Cognitive Overload and Orthographic Errors: 
When Cognitive Overload Enhances Subject–Verb Agreement Errors. 
A Study in French Written Language

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Three experiments were carried out to test the hypothesis that cognitive overload enhances the occurrence of subject–verb agreement errors in French. Highly educated adults were presented orally with sentences they were required to write down. The sentences were of the types "N1 de N2 V" (Noun 1 of Noun 2 Verb: Le chien des voisins arrive The neighbours' dog is arriving) versus "Pr1 Pr2 V" (Pronoun 1 Pronoun 2 Verb: Il les aime He likes them). In these sentences, N1 (Pr1) and N2 (Pr2) matched or mismatched in number. In the three experiments, the sentences had to be recalled either in an isolated condition (i.e. every presented sentence had to be immediately recalled) or with a concurrent task: click counting (Experiment 2) or serial recall of series of five words presented immediately after the sentences (Experiments 1 and 3). Participants showed errors when performing two concurrent tasks and almost no error when recalling isolated sentences. As expected, errors occurred when N1 (Pr1) and N1 (Pr2) mismatched in number. The results are consistent with our hypothesis and with a functional approach of written composition.

In the French language, the number marks are written but very often not pronounced. For example, in the sentence: "Les jeunes filles sages jouent dans la cour" [The young wise girls are playing in the courtyard], five marks indicate the plural when the sentence is written, whereas only one mark is present (les compared to la) when the sentence is pronounced (Dubois, 1965). This double characteristic—number marks orally absent

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but present when written—makes the French language interesting. Indeed, subjects must manage the subject–verb agreement in the written output without any available oral cue.

In this respect, it has been reported that highly educated adults produce both rare and standard errors when composing texts (Fayol & Got, 1991):

"Le chien des voisins arrivent" (instead of "arrive") [The neighbours' dog arrive; instead of arrives];

"Les amis du pêcheur parlent" (instead of "parlent") [The fisherman's friends talks; instead of talk];

"Paul prend des outils. Il les range" (instead of "range") [Paul takes tools. He put them back in their place; instead of puts].

All these errors have common features:

1. two nouns or pronouns are plausible semantic subjects of the same verb;
2. the two nouns or pronouns differ as to number;
3. this difference in number is not orally marked in the verb but is marked when written;
4. the mistake consists in making the verb agree with the second noun or pronoun instead of the first noun or pronoun—a phenomenon referred to as "proximity concord" (Bock & Miller, 1991).

In addition, these orthographic mistakes are made only intermittently by the same writers. This inconsistency suggests that writers know and usually apply the subject–verb agreement rule; however, sometimes they make proximity agreement errors in conditions that still have to be determined.

The proximity concord error effect has already been reported with French native speakers (Fayol & Got, 1991) and with English native speakers (Bock & Cutting, 1992; Bock & Miller, 1991; Francis, 1986). Fayol and Got proposed a functional explanation to account for the subject–verb agreement error effect. According to their theory, highly educated adults are likely to have stored the declarative knowledge involved in subject–verb agreement tasks. That is, they know that the verb agrees in number with the head noun of the subject noun phrase in French.

In addition, as most of the time they do not make mistakes, it can be reasonably assumed that they have stored the relevant procedural knowledge (Anderson, 1983). Therefore, the difficulty consists more probably in the on-line management of the agreement.

We assume that verbal plural inflections are accessed via what Stemberger (1985) called "shared representations". This means that, at least in regular cases (i.e. with most French regular verbs), the lexicon has only one copy of a given morpheme (i.e. here the final -nt inflection) and that copy is accessed via many different words (i.e. verbs).

We also assume that encountering a plural noun (e.g. "les chiens" [the dogs]) or a plural pronoun ("ils or elles" [they]) triggers the activation of the regular verb plural morpheme (-nt). This activation leads to the appending of -nt to the end of the immediately following verb. If writers are expert, they have automatized the access to the plural verb morpheme, and as a consequence the plural agreement occurs automatically. Most of the time, the subject–verb agreement succeeds. However, sometimes automatic activation leads to erroneous agreements.

Some data are consistent with the predictions of automatically triggered subject–verb agreement errors. Indeed, several examples of syntactic accommodations have been reported (Garrett, 1980; Stemberger, 1985). In these syntactic accommodations, a given verb is made to agree with a noun that erroneously appears in subject position. This leads to a mistake: the verb agrees with the local (i.e. erroneous) subject instead of the semantic subject. Such data suggest that in some cases subject–verb agreement is performed in an automatic fashion.

Cases of syntactic accommodations are rather rare. However, subject–verb agreement errors tend to occur in another context: where the noun or the pronoun immediately preceding the verb (i.e. the local noun or pronoun) is not the subject of the verb and where this local noun (pronoun) is a semantically plausible subject candidate of the verb. For example, in a sentence like "Le chien des voisins arrive" [the neighbours' dog arrives], "le chien" [the dog] is the subject of the verb, whereas "des voisins" [neighbours], the local noun, immediately precedes the verb. The automatic activation hypothesis predicts that the plural morpheme -nt will be automatically triggered after "les voisins" [neighbours]. This automatic activation leads to the adjunction of -nt to the verb. This effect is referred to as the "proximity concord error effect" in the literature (Bock & Miller, 1991).

Avoiding the occurrence of a proximity concord error ("Le chien des voisins arrivent" instead of "Le chien des voisins arrive") requires the writer to control the relevance of the agreement. That is, automatic activation not being reliable, the writer must compute the agreement in a controlled fashion: he/she must check the relevance of the automatically triggered agreement, compute the relevant agreement, and finally write down the correct morpheme. Such a series of processes is likely to be resource-consuming. It cannot proceed without the involvement of the working memory system (cf. Baddeley, 1986). This analysis suggests that when working memory is overloaded, the processes of checking and computing agreement can be disrupted. The present paper aimed at testing the hypo-
thesis that this impairment enhances the occurrence of proximity concord errors: when working memory is overloaded, the probability for the verb to be made to agree with the immediately preceding noun or pronoun increases.

Three arguments can be invoked to support the aforementioned functional explanation of subject–verb agreement errors. (1) In the available literature as well as in our informal observations, no written mistakes have yet been reported in French when number marks are orally present. Mistakes occur only when the written verb agreement cannot rely on any oral cue. For example, errors occur with "il chante/ils chantent" [he sings/they sing] but not with "il vais/ils vont" [he goes/they go], because in the latter case the difference is orally marked, whereas this difference is not audible in the former case. This suggests that in cases where no oral cue is available, subjects have to deal with written language alone—a rather rare condition in French language. (2) As noted by Wing and Baddeley (1980), orthographic errors occur mainly towards the ends of sentences in general, and for subject–verb agreement in particular. (3) Subject–verb agreement errors consist in making the verb agree with the nearest noun (or pronoun, local noun or pronoun). As a consequence, these errors appear only when two nouns or pronouns differing in number (i.e., one singular and one plural) are competing for the same verb. Such proximity concord errors are the most frequent in the French language (see Francis, 1986, for a similar effect in written English).

In the present paper, we bring evidence that the occurrence of these rare and unsystematic agreement errors is enhanced by cognitive overload. This means that writers' cognitive capacity has too much to manage simultaneously. To understand how such an overload happens, it suffices to consider that when the writer has conceptually and linguistically planned a sentence segment, this segment is put into a buffer while waiting for graphic realization (Garrett, 1980, 1982; Levelt, 1989). Due to the slow rate of written production, this segment remains in the buffer for a relatively long time. Therefore it has to be recycled in order to prevent decay. However the recycling is probably phonologically driven—that is, no written mark is available.

The slow rate of written production also enables subjects to perform other activities in parallel. Several researchers have reported that expert adults plan forthcoming segments \((s+1, s+2)\) while graphically executing another already planned segment (Chanquoy, Fournil, & Fayol, 1990; Power, 1985, 1986). Thus writers could be engaged in two or three activities simultaneously: planning a segment \(s+1\), transcribing a segment \(s\), and controlling the correctness of a previous segment \(s-1\) afterwards.

Subject–verb agreement errors would be stressed in highly educated adults, especially in cognitive overload conditions. Such an overload occurs when they are simultaneously:

transcribing an already planned segment stored in a buffer; retrieving information from long-term memory in order to plan another segment.

Most of the time, this overload does not transpire. However, occasionally it enhances the occurrence of mistakes when the writer has to write down an orally unmarked subject–verb combination. In cognitive overload conditions, knowing the agreement rule and being able to apply it would not be enough. The writer would also have to pay attention to written subject–verb agreement mark(s) that are not supported by oral cues. Because of the current overload, the writer would be unable to deal with any orthographic agreement problem. When such a problem arises, an error becomes more likely: the writer tends to rely spontaneously on proximity criteria (the closest noun or pronoun) to make the verb agree.

The aim of the three present experiments was to test the hypothesis that occurrence of subject–verb agreement errors is enhanced by a temporary cognitive overload, leading the writers to rely on proximity criteria to make the verb agree.

We devised a task in which highly educated adults had to deal with two activities simultaneously: the graphic transcription of an orally given sentence (i.e., a written recall task) and either the maintaining of a series of words in working memory or the counting of a series of clicks. The purpose of the written recall was to simulate the transition from the phonological representation of an already planned segment to its graphic realization. The temporary storage of a series of words versus the counting of clicks would correspond to a cognitively expensive secondary task. This task would force the writer to focus his/her attention away from the transcription of the orally given sentence.

The cognitive overload hypothesis predicted a secondary task effect. Indeed, highly educated adults would not make any subject–verb agreement errors when recalling orally presented sentences by writing them down. However, when involved in two simultaneous activities, writers were expected to increase their subject–verb agreement errors. One of the activities was the graphic transcription of the to-be-caled sentence, an activity supposedly requiring low cognitive load. The other activity was the secondary task demanding a more resource-consuming control.

In summary, the present experiments were carried out to check that subject–verb agreement errors are associated with a temporary cognitive overload. This hypothesis predicts that highly educated adults should fail more often in correctly making the verb agree with the head noun of the subject noun phrase in the two concurrent task conditions than in the single task condition. This hypothesis was tested with a written recall task performed in parallel to either a click-counting task (Experiment 2) or a word-recall task (Experiments 1 and 3).
EXPERIMENT 1

We wanted to show that it was possible to produce in the laboratory subject–verb agreement errors that were similar to those encountered in written composition. Two groups of undergraduates were submitted to two tasks. First they were required to recall orally presented sentences by writing them down. Group 1 had to perform only this one task. Group 2 was also required to recall a series of five words after each sentence. Group 2 members' knowledge of the subject–verb agreement rule was tested a week later for control. Writers were explicitly asked to make the verb agree with the subject in all the experimental sentences.

The hypothesis that a cognitive overload increases the appearance of the disruption of orthographic performance enables us to test the two following predictions: (1) this agreement error effect should be greater when the two nouns differ in number; (2) the number of subject–verb agreement errors should increase when the subjects have to recall both sentences and words.

Method

Subjects

Forty undergraduate students at the University of Bourgogne at Dijon (France) (18 males and 22 females) volunteered to participate in the experiment. The mean age of the students was 18.9, ranging from 17.3 to 20.6 years.

Stimuli

The stimuli were sentences and words.

a. Sentences. Twenty pairs of nouns (N1/N2) were selected such that each noun could be a semantically plausible subject of the same verb (V). For example “pomme” [apple] and “branche” [branch] can both be meaningfully associated with the verb “tomber” [to fall down]: “the apple falls down/the branch falls down”. Each pair of nouns was presented together with a verb.

Four blocks of five sentences were created by varying the number (Singular = S/Plural = P) of each of the nouns (N1/N2). This yielded:

5 sentences with N1 and N2 in the singular (noted SS). For example: “Le père de l'enfant s'inquiète” [The child's father is worried];

5 sentences with N1 and N2 in the plural (noted PP). For example: “Les roues des wagons s'usent” [The wheels of the wagons are wearing out];

5 sentences with N1 singular and N2 plural (noted SP). For example: “Le chien des voisins arrive” [The neighbours' dog is coming];

5 sentences with N1 plural and N2 singular (noted PS). For example: “Les pommes de la branche tombent” [The apples on the branch are falling down].

b. Words. For the “sentences + words” condition, 20 lists of five words were drawn up, with the following constraints: all the words were monosyllabic; they belonged to different semantic categories (to control for regrouping strategies); they were phonologically similar in order to increase the attentional load in the working-memory system (Baddeley, 1966, 1986; Conrad, 1964; Drewnowski & Murdock, 1980); for example: “riz, pi, si, cri, ni”.

c. Recall Booklets. To avoid possible revisions and corrections, recall booklets were made. These booklets consisted of 23 pages for the “sentences alone” group (three pages for the training sentences and 20 pages for the 20 experimental sentences) and 46 pages for the “sentences + words” group (six pages for training and 20 pages for the sentences alternating with 20 pages for the word lists).

d. Control of Spelling Abilities. To test subjects' spelling abilities, the 20 experimental sentences were grouped in five blocks of four sentences (SS, PP, SP, PS). These blocks were submitted to the subjects without the verb-endings (for example: “Le chien des voisins arr...” [The neighbours' dog arrives...]). Participants were asked to make the agreement. Each block took up a page and the five pages (5 × 4 sentences) were put together based on a circular permutation to prevent a possible order effect.

Procedure

The 20 subjects in each condition were randomly assigned to five groups so as to vary the order of presentation of the 20 sentences (presented with or without the series of words). The sentences were divided into blocks of four. A circular permutation enabled the experimenter to assign each group of subjects with a different presentation order.

The instructions and the sentences followed (or not) by words had been tape-recorded before the experimental sessions. Pauses were inserted between the items such that writers had time to write down the sentences for the first group and the sentences and the words for the second group. Participants received the following instructions (the additional instructions for the “sentences + words” group are given in parentheses):
"The objective of this experiment is to study the memorization of sentences (and words). I will now explain what you have to do. You are going to hear 20 sentences (each one followed by a series of five words)."

[A one-sentence example was then given, either followed or not followed by words.]

"After each pip, you must write down what you can remember in the booklet that was given to you. Please write on page one the sentence as it was presented to you (and the series of words on page one a), the second sentence on page two (the words on page two a) and so on. Please pay attention to the numbering of the pages in the booklet."

Four sentences were first presented for the practice trials.

A week later, the subjects were told that their spelling ability was going to be tested. They were asked to make subject and predicate agree in the experimental sentences, which were given to them without the verb-endings. Sentences were presented in a different order than in the experimental sessions.

Scoring. Because the task was easy, all sentences were correctly recalled: as we chose only regular verbs, the errors were unambiguously inflection errors on verbs. Therefore our dependent variable was the number of errors divided by the number of correctly recalled sentences (i.e. error proportions). The same scoring procedure was used in the three experiments reported here.

Results and Discussion

The proportions of erroneous verb agreements were computed for each subject in each experimental condition. The proportions of agreement errors are displayed in Figure 1 (see the raw data in Table 1). The data were analysed in a 2 (group: with or without word to recall) × 2 (condition: match vs. mismatch) × 2 (subject number: singular vs. plural) ANOVA, with repeated measures on the last two factors.

As expected, more agreement errors occurred in the presence (0.16) than in the absence (0.04) of words to be recalled, $F(1, 38) = 19.13$, $p < 0.001$, $MS_e = 0.028$, with participants random; $F(1, 16) = 44.55$, $p < 0.0001$, $MS_e = 0.003$, with items random. In addition, the proportions of errors varied with conditions: 0.03 in the match condition versus 0.17 in the mismatch condition, $F(1, 38) = 29.47$, $p < 0.0001$, $MS_e = 0.027$, with participants random; $F(1, 16) = 83.63$, $p < 0.0001$, $MS_e = 0.002$, with items random. Interestingly, the Group × Condition simple inter-

| Number of Agreement Errors in Experiment 1 |

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FIG. 1. Proportions of agreement errors associated with number-matching or number-mismatching subjects and local nouns and with memory load conditions (Experiment 1).
action was significant with participants as well as with items random, $F(1, 38) = 8.46, p < 0.01, MS_e = 0.027$, and $F(1, 16) = 18.95, p < 0.001, MS_e = 0.003$, respectively (see Figure 1). Planned comparisons revealed a significant group effect only in the mismatch condition, $F(1, 38) = 13.37, p < 0.001$, with subjects random; $F(1, 16) = 121.55, p < 0.001$, with items random. Finally, there was a Subject Number × Condition interaction, $F(1, 38) = 5.47, p < 0.05, MS_e = 0.018$, with participants random; $F(1, 16) = 10.67, p < 0.01, MS_e = 0.002$, with items random. This interaction is better understood when the net error proportions are taken into account. The net proportions represent the proportion of errors in each mismatch condition (where the subject and local nouns mismatched in plurality—i.e. SP/IP) minus the proportion in the corresponding control condition (where the subject and local nouns matched in plurality, i.e. SS/PP). As can be seen in Figure 2, the increase in agreement errors was greater when the local noun was plural (+0.17) than when the local noun was singular (+0.06). This increase in agreement errors did not interact with the group factor, $F(1, 38) = 1.37$, n.s., with participants random; $F(1, 16) = 2.11$, n.s., with items random. No other effect was significant. These patterns of results replicate Bock and Miller's (1991) findings. In addition, as expected, overloading the working-memory system enhanced these patterns of results.

The results of Experiment 1 are very clear and consistent with our hypothesis. On the one hand, when the participants recalled only sentences, the rate of agreement errors was very low (0.04), and the proportions of errors were greater when the local noun was plural than when it was singular. On the other hand, when the participants recalled both sentences and words, the number of erroneous agreements increased steadily and reached about 30%. Moreover, the pattern of errors was not modified in the sentence + words condition—that is, the proportion of agreement errors remained greater with plural local nouns than with singular local nouns.

Finally, the increase in number agreement error proportions in the "sentences + words" condition was not associated with a change in the proportion of words recalled: the means (out of five words) remained approximately the same ($F < 1$).

In sum, when "experts" had simultaneously to: (1) transcribe a string of the type "N1 of N2 V" in which N1 and N2 differed in number and in which the verb ending was not audible and (2) maintain an activity and/or retrieve lexical items from memory for future recall, a significant increase in the proportions of agreement errors was observed. Subjects tended to make the verb agree with the local noun (N2). These mistakes could not be attributed to an ignorance of the agreement rule and its implementation. Indeed, all the adults achieved the maximum score (100%) of correct agreement in the explicit agreement task when they were presented with the task a week later. Moreover, the number of agreement errors was very low when the adults recalled the sentences alone.

The results of this first experiment are very interesting, because they show that loading the working-memory system enhanced the occurrence of agreement errors, the pattern of which was already observed with the sentence alone condition (Bock & Miller, 1991). However, it could be argued that these results were material-specific or secondary-task specific. Indeed, because we used a secondary task that disrupted the phonological
loop, it could be argued that the phonological loop is critical in the orthographic task. Although this argument is not inconsistent with the hypothesis that working-memory overload results in an increase of subject–verb agreement errors, we wanted to extend the conclusions of Experiment 1. Therefore in Experiment 2 we used another secondary task and different material.

**EXPERIMENT 2**

The first experiment showed that subject–verb agreement errors can be experimentally elicited and that the errors so induced are similar to spontaneously produced errors. In addition, this first experiment demonstrated that overloading the working-memory system enhanced this effect. The aim of Experiment 2 was to verify with a new population and new material whether the introduction of a new secondary task (counting clicks) during the transcription of a “N1 of N2 V” type of sentence would increase subject–verb agreement errors.

In Experiment 2, the participants were asked to perform the same orthographic task as in Experiment 1, with one exception: the secondary task was a counting task—a task that supposedly involves resources in the phonological loop and in the central executive systems in working memory. The material was of the same type as in Experiment 1 (“N1 of N2 V” sentences). However, we used a new set of N1, N2, and V in order not to restrict our conclusions to specific material. The same output as in Experiment 1 was expected.

**Method**

**Subjects**

Sixty-two undergraduate students at the University of Bourgogne at Dijon (France) (51 males and 11 females) volunteered for participating in the experiment. The mean age was 19.1, ranging from 18.3 to 21.1 years.

**Stimuli and Procedure**

a. **Sentences.** The sentences were built in the same manner as those used in Experiment 1. Forty “N1 of N2 V” sentences were devised: 10 SS, 10 PP, 10 PS, and 10 SP. The same randomization procedure as in Experiment 1 was used.

b. **Clicks.** The sentences were tape-recorded. Each of them was associated with three musical notes. The first note announced the start of the sentence. The second note indicated to the participants that they could begin writing down the sentence. The third note indicated that the recall time was over. A pre-test enabled us to determine that an interval of 10 sec was enough for the recall between the second and the third note. The “with-click” group had to transcribe the same sentences as the other group; however, they also had to count clicks while recalling the sentences. For each sentence, six to ten audible clicks had been randomly inserted between the second and the third note. After a series of pre-tests, a 12-sec interval was left to allow subjects both to recall the sentence and to count the clicks.

In sum, after listening to each sentence, the “without-click” group had 10 sec in which to recall, whereas the “with-click” group had 12 sec to do the recall and at the same time to count six to ten clicks.

c. **Recall Sheets.** The recall was made on sheets of paper. To prevent possible revisions or corrections, the instructions specified that as soon as the recall had been made, each sentence had to be covered immediately by another sheet of paper. For the “with-clicks” group, participants had to cover the recalled sentence before writing down the number of clicks.

**Results and Discussion**

The dependent variable was the proportion of erroneous subject–verb agreements out of ten sentences per condition. The proportions of errors are displayed in Figure 3 (see the raw data in Table 2).

As in Experiment 1, the proportions of errors were analysed in a 2 (group: with or without clicks) × 2 (condition: match vs. mismatch) × 2 (subject number: singular vs. plural) ANOVA, with repeated measures on the last two factors.

As in Experiment 1, the results revealed the expected effects:

The group effect proved to be significant, $F(1, 60) = 14.7, p < 0.001$, $MS_e = 0.016$, showing that the without-click group made fewer mistakes (0.03) than did the with-clicks group (0.09).

The condition effect was also significant, $F(1, 60) = 49.67, p < 0.0001$, $MS_e = 0.012$, showing that the proportions of erroneous agreements were greater in the mismatch (0.11) than in the match condition (0.01).

The Group × Condition interaction was significant, $F(1, 60) = 7.95, p < 0.01$, $MS_e = 0.012$. This interaction was portrayed in a greater increase in error proportions in mismatch than in match conditions when participants had to count clicks as compared with the sentence-alone condition (see Table 2). Planned comparisons revealed a significant group effect only in the mismatch condition, $F(1, 60) = 13.36, p < 0.001$.

The subject number proved to be significant, $F(1, 60) = 12.42, p < 0.001$, $MS_e = 0.006$, showing that the proportion of errors was greater...
**EXPERIMENT 2**

![Bar chart](image)

**NUMBER OF SUBJECT AND LOCAL NOUN**

FIG. 3. Proportions of agreement errors associated with number-matching or number-mismatching subjects and local nouns and with memory load conditions (Experiment 2).

**TABLE 2**

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<th>Working Memory Conditions</th>
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with plural (0.08) than with singular (0.04) local nouns. This subject number effect interacted with the condition factor, $F(1, 60) = 34.01$, $p < 0.0001$, $MS_e = 0.005$. As in Experiment 1, the net proportions of errors were computed. As can be seen in Figure 4, the increase in agreement errors was greater when the local noun was plural (+0.10) than when the local noun was singular (+0.04). This increase in agreement errors did not interact with the group factor ($F < 1$). No other effect proved to be significant.

The proportions of erroneously counted clicks were higher in the mismatch (0.24) than in the match (0.19) condition, $F(1, 30) = 7.33$. 

**EXPERIMENT 2**

![Bar chart](image)

**NUMBER OF LOCAL NOUN**

FIG. 4. The net proportions of agreement errors after singular and plural local nouns for sentences and sentences + clicks conditions (Experiment 2). The net proportion represents the proportion of errors in each mismatch condition (where the subject and local nouns mismatched in plurality) minus the proportion in the corresponding control condition (where the subject and the local nouns matched in plurality). The numbers indicate the error proportions in the control conditions.
In addition, these proportions varied with the subject number factor, $F(1, 30) = 22.16, p < 0.0001, MS_e = 0.023$, showing that the proportion of erroneously counted clicks was higher when head nouns were plural (0.28) than when they were singular (0.15). Finally, the Condition $\times$ Subject Number interaction effect proved to be significant, $F(1, 30) = 4.61, p < 0.05$. The interpretation of these effects is clearer when net proportions are considered. Net proportions were computed using the same procedure as in Experiment 1. These net proportions varied with the number of the local noun: the singular and the plural local noun conditions yielded 0.01 and 0.10 erroneously counted clicks, respectively, $F(1, 30) = 4.61, p < 0.05, MS_e = 0.027$.

The second experiment replicated the effects observed in Experiment 1: (1) the number of erroneous agreements was greater in the mismatch conditions, especially when the sentence recall took place in parallel with click counting, and (2) higher rates of errors occurred in the SP than in the PS conditions. In addition, as far as the secondary task is concerned, different patterns of results emerged in Experiments 1 and 2. The accuracy in the secondary task of click counting was lower in mismatch than in match conditions, whereas no such effect was observed with to-be-recalled series of words. This counting-click effect suggests that counting clicks is a more reactive task to achieving agreement of the verb with the relevant subject in the mismatch than in the match conditions. The reasons for this differential effect of secondary task are not yet clear.

These results suggest that, consistent with our hypothesis, the management of the click-counting task induced a reduction in the attentional resources allocated to the written recall of the sentences, as did the recall of series of words. As a consequence, in the absence of an oral mark of verb agreement, the probability for an erroneous agreement increased when head and local nouns mismatched.

**EXPERIMENT 3**

The third experiment was aimed at studying the management of subject–verb agreement in a more complex situation. Subjects had to recall a series of two sentences, sometimes followed by words. The paradigm was the same as in Experiment 1, but with two exceptions. First of all, we manipulated the place of the verb. Studies on the reading of sentences have already shown that the attention paid to surface aspects decreases at the ends of sentences (e.g. Carrithers & Bever, 1984; Green, 1977; Jarvela, 1971). In oral language production, using a secondary task (responding as fast as possible to a heard tone), Ford and Holmes (1978) found that the processing load increased at the ends of sentences. As far as written produ-

duction is concerned, Wing and Baddeley (1980) reported that the number of spelling errors increased steadily towards the ends of sentences. These effects are typically interpreted in terms of cognitive load—that is, a load increase is created at the ends of clauses or sentences by the occurrence of certain high-level processes (e.g. integration in reading and planning the next segment in writing).

In the two previous experiments, the increase in erroneous agreements was very important when an extra cognitive load was added—that is, when subjects had to recall both sentences and words. However, in all cases the verb ended the sentences, and therefore we can surmise that the increase in agreement errors could be partially due to the location of the verb in the sentences, together with the secondary task. The error rate would be especially high because the cognitive overload is particularly great at sentence endings. This increase in cognitive load at the end of sentences would lead the writers to focus their attention away from the control of orthographic agreement problems. Such an attention shift would not occur or would be weaker when the verb does not appear at the ends of the sentences. To control for this potential confound, we used sentences that might or might not end with a verb. The idea was that the material placed after the verb (i.e. an adverbial phrase) would make orthographic control possible. This predicts that the number of agreement errors should decrease when sentences end with a complement rather than with the verb.

The second important modification concerned the use of another condition in which the verb of the target sentence was preceded by two pronouns instead of two nouns. The pronoun condition was intended to enable us to generalize our conclusion to pronouns. In addition, this manipulation was aimed at controlling for the possibility that the subject–agreement error effect reported up to now does not arise from the difficulty participants experienced in determining the subject among the two competing nouns.

To achieve this, all the sentences used in this experiment included an adverbial phrase, placed either at the beginning or at the end of the sentence. As a consequence, the verb appeared either at the end of the sentence (when the adverbial phrase was at the beginning) or towards the middle of the sentence (when the phrase was at the sentence ending).

**Method**

**Subjects**

Twenty-four undergraduate students at the University of Bourgogne, Dijon; France (13 males and 11 females; mean age: 18.4; range: 17.4–19.10) agreed to take the test.
Stimuli

A new set of stimuli was devised, comprising 48 sequences of two sentences (a beginning sentence followed by a target sentence), composed according to the following scheme (see examples below):

Beginning sentence: article + noun 1 + verb 1 + article 2 + noun 2 (approximately six syllables)
Target sentence: pronoun 1 (subject of the verb) + pronoun 2 (object of the verb) + verb 2 (approximately five syllables) + an adverbial phrase (three syllables long) placed either at the beginning or at the end of the sentence

Each sequence, therefore, consisted of approximately 14 syllables, and the agreement problem concerned the target sentence verb. Indeed, the target sentence could be arranged in four combinations as a function of the number of the pronouns: SS: il le [he/him]; PP: ils les [they/them]; SP: il les [he/him]; PS: ils le [they/him].

The four sentences below illustrate the way the material was designed (the adverbial phrase is between brackets in its two possible places):

SS: “Le soldat perd un gant. (Sans un bruit) il le ramasse (sans un bruit).” [The soldier loses a glove. (Noiselessly) he picks it up (noiselessly).]
PP: “Les enfants voient des fruits. (En sautant) ils les attrapent (en sautant).” [The children see fruits. (By jumping) they catch them (by jumping).]
SP: “Le lion a des petits. (Le matin) il les promène (le matin).” [The lion has lion cubs. (In the morning) he walks with them (in the morning).]
PS: “Les vieux ont un journal. (Chaque jour) ils le consultent (chaque jour).” [Old people have a newspaper. (Everyday) they read it (everyday).]

The 48 sequences of two sentences were divided into four blocks of 12 (12 SS; 12 PP; 12 SP; 12 PS). Within each block of 12, 6 sequences had the adverbial phrase at the beginning of the target sentence and the 6 other sequences had the adverbial phrase at the ending of the target sentence. Furthermore, lists of five words were added alternately to 3 out of 6 sequences.

Procedure

The 48 sequences were distributed into blocks, so that each block contained eight experimental conditions (two locations of the adverbial phrase × four types of target sentences). Each block was alternately associated with the lists of words in such a way that when Block 1 contained sequences followed by words, Block 2 had no words. In another condition, Block 1 had no words, and Block 2 had words.

The 24 subjects were randomly divided into groups of six, so as to alternate the with/without word blocks to control for a possible order effect. Each subject saw the 48 sequences: 24 with words, 24 without words (alternating for one group out of two); 24 with an adverbial phrase at the beginning of the target sentence, 24 with the adverbial phrase at the ending of the target sentence: 12 SS, 12 PP, 12 SP, 12 PS.

On each booklet page participants recalled only one thing: either a two-sentence sequence or a series of words. Neither revision nor correction was possible.

Results and Discussion

The mean proportions of erroneous verb agreements are displayed in Figure 5 (see Table 3 for the raw data). The proportions were analysed with a 2 (group: with- or without-words to recall) × 2 (condition: match vs. mismatch) × 2 (subject number: singular vs. plural) × 2 (location of the adverbial phrase: at the beginning or at the ending of the target sentence) ANOVA, with repeated measures on each factor.

The results showed that the proportion of erroneous agreements was higher in the “with word” condition (0.28) than in the “without word” condition (0.12), \(F(1, 23) = 74.23, p < 0.0001, M_S = 0.032\). The proportion of errors also varied with the conditions, \(F(1, 23) = 32.45, p < 0.0001, M_S = 0.091\), indicating that more errors were committed in the mismatch (0.28) than in the match (0.11). The subject number factor also proved to be significant, \(F(1, 23) = 7.18, p < 0.05, M_S = 0.143\), showing more errors in the plural (0.25) than in the singular (0.14) condition.

More importantly, several interactions proved to be significant. The Group × Condition, \(F(1, 23) = 10.84, p < 0.004, M_S = 0.027\), and the Condition × Subject Number, \(F(1, 23) = 4.78, p < 0.05, M_S = 0.061\), interactions were qualified by a three-way Group × Condition × Subject Number interaction effect, \(F(1, 23) = 5.69, p < 0.05, M_S = 0.058\). As in Experiments 1 and 2, these interactions were better understood when taking into account the net proportion errors. As can be seen in Figure 6, the net proportions of agreement errors increased steadily when writers recalled words together with sentences for which the local pronoun was plural. Indeed, the increase was only significant when writers recalled sentences + words instead of sentences alone in the plural local noun condition, \(F(1, 23) = 5.38, p < 0.05, M_S = 0.108\).

As expected, the location of the adverbial phrase proved to be significant, \(F(1, 23) = 10.92, p < 0.01, M_S = 0.034\), showing that the pro-
portion of agreement errors was lower (0.16) when the adverbial phrase was placed at the end rather than at the beginning (0.23) of the sentences. This adverbial phrase location effect was significant only in the secondary task condition, $F(1, 23) = 5.66, p < 0.05, MS_e = 0.058$. No other effect reached conventional significance.

As far as the number of recalled words (out of five) is considered, only the adverbial phrase location proved to be significant, $F(1, 23) = 7.33, p < 0.02, MS_e = 0.26$. More words were recalled when the adverbial

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**TABLE 3**

Number of Agreement Errors in Experiment 3

<table>
<thead>
<tr>
<th>Working Memory Conditions</th>
<th>Plurality of Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Singular</td>
</tr>
<tr>
<td><strong>Number mismatch</strong></td>
<td></td>
</tr>
<tr>
<td>Sentences</td>
<td>20</td>
</tr>
<tr>
<td>Sentences + Words</td>
<td>35</td>
</tr>
<tr>
<td><strong>Number match (control)</strong></td>
<td></td>
</tr>
<tr>
<td>Sentences</td>
<td>2</td>
</tr>
<tr>
<td>Sentences + Words</td>
<td>5</td>
</tr>
</tbody>
</table>

**NUMBER OF LOCAL PRONOUN**

FIG. 6. The net proportions of agreement errors after singular and plural local pronouns for sentences and sentences + words conditions (Experiment 3). The net proportion represents the proportion of errors in each mismatch condition (where the subject and local pronouns mismatched in plurality) minus the proportion in the corresponding control condition (where the subject and local pronouns matched in plurality). The numbers indicate the error proportions in the control conditions.
phrase ended the sentences than when it began the sentences (3.64 vs. 3.44). In addition, this adverbial phrase location interacted with condition, $F(1, 23) = 14.12, p < 0.01, MS_e = 0.249$. The beginning/end difference proved to be significant only in the mismatch condition, $F(1, 23) = 21.43, p < 0.001, MS_e = 0.25$.

Thus, under the mismatch condition only, when the adverbial phrase moved from the beginning to the end of the sentences, the number of recalled words increased. At the same time, the number of agreement errors decreased—an effect observed only in the sentences + words condition. This suggests that the cognitive load was reduced when a linguistic segment appeared after the verb, allowing enough time to resolve the conflict of agreement between the two competing nouns.

The results of Experiment 3 showed that when expert adults had to recall both sentences and words, the proportion of agreement errors increased when the two pronouns mismatched. The errors consisted in making the verb agree with the local pronoun—that is, the one that was closest to the verb. This proximity concord result replicated the results observed in Bock and Miller’s (1991) research and in Experiments 1 and 2.

In addition, in this last experiment we also intended to test the impact of the location of the to-be-agreed verb on the error rate. We expected a decrease of erroneous agreements when an adverbial phrase was added at the end of the target sentence. The data confirmed this prediction. Moreover, the decrease was especially dramatic when the two pronouns mismatched under the sentences + words condition—that is, in the condition with the most conflict and the largest overload.

**GENERAL DISCUSSION**

The results of the three experiments reported in the present paper are very clear and consistent with our predictions. Indeed, subject–verb agreement errors occurred much more often when the two nouns (pronouns) mismatched in number than when they matched. When the number of the first noun (pronoun) and that of the second noun (pronoun) were different, the writers tended to make the verb agree with the nearest noun (pronoun)—that is, to commit a proximity concord error. Moreover, this proximity concord error effect was larger when the local noun was plural. All these effects replicated Bock and Miller’s (1991) findings.

Beyond replicating the subject–verb agreement error effect, three major contributions emerge from the present investigations: (1) The agreement error effect did not appear when participants were explicitly asked to make the verb agree with its subject in the experimental sentences. This effect was rather weak when participants recalled the sentences alone, and it increased steadily when a secondary task was used in parallel with the sentence recall. These results show that the subject–verb agreement error effect can be enhanced when the working-memory system is overloaded (we discuss this effect further), whatever the secondary task used.

(2) Experiment 3 allows us to extend the conclusions of Experiments 1 and 2 to pronouns. Indeed, using a subject pronoun and an object pronoun before the verb entailed the occurrence of the same subject–verb agreement errors as those observed in the two previous experiments—that is, errors were most pronounced when the two pronouns mismatched, when the local pronoun was plural, and when a secondary task was used. Therefore, subject–verb agreement errors did not occur only when two nouns belonging to the same noun phrase were competing for the same verb. These errors also appeared when two lexical items did not belong to the same phrase. This result suggests that subject–verb agreement errors are not mark- or phrase-specific, a fact that future research will have to confirm.

(3) The last main contribution of the present results comes from observing a difference in the agreement error rates when adverbial phrases were moved from the beginnings to the ends of the sentences. This effect is consistent with our theoretical prediction that the cognitive load is particularly high at the ends of sentences (Wing & Baddeley, 1980). As a consequence, subject–verb agreement problems are particularly difficult to control when occurring at the end of sentences. This analysis predicted that placing an adverbial phrase after the verb would facilitate the management of the subject–verb agreement. Our results are consistent with this prediction. The manipulation of the verb position enabled us to show that agreement errors occurred significantly more frequently when the verb ended the sentences. In contrast, placing the verb in the middle of the sentences facilitated the management of the agreement. This agreement occurred either immediately (on-line) or later on in the sentence. Indeed, the writer controlled the previous segment(s) while writing one of the following segments. Congruent with the cognitive-load functional conception, participants performed better on the secondary task when the verb was not in the final position.

It is important to consider how a secondary task disrupted the participants’ subject–verb agreement performance. First of all, it cannot be argued that the participants did not know the rule. Indeed, all of them showed perfect performance a week later, when they were explicitly asked to perform the subject–verb agreement task on the experimental sentences. Therefore all of them knew the rule and were able to use it. The problems occurred when these same participants had to use the rule while simultaneously performing another task. The secondary task disrupted the management of the subject–verb agreement rule. This is consistent with a cognitive resources interpretation.
According to the functional approach contended here, subject–verb agreement errors increase when writers are overloaded, such as when writers are performing two concurrent tasks. Due to the current overload, the writer experiences more difficulties in dealing with any orthographic agreement problems. When such a problem arises, an error becomes likely because the writer has no mental resources left. As a consequence, for subject–verb agreement the writer tends to rely spontaneously on proximity criteria, making the verb agree with the closest noun or pronoun. Moreover, this effect is stronger when the closest noun or pronoun is plural.

We assumed that encountering a plural noun (pronoun) triggers the activation of the plural morpheme (i.e., -nt) in French. Such an activation does not occur when the local noun is singular. The activation leads expert writers to make the verb agree with the closest (local) noun (or pronoun). When writers have cognitive resources available, they can control for the relevance of the triggered agreement. This control is perhaps facilitated by the relative slowness of written transcription. Therefore most performance errors do not transpire, even though the potential errors morphemes are triggered. However, when cognitive resources are lacking, writers cannot control for the relevance of the triggered morphemes. It can be hypothesized that these errors are either not detected or not edited, because writers have not enough resources left to select between the competing inflections. Using a secondary task in our experiments enabled us to disrupt the control processes and thus to reveal these automatically triggered errors.

Such a functional interpretation of our results is consistent with a theoretical analysis combining both an architecture component suggested by Garrett (1980, 1982) and Levelt (1989) and functional aspects concerning the on-line management of written production. In Garrett’s as in Levelt’s language production models a message is produced in three steps. First, the message is conceptually planned. It is then linguistically elaborated. Finally, it is materially realized. When a sentence segment has been conceptually and linguistically planned, this segment is sent into a buffer, waiting for the phonetic and/or orthographic realization. Due to the slow rate of written production, the segment remains in the buffer for a relatively long time. Therefore, this segment has to be recycled to prevent it from decaying. However, the recycling is assumed to be phonologically driven (Hulme, Maughan, & Brown, 1991)—that is, with no available written mark. The slow rate of written production also allows writers who are graphically transcribing a segment to perform other activities in parallel. Several researchers have shown that expert adults plan forthcoming segments (i.e., segments $s + 1$, $s + 2$, etc.) while they are writing another previously planned segment (Chanquoy, Foulin, & Fayol, 1990; Power, 1985, 1986).

Thus, writers could be simultaneously engaged in two and even three activities: planning a segment $s + 1$, transcribing a segment $s$, and controlling the correctness of a previous segment $s − 1$ afterwards.

The experimental paradigm used in the three reported experiments fits well with the aforementioned conception. Writers whose declarative and procedural knowledge of the French subject–verb agreement rule had been ascertained had to recall sentences—that is, already-planned segments stored in a buffer. In some cases, they had both to recall the sentences and either to count clicks while writing down the sentences or to recall a series of five words serially following the recall of the sentence. The secondary tasks were sufficiently resource-consuming to force writers to divert their attention away from the processing of the written aspects of the sentence recall. We assumed that this experimental situation would roughly simulate what corresponds to the written transcription of an already planned linguistic segment while planning some aspect(s) of the following segment(s) before writing it (them) down. Therefore, writers were overloaded when transcribing the problematic sentences, and thus they would tend to produce subject–verb agreement errors similar to those observed in the spontaneous written compositions (Fayol & Got, 1991; Francis, 1986; Wing & Baddeley, 1980).

The experimental paradigm used in the three reported experiments proved to be very fruitful. As expected, it enabled the eliciting of mistakes that are similar to those committed by highly educated adults when dealing with complex situations such as composing a text. Indeed, in written composition, writers have to manage all the parameters of the production, being always on the verge of being overloaded. As a consequence, they sometimes fail to apply a rule and/or to control its application. This is why the errors are rare and why they are committed only from time to time by the same writer. The data collected in the three experiments give the same types of results, whatever the secondary task (counting clicks or recalling words).

A problem remains in our data as concerns the secondary task. Indeed, the number of words recalled in Experiment 1 did not vary as a function of any variable, whereas some variations were observed in the counting-clicks task (Experiment 2) and in the serial recall of words in Experiment 3. At the moment, this inconsistency still remains unclear.

The first two Experiments differed on both the mean number of erroneous agreements (0.10 and 0.06 in Experiments 1 and 2, respectively) and the secondary task performance. Although due to the different secondary tasks used no direct comparison was possible, only counting clicks varied as a function of the match/mismatch and of the subject number conditions. Counting-clicks accuracy was lower in the mismatch and the plural local-noun condition—that is, when the number of erroneous agreements was
the largest. This result suggests that at least some participants had detected an agreement problem and were trying to deal with it. However, the secondary task disrupted the control and enhanced the occurrence of errors that would most likely not have transpired in non-overloading situations.

The third experiment partially replicates the findings of Experiment 2 with regard to the secondary task. However, the secondary task was a serial recall of series of five words, as in Experiment 1. In Experiment 3, the number of recalled words increased when adverbial phrases were at the ends of the sentences—that is, when the load was the slightest (as compared with the case in which the verb occurred at the end of the sentences). Moreover, the beginning/end difference only reached significance in the mismatch condition. The comparison of the numbers of recalled words revealed that the performance in the serial recall dropped to 3.26 under the mismatch condition and that this mean was the only one to differ significantly from all the others (as revealed by HSD Tukey tests). Therefore, as in Experiment 2, the performance in the secondary task was especially weak when the number of erroneous agreements was the highest.

Considering both the weak performance on the secondary task when pronouns were mismatched and the improvement in this performance when the adverbial phrase was moved to the end of the sentence leads to the conclusion that (at least) some participants detected the existence of an agreement problem and tried to manage it. Their attempt to control for the relevance of the inflection entailed a decrease of the available cognitive resources, leading to a decrease in the number of recalled words.

Thus the results observed in the performance in the secondary task in Experiments 2 and 3 are consistent. However, the results in Experiment 1 are not consistent with those collected in the two other experiments. Indeed, the number of recalled words remained high under all conditions (approximately 3.7) and did not vary. It was as if participants in Experiment 1 had not detected the existence of agreement problems, which nevertheless led them to commit mistakes. This interpretation remains tentative, but it allows one to think of control processes as a two-step process, the first step consisting in detecting that a problem arises, and the second step in managing the selection of the relevant inflection in a controlled manner. This second step would be completed only if the first step has previously occurred, and only this second step would be resource-consuming. If this is true, having not detected a problem would not lead one to allocate cognitive resource to the control of agreement. By contrast, having survived the existence of a problem would require the writer to draw on attentional resources to control for the relevance of inflections. This control would leave fewer resources available to manage any secondary task.

At the moment, the two-step process of detecting these agreement problems remains quite speculative. It allows one to explain our results partially; however, more research is needed.

The functional model that we have developed enables us to understand why subject–verb agreement errors occur so rarely and, at the same time, why errors are unavoidable, even by experts. This explanation fits well with the data collected in written French language as well as in oral English by Bock and Miller (1991). Indeed, Bock and Miller found an increase in the number of errors when the local noun was plural—a fact systematically observed in our experiments.

As the task we used can hardly be considered a written production task, this raises the problem of the ecological validity of our results. This problem cannot be disregarded. However, as explained in the theoretical part of this paper, using a recall task can be justified by reference to the current conceptions of the language production process. Indeed, in all these conceptions at least one buffer is introduced whose role is to keep in an active state previously produced information prior to its material realization. It remains for future research to look for more ecological methodologies.

REFERENCES


Towards a Clarification of Spatial Processing

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Three experiments that adopt an interference paradigm to investigate characteristics of a type of movement causing interference with spatial processing are reported. Experiment 1 illustrates the importance of distinguishing between movement and attention to movement when investigating the movement characteristics of spatial processing. The technique of passive movement is used to minimize attention in the subsequent experiments. Experiment 2 confirms earlier experiments showing that passive movement causes interference in spatial processing. However, it extends the previous findings by demonstrating that passive movement is detrimental to spatial processing only when the movement is to a sequence of locations known in advance by the subjects. Experiment 3 demonstrates that the movement interference cannot be interpreted as a general interference effect but that it is selective for spatial processing. The results of these experiments permit a more precise delineation of the disruptive effects of movement in spatial processing and allow an explicit definition of spatial processing to be put forward.

One of the major concerns of investigations into visuo-spatial memory has been to elucidate the nature of the cognitive codes underlying spatial processing. This has been particularly true within the working memory model developed by Baddeley and his colleagues (Baddeley & Hitch, 1974; Baddeley, 1981, 1983; Baddeley & Lieberman, 1980). Currently, the working memory model comprises a central executive (CE) and two slave systems, which are controlled by the CE. The extent of the control has not yet been made explicit, nor have the circumstances under which the control is exercised been fully defined. Nevertheless, considerable progress has been made towards a detailed understanding of one of the two slave systems, the articulatory loop (AL).

Initially, the AL was considered a uniform system responsible for handling verbal information and showing phenomena associated with short-term memory as described by the modal model (Atkinson & Shiffrin, 1971). In their pioneering work, Baddeley and Hitch (1974) demonstrated that it