(1, 62) = 4.31$, $F(2, 78) = 7.84$), violation span ($F(1, 62) = 65.76$, $F(2, 78) = 73.18$), and violation type ($F(1, 62) = 64.17$, $F(2, 78) = 119.8$), and Age × Violation Position interaction ($F(1, 62) = 10.21$, $F(2, 78) = 5.05$) were significant.

Most interestingly, the Age × Violation Position interaction was significant ($F(1, 62) = 10.1$, $F(2, 78) = 5.05$). Young adults needed

<p>| Table 1. Mean detection times (in ms) for each type of ungrammatical sentence, in young and older adults |
|---------------------------------------------------|---------------------------------------------------|---------------------------------------------------|
| Early violations                                 | Late violations                                  |                                                   |</p>
<table>
<thead>
<tr>
<th>Intraphrasal</th>
<th>Interphrasal</th>
<th>Mean</th>
<th>Intraphrasal</th>
<th>Interphrasal</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young adults</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Word order violations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intraphrasal</td>
<td>1002</td>
<td>1369</td>
<td>1186</td>
<td>1076</td>
<td>1291</td>
</tr>
<tr>
<td>Interphrasal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Older adults</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fast older adults</td>
<td>1357</td>
<td>1943</td>
<td>1650</td>
<td>1484</td>
<td>1693</td>
</tr>
<tr>
<td>Slower older adults</td>
<td>2325</td>
<td>2722</td>
<td>2524</td>
<td>2269</td>
<td>2373</td>
</tr>
<tr>
<td>Word agreement violations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intraphrasal</td>
<td></td>
<td>780</td>
<td>669</td>
<td>555</td>
<td>759</td>
</tr>
<tr>
<td>Interphrasal</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Older adults</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fast older adults</td>
<td>959</td>
<td>1360</td>
<td>1159</td>
<td>819</td>
<td>1160</td>
</tr>
<tr>
<td>Slower older adults</td>
<td>2254</td>
<td>2604</td>
<td>2429</td>
<td>2098</td>
<td>2180</td>
</tr>
</tbody>
</table>
comparable amounts of times to detect late and early violations (926 vs. 922 ms; $F_s < 1$). In contrast, older adults were faster at rejecting ungrammatical sentences with late occurring violations than early violation sentences (1760 vs. 1940 ms; $F_1(1, 31) = 12.25$, $F_2(1, 39) = 9.54$). Moreover, the lack of significant $Age \times Violation \ Span$ interaction, $F_1(1, 62) = .67$, $F_2(1, 78) = 3.26$, revealed that both young and older adults rejected sentences with intraphrasal violations more quickly than sentences with interphrasal violations (798 vs. 1050 ms, $F_1(1, 31) = 23.3$, $F_2(1, 39) = 44.2$, in young adults; 1696 vs. 2004 ms, $F_1(1, 31) = 47.5$, $F_2(1, 39) = 38.7$, in older adults). Similarly, the lack of significant $Age \times Violation \ Type$ interaction revealed that both young and older adults detected ungrammatical sentences with agreement violations more rapidly than ungrammatical sentences with word order violation (663 vs. 1185 ms, $F_1(1, 31) = 82.30$, $F_2(1, 39) = 106.88$, in young adults; 1678 vs. 2021 ms, $F_1(1, 31) = 14.05$, $F_2(1, 39) = 37.84$, in older adults).

In summary, of the three crucial interactions involving the age factor tested here, only one was significant—the $Age \times Position$ interaction. It resulted from younger adults not showing larger detection times for early violations compared to late violations, in contrast to older adults. The other two crucial interactions, $Age \times Violation \ Span$ and $Age \times Violation \ Type$, were not significant. These latter results indicated that both young and older adults were sensitive to whether grammatical violations were inter- or intraphrasal and to whether it concerned an agreement or a word-order violation.

The next analysis sought to determine whether young and older participants rely on linguistic factors tested here with equal weights. Following Kail (2004), a separate ANOVA was conducted. For each group, we have estimated percentages of variance as $S_{effect}/S_{total}$, the later including all interactions. This analysis gives an information ($\eta^2$) about the magnitude of the effect of each factor (violation position, violation span, and violation type); in other words, its contribution to detection times. Figure 1 displays percentages of variance accounted for by each main effect, separately in young and older adults. In young adults, the largest contribution to detection times came from violation type (79%), then violation span (18%), and finally violation position (3%). This replicates Kail’s (2004) findings. In older adults, violation type remained the most important contributing factor to detection times (44%); but it made smaller contribution than in young adults. In contrast, the contribution of the other two factors, violation span (36%) and violation position (12%), increased in older adults.
Careful examination of individuals’ detection times suggested large individual differences in older adults. To more systematically analyze these individual differences, we separated older individuals into two groups, so-called fast and slower older adults, with 16 participants in each group. Group assignment of older adults was based on participants’ times to detect agreement errors occurring late in intraphrasal sentence. These agreement, late intraphrasal violations were the easiest items (i.e., they were detected most quickly by young and older adults) both here and in Kail’s (2004) study. In this easiest condition, mean detection times were 819 ms (range = 473–1196 ms) and 2098 ms (range = 1283–3265 ms) for fast and slower older adults, respectively. Note that both groups of older adults had similar mean scores (mean = 26.5) on the Mill-Hill Vocabulary test and comparable age (means = 77 and 76.7 for fast and slower older adults, respectively).
Again, two series of analyses were run. The goals of these analyses were to determine whether cue strength and cue cost change with age differently in fast and slower older adults. First, two series of ANOVAs were run to compare aging effects on cue strength in fast and slower older adults. The first one included the group of young adults, and the second one focused on each of the two groups of older adults. The first ANOVA involved a mixed design, 3 (young, fast, and slower older adults) \times 2 (violation position) \times 2 (violation span) \times 2 (violation type). Then, analyses in each of the two groups of older adults involved within-participants ANOVAs, 2 (violation position) \times 2 (violation span) \times 2 (violation type). Again, these ANOVAs were run with participants (F1) and items (F2) as random factors. The second series of analyses aimed at determining whether the relative contributions of each factor (violation span, position, and type) in fast and slower older adults’ detection times were the same (or different). In this second series of analyses, we examined percentages of variances accounted for in detection times by each factor.

**Accuracy**
There was a significant main effect of group on error rates, F(2, 61) = 18.77, as young adults (1.6%) made fewer errors in detecting ungrammatical sentences than fast older adults (12.7%) or slower older adults (8.1%). Although slower older adults tended to make fewer errors than fast older adults, the difference between these two groups of older adults was not significant, F(1, 30) = 2.33. In fast older adults, violation span was the only factor to have a significant effect on error rates, F(1, 15) = 4.81, indicating that fast older adults made fewer errors at detecting intraphrasal violations (8.8%) than interphrasal violations (16.6%). In the slower older adults, none of the factors were significant (Fs < 3.53).

**Mean Detection Times**
Mean detection times and standard deviations as a function of groups are shown in Table 1. The overall analysis showed a significant effect of group on detection times, F1(2, 61) = 48.62, F2(2, 117) = 255.41. Both groups of older adults differed from each other (1347 vs. 2353 ms), F1(1, 46) = 24.45, F2(1, 78) = 374.98. Also, each group of older adults differed from that of young adults: young versus fast older adults, F1(1, 46) = 12.38, F2(1, 78) = 70.39; and young versus slower older adults, F1(1, 46) = 96.75, F2(1, 78) = 880.19. The following main and interaction effects also came out as significant: violation span, F1(1, 61) = 67.30, F2(1, 117) = 71.84; violation type,
Analyses in each of the two groups of older adults revealed that fast older adults showed no significant difference between early and late violations, $F_s < 2.58$, in contrast to slower older adults who took more time to detect early than late violations (2476 vs. 2230 ms), $F(1, 15) = 11.40, F(2, 39) = 19.97$. This shows that fast older adults displayed the same insensitivity as young adults to violation position. It is interesting because it suggests that the role of contextual (or violation position) information in older adults is mediated by speed of processing. Indeed, when age was kept constant (by comparing detection times for early vs. late violations in older adults of comparable age), the effect of violation position was a significant constraint of online sentence processing in slower older adults only.

The Group × Violation Span interaction was not significant, $F(2, 61) = 1.56, F(2, 117) = 2.01$, revealing that all participants detected intraphrasal violations more quickly than interphrasal violations. More specifically, mean detection times for intra- and interphrasal sentences were 1154 versus 1539 ms ($F(1, 15) = 38.85, F(1, 39) = 38.27$) in fast older adults, and 2236 versus 2469 ms ($F(1, 15) = 12.90, F(2, 39) = 9.66$) in slower older adults.

The Violation Position × Violation Span was significant only in slower older adults, $F(1, 15) = 4.14, p < .05$ and $F(2, 39) = 6.57, p < .013$, but not in fast older adults, $F(1, 15) = 3.19, p < .09$. Slow older adults detected more rapidly interphrasal violations occurring at the end of the sentence (2276 ms) than at the beginning of the sentence (2663 ms); this position effect was not found for intraphrasal violations in slower older adults (2290 vs. 2184 ms, $F_s < 1$).

Only fast older adults were quicker at detecting agreement violations than word order violations (1074 vs. 1619 ms, $F(1, 15) = 48.31, F(2, 39) = 94.53$). Slower older adults detected agreement violations (2284 ms) and word order violations (2422 ms) equally rapidly, $F_s < 1.82$.

To summarize, slower older adults showed a specific processing profile. In particular, they did not take into account the morphological cues that have high validity in French and can be accessed at low cost as compared to word order. At the same time, they became more dependent on contextual information, whereas the other two groups, young adults and fast older adults, did not need to rely on this contextual information.
To compare the costs of cues across groups, we have estimated percentages of variance of detection times accounted for by each factor. Again, this was determined by comparing percentages of variance accounted for ($S_{\text{effect}}/S_{\text{total}}$) in mean correct detection times of ungrammatical sentences by each of the three factors (violation position, violation span, and violation type) tested here (see Figure 1).

Recall that the largest contribution to young adults’ detection times came from the violation type (79%) with rapid access to morphological violations, then violation span (18%) with faster processing of intraphrasal violations, whereas the violation position (3%) was not an important cue for young adults’ online grammaticality judgments.

In fast older adults, the same hierarchy of cues was observed but relative weights of cues changed. Compared to young adults, violation type decreased (62%) in fast older adults but remained the dominant cue, followed by violation span, which increased (31%); the violation position remained the least important and weak cue (3%).

Very interestingly, the hierarchy of cues changed in slower older adults. The dominant cue was violation position (39%), with faster processing of grammatical violations occurring later in the sentence, thereby taking advantage of the syntactic contextual information. Then, violation span (35%) was an important cue, and the interaction between violation position and violation span explained 13% of variance. The other main change concerned the decreased importance of violation type (12%), as if these slower older adults were not able to exploit the low cue cost of morphology in French, whereas they remained able to take advantage of the less complex intraphrasal violations.

**DISCUSSION**

We found the following phenomena that are important for understanding how young and older people process sentences in real time. First, both young and older participants’ grammaticality judgment were influenced by the type of violations as well as by violation position in the sentence and whether violations concerned elements belonging to the same constituent versus to different constituents. Second, cost of linguistic cues varied with participants’ age. Finally, there were individual differences in aging effects on grammaticality judgments. In this section, we discuss the implications of these findings to further understand age-related changes in online sentence processing.
The present findings replicate and complement previous findings regarding the use of linguistic cues in sentence comprehension and effects of age on this use. The present results replicate the fact that participants are faster at detecting violations of agreement cues than word order cues. This was found previously in both French young adults and children (e.g., Kail, 2004) and shows that grammatical morphology is a strong cue used by the system during online comprehension of sentences. This is consistent with CM assumption that valid cues in a given language guide language comprehension. Here, the importance of morphosyntactic violations was also found in older adults, suggesting that, like young adults, grammatical morphology is used by older adults during online sentence processing.

Moreover, the present findings replicated the fact that intraphrasal violations were detected more quickly than interphrasal violations. This was found in several previous studies in young adults (e.g., Wulfeck, 1993; Lambert & Kail, 2001; Kail et al., 2012); it was also found here in older adults. This effect has been thought to result from the larger demands of working-memory resources to make attachments between units when detecting interphrasal violations as compared to when detecting intraphrasal violations. Note that despite decreased working-memory capacities with age, the demands did not exceed available working-memory resources in older adults enough to result in early-late difference larger in older than in young adults.

Finally, an interesting difference between young and older adults occurred in the present results. Older adults rejected ungrammatical sentences when violations occurred late in the sentences more quickly than sentences in which violations occurred early. Older adults most likely used their grammatical knowledge to build up expectations over the course of the sentence. This suggests that older adults are able to use their grammatical knowledge online. Although this effect of violation position was found in previous studies in young adults (e.g., Kail, 2004), it was not replicated here for unknown reasons.

All in all, analyses of participants’ times to reject ungrammatical sentences showed that grammaticality judgments were influenced by the type and position of violations. Like young adults, older adults’ language comprehension system is sensitive to linguistic cues such as word order, verbal agreement, as well as sentence structures.

**Age, Cue Strength, and Processing Speed in Online Sentence Processing**

Interestingly, the second series of analyses showed age-related differences in the costs of linguistic cues and individual differences among
older adults in these costs. In young adults and in fast older adults, the main determinant of ungrammaticality judgment times was violation type (i.e., difference between word agreement and word order). The magnitude of the contribution of violation type to participants’ detection times decreased with age, accounting for 79% of young adults’, 62% of fast older adults’, and 35% of slow older adults’ detection times. This decreased contribution of morphology to participants’ detection times suggest increased selective vulnerability of morphology in slow older adults. Note that previous studies with clinical populations (e.g., Broca’s aphasics, children with early focal brain injury, and children with specific language impairment) have found that grammatical morphology is a special area of vulnerability (Wulfeck et al., 1991, 2004). Such an outcome was also found in studies of typical adults under stress simulating profiles of aphasia (partial noise mask, low-pass filtering and/or auditory compression processing, processing in dual-task conditions) in German as well as in Italian or in English (Bates et al., 1994; Blackwell & Bates, 1995; Dick, Bates, Ferstl, & Frederici, 1999; Kilborn, 1991).

Increased selective vulnerability of morphology with age may be the result of decreased salience of grammatical morphemes. As suggested by the transmission deficit hypothesis proposed by MacKay and collaborators (e.g., MacKay & James, 2004), aging may weaken connections among units and memory representations of morphemes, leading to difficulties in computing lower phonological levels and to increased morphological processing times. In fast older adults, it is possible that memory representations and connections among units decreased, but not to a point where fast older adults are not using morphology as the most important cue to make their ungrammatical judgments. In contrast, violation type was not the main contributor of slow older adults’ detection times, changing the hierarchy of contributors to detection times in this group.

It was interesting that the large decrease with age of contribution of morphology to detection times was accompanied by an increased contribution of violation span in fast older adults or of violation position in slow older adults. It is possible that decreased working-memory resources in fast older adults increased the contribution of violation span to their detection times. Recall that violation span has been interpreted as resulting from larger working-memory demands for detecting interphrasal errors than for detecting intra-phrasal errors (Kail, 2004; Kail et al., 2012). Decreased working-memory resources with age led fast older adults’ detection times to be more affected than young adults’ by the violation span factor. This is consistent with previous studies showing significant relationships
between age-related changes in working-memory capacities and online grammaticality judgments (e.g., Kemtes, 1999; Dede, Kemtes, Caplan, & Waters, 2004). For example, Kemtes (1999) found that older adults had smaller verbal working-memory spans and were slower at detecting nonsense sentences although their speed of judgments was not differentially affected by syntactic complexity.

**Strategic Shift in Hierarchy of Linguistic Cues as an Adaptative Process**

Finally, one fascinating finding in this experiment was the changed hierarchy of contributors to slow older adults’ detection times. Violation position made the largest contribution to slow older adults’ detection times, followed by violation type, violation span making the lowest contribution. Slow older adults were slowed in processing sentences with word-order violations. This may be a specific instance of older adults encountering difficulties while processing complex sentences such as object relativized clauses because they did not respect the canonical subject-verb-object (SVO) word order (e.g., Stine-Morrow, Ryan, & Leonard, 2000). In addition to difficulty in processing complex sentences, it is possible that lower accessibility to morphology led slow older adults to rely on other linguistic cues, mainly contextual information, thereby developing strategies to compensate for this processing deficit. This would be consistent with previous evidence in the literature showing that older adults take differential advantage of sentential context to process linguistic cues such as phonology or orthography (e.g., Stine-Morrow, Miller, & Nevin, 1999) or take advantage of language material that enables them to draw on their knowledge of language structure (Wingfield & Stine, 1991). For example, older adults showed poorer performance than young adults in identifying isolated words, and particularly in auditory and visual noise conditions. However, when the words were embedded in context providing semantic constraints, age differences were greatly reduced if not eliminated (Speranza, Daneman, & Schneider, 2000).

Note that changed hierarchy of contributors to slow older adults’ detection times can be viewed as an adaptive strategy for these older adults to cope with their decreasing general processing resources and decreased efficacy of specific linguistic processes with age. Such adaptive strategic changes have been observed in many different cognitive areas outside language processing (see Lemaire, 2010, for a recent discussion). For example, in the domain of episodic memory, Bouazzaoui et al. (2010) have found that older adults switched from
most frequent use of internal memory strategies (e.g., mental rehearsal) to most frequent use of external memory strategies (e.g., use of post-it) as a way to adjust to their decreased processing resources. As another example, Gandini, Lemaire, Anton, and Nazarian (2008) and Gandini, Lemaire, and Dufau (2008) found that, to solve numerosity estimation tasks, older adults switched from most frequent use of anchoring (or counting-based) strategy to most frequent use of benchmark (or perceptually based) strategy to estimate numerosities of large number of elements. Such adaptive changes may be a general feature of the aging human cognitive system.

In summary, the present study showed that older adults use similar linguistic cues than young adults during online sentence processing. However, given age-related decrease in cognitive resources, they use these cues somewhat differently. Age-related changes involved moving from heavily relying on morphological cues to detect ungrammatical sentences to using contextual information more and more. Such a strategic shift of sentence processing may be adaptive on the part of older adults to optimize efficacy during online sentence processing.

REFERENCES


Example of a grammatical sentence: (40 grammatical sentences)

Chaque semaine, la voisine remplit le frigo après avoir fait les courses au marché.

“Every week, the neighbor fills the fridge after going shopping at the market.”

Eight ungrammatical sentences corresponding to one grammatical sentence

(8 lists of 40 grammatical and 40 ungrammatical sentences)

1. Chaque semaine, le voisine remplit le frigo après avoir fait les courses au marché.
2. Chaque semaine, la voisine remplissent le frigo après avoir fait les courses au marché.
3. Chaque semaine, après avoir fait les courses au marché le voisine remplit le frigo.
4. Chaque semaine, après avoir fait les courses au marché la voisine remplissent le frigo.
5. Chaque semaine, voisine la remplit le frigo après avoir fait les courses au marché.
6. Chaque semaine, remplit la voisine le frigo après avoir fait les courses au marché.
7. Chaque semaine, après avoir fait les courses au marché voisine la remplit le frigo.
8. Chaque semaine, après avoir fait les courses au marché remplit la voisine le frigo.

- Violation Type: (a) agreement violation (Sentences 1, 2, 3, 4); (b) word order violation (Sentences 5, 6, 7, 8)
- Violation Position: (a) early violation (Sentences 1, 2, 5, 6); (b) late violation (Sentences 3, 4, 7, 8).
- Violation Span: (a) intraphrasal violation (Sentences 1, 3, 5, 7); (b) interphrasal violation (Sentences 2, 4, 6, 8).