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# Executive control is shared between sentence processing and digit maintenance: Evidence from a strictly timed dual-task paradigm

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We investigated whether the comprehension of syntactically difficult sentences taxes the executive control component of working memory more than the comprehension of their easier counterparts. To that end, we tested the effect of sharing executive control between sentence comprehension and the maintenance of a digit load in two dual-task experiments with strictly controlled timing (Barrouillet, Bernardin, & Camos, 2004). Recall was worse after participants had processed one (Experiment 2) or two (Experiment 1) difficult sentences than after they had processed one or two easy sentences, respectively. This finding suggests that sentence processing and the maintenance of a digit load share executive control. Processing syntactically difficult sentences seems to occupy executive control for a longer time than processing their easy counterparts, thereby blocking refreshments of the memory traces of the digits so that these traces decay more and recall is worse. There was no effect of the size of the digit load on sentence-processing performance (Experiment 2), suggesting that sentence processing completely occupied executive control until processing was complete.

***Keywords:*** Dual-task paradigm; Executive control; Sentence processing; Time-based resource-sharing model; Working memory.

Working memory is generally viewed as a limited-capacity system in which information is temporarily stored and manipulated (e.g., Baddeley, 1986; Baddeley & Hitch, 1974). Most theories of working memory assume a central, domain-general executive control system, also called "attention" (Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007), "controlled attention" (Engle, Kane, & Tuholski, 1999), the "focus of attention" (Cowan, 2000; Oberauer, 2009), or the updated version of the "central executive" in the model of Baddeley (Repovš & Baddeley, 2006). This central system is assumed to be involved in both processing and storage tasks. Evidence for this dual involvement has been found in numerous dual-task experiments (e.g., Baddeley & Hitch, 1974; Rohrer & Pashler, 2003), in which a storage task and a processing task had to be performed simultaneously. It was observed that performance on either or both tasks was impaired compared to a single-task setup. Apart from this executive control system, a number of working memory theories also postulates the existence of additional, passive, domain-specific storage systems that function without executive control (Repovš & Baddeley, 2006). For example, Baddeley (1986) suggested that the phonological loop and the visuospatial sketchpad are responsible for the short-term storage of a limited amount of verbal and visual or spatial information respectively.

In the present paper, we study the role of working memory in sentence comprehension.

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Sentence comprehension involves a number of subprocesses, like word recognition, retrieval of the pronunciation, meaning and grammatical features of the words, building the syntactic structure of the sentence, assignment of the thematic roles to the noun phrases, and integrating the meaning of the sentence into the wider discourse context. In the present paper, we investigate the role of working memory in *the syntactic processes* involved in sentence comprehension and we will use the terms "sentence comprehension" and "sentence processing" in that sense.

It is well-established that some sentences are easier to process than others. For example, a sentence with a subject-extracted relative clause like (1a) is generally easier to process than a sentence with an object-extracted relative clause like (1b).

(1a) The reporter who attacked the senator admitted the error.

(1b) The reporter who the senator attacked admitted the error.

The difference in sentence-processing difficulty is reflected in longer reading times and more comprehension errors on difficult sentences than on easy sentences (e.g., Frazier, 1987; Frazier & Flores d'Arcais, 1989; Mak, Vonk, & Schriefers, 2002). There can be numerous reasons, of course, why one sentence is more difficult than another one, but many theories of language comprehension have directly or indirectly hypothesised that these behavioural data reflect the fact that processing difficult sentences taxes working memory more than processing easy sentences (e.g., Frazier, 1987; Gibson, 1998; Just & Carpenter, 1992; Miller & Chomsky, 1963; but see MacDonald & Christiansen, 2002, and MacWhinney, 1977, for alternative explanations).

When considering the processes involved in sentence comprehension, it is indeed easy to imagine a role for working memory. Sentence processing is considered to be an incremental process (Reichle, Rayner, & Pollatsek, 2003; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995), in which each new, incoming word has to be assigned a syntactic function and has to be integrated into the syntactic structure that has been processed so far. This process is thought to be computationally demanding and is therefore assumed to rely on working memory (e.g., Gibson, 1998). Beside these processing demands, sentence comprehension is also assumed to involve storage demands. More specifically, in order to be able to integrate an incoming word with the part of the sentence processed so far, either these previously processed elements or the to-be-expected upcoming elements (e.g., Chomsky & Miller, 1963; Gibson, 1998) have to be kept in short-term memory. Given that most working memory theories (e.g., Barrouillet et al., 2004; Repovš & Baddeley, 2006) assume that executive control is needed for processing as well as for the active maintenance of items in short-term memory, we investigated the hypothesis that executive control is involved in sentence comprehension.

More specifically, we hypothesised that processing syntactically difficult sentences (e.g., object-extracted relative clauses) taxes executive control for a longer time than processing their syntactically easier counterparts (e.g., subject-extracted relative clauses). To test this hypothesis, we set up two dual-task experiments in which participants had to maintain an extrasentential memory load while processing either a syntactically difficult or a syntactically easy sentence. In Experiment 1, we manipulated sentence-processing difficulty but kept the memory load size constant, whereas in Experiment 2 both factors were manipulated. As we will explain later, we hypothesised that executive control is needed for the active maintenance of an extrasentential digit load as well as for the sentence comprehension task. Therefore, we expected the recall of the digit load to be worse after processing syntactically difficult sentence than after processing syntactically easier sentences.

Our expectations were based on the recent work of Barrouillet and colleagues (e.g., Barrouillet et al., 2004, 2007; Portrat, Barrouillet, & Camos, 2008). These authors extensively studied the way in which executive control is shared between a storage and a processing task in a dual-task situation. In a series of dual-task experiments, they observed that the maintenance of a memory load suffered from the presence of a simultaneous processing task, and that the amount of impairment increased with the difficulty of the intervening processing task. This observation led them to formulate the *time-based resource-sharing* theory, in which they assume that executive control can be shared among processing and storage tasks, but only in a strictly *serial* fashion, namely one task at a time. The sharing of executive control is then realised by alternating between controlled processing of the intervening task on the one hand and refreshment and reconstruction of the memory representations of the items of the storage task on the other hand. Also, the more difficult the processing task is, the longer it will occupy the executive control system before it becomes available again for the storage task. As a consequence, less time will be left for reactivation of the memory load through executive control, thus leading to *passive decay* of the memory load and thus to poorer recall performance.

Applying these assumptions to the dual-task experiments in the present study, we expected that the processing of a syntactically more difficult sentence would occupy executive control for a longer time than the processing of its easier counterpart, thereby blocking the refreshment of the memory items of the extrasentential memory load for a longer time. As a consequence, we expected the recall of that load to be worse after processing difficult compared to easy sentences. This effect would suggest that executive control is needed for the processing of the syntactic difficulty in syntactically difficult sentences.

However, we had to take care to select the appropriate extrasentential memory load to test this hypothesis. As discussed, one mechanism of forgetting in short-term memory is the *passive decay* of the storage items when executive control is switched away, for example, to the processing task (Barrouillet et al., 2007). However, still another mechanism of forgetting in short-term memory has been proposed: *similarity-based interference* (Lange & Oberauer, 2005; Nairne, 1990; Oberauer, Lange, & Engle, 2004). It has been observed that the recall of items that are similar to each other in terms of certain features (phonological, semantic, etc., see further) is worse than the recall of dissimilar items. It is therefore assumed that the representations of similar items can interfere in short-term memory. In the present study, we wanted to make sure that forgetting of the extrasentential load is due to passive decay of the load through the sharing of executive control with sentence processing and not to interference between the memory representations of the load and those of the material in the sentence in short-term memory (Saito & Miyake, 2004). Therefore, we selected an extrasentential load that is dissimilar to the material in the sentence, at least in terms of those linguistic features in which the sentence material is represented in short-term memory during the incremental process of sentence comprehension.

Considerable evidence suggests that the sentence material is temporally stored in terms of its semantic features and not in terms of its phonological features. For example, some brain-damaged patients with severely reduced phonological short-term memory (one to two items) have been reported to have a normal ability to process both easy and difficult sentences (e.g., Baddeley, 2000; Martin, 2006; Waters, Caplan, & Hildebrandt, 1991). Also, when disturbing the articulatory rehearsal process of phonological material with a concurrent articulation task, Waters, Caplan, and Hildebrandt (1987) did not find worse plausibility judgements to syntactically difficult object-extracted relative clauses than to syntactically easier subject-extracted relative clauses. Thus, sentence comprehension appears not to rely on the maintenance of the phonological representations of the sentence material.

Rather, more recent studies suggest that the material in the sentence is encoded, stored and/or retrieved in terms of its semantic features (e.g., Lewis, Vasishth, & van Dyke, 2006; Martin, 2006; McElree, Foraker, & Dyer, 2003). For example, Fedorenko, Gibson, and Rohde (2006) found that the self-paced reading times of an English object-extracted relative clause like "who the parents liked" in the sentence "The babysitter who the parents liked planned a trip..." were longer when a load that was semantically similar to the NPs in the sentence ("the babysitter" and "the parents") had to be maintained than when a semantically dissimilar load had to be maintained. On the other hand, the reading times of the subject-extracted relative clause "who liked the parents" in that same sentence were unaffected by the similarity of the extrasentential load (see, for related evidence, Gordon, Hendrick, & Levine, 2002; Potter & Lombardi, 1990; van Dyke & McElree, 2006). These results can be explained by the fact that in the object-extracted relative clause, the embedded subject "the parents" intervenes between "the babysitter" and "liked". Thus, to integrate the embedded verb "liked" with its object "the babysitter", this last element has to be retrieved from memory. When semantically similar items (the extrasentential word load) are also stored in memory, the to-be-retrieved item can suffer from similarity-based interference (Lewis & Vasishth, 2005; Lewis et al., 2006; van Dyke & Lewis, 2003). In contrast, in subject-extracted relative clauses, "the babysitter" can immediately be integrated with "liked". Hence, no interference of the extrasentential word load can occur. In summary, this line of research suggests that sentence material is temporally stored in terms of its semantic features. To exclude forgetting due to similarity-based interference between the extrasentential load and the material in the sentence in the present study, we selected a maintenance task in which the load is *semantically dissimilar* to the material in the sentence: a digit load maintenance task.

The dual-task effect between sentence processing and the maintenance of an extrasentential digit load has been tested in a number of previous studies, but the results seem, at first sight, unclear (for an overview, see Waters, Caplan, & Yampolsky, 2003). For example, Waters and colleagues (1987) found a larger effect of the concurrent articulation of a random six-digit load versus that of a familiar six-digit load (i.e., the sequence 1, 2, 3, 4, 5, 6) on semantic acceptability judgements to sentences. Moreover, the maintenance of the random digit load was more detrimental for judgements about difficult, object-relativised sentences than for those about the easier, subject-relativised sentences. This interaction suggests that the processing of syntactic difficulty and the maintenance of a random digit sequence compete for executive control. On the other hand, in a sentence-picture matching task, Waters, Caplan, and Rochon (1995) found that patients with dementia of the Alzheimer's type as well as their controls recalled a random sequence of digits equally well after processing a difficult sentence (in terms of syntactic complexity) than after processing a simple sentence, suggesting that the tasks do not share executive control. The pattern of results from previous studies thus does not provide a conclusive answer to the question whether the processing of syntactic difficulty and the maintenance of a random digit sequence compete for executive control. One of the reasons for this mixed pattern of results might be that previous studies all used a self-paced paradigm, in which it is more difficult to capture the subtle effects of a tradeoff between both tasks. In the present study, we therefore controlled the time within which both tasks had to be performed over conditions.

The importance of applying the same strictly controlled temporal boundaries across conditions has been advocated by the authors of the time-based resource-sharing model (e.g., Barrouillet et al., 2007). As already explained, this model assumes that executive control is shared *serially* between a storage and a processing task. A methodological consequence of this assumption is the importance to strictly control the time within which two tasks in a dual-task paradigm have to serially share executive control, in order to be able to capture the subtle effects of a tradeoff of executive control between both tasks.

In the present study, we applied this time-controlling methodology to test the hypothesis that processing a sentence for comprehension is a controlled process which requires executive control. As illustrated in Figure 1, we predicted that when fixing the time window between digit presentation and digit recall and consequently fixing the time within which a sentence has to be processed while maintaining a previously presented digit load, processing of a difficult sentence will occupy executive control for a longer time than processing of its easy counterpart. As a consequence, the maintenance of a digit load will be impaired more after a difficult sentence than after its easier counterpart.

We performed two experiments. In the first experiment, we tested the effect of sentence-processing difficulty on digit recall. Participants had to maintain a digit load while processing two easy or two difficult sentences for comprehension. In the second experiment, we tested the same effect and additionally tested the effect of the size of the digit load on sentence-processing performance. In this experiment, only one easy or difficult sentence had to be processed during maintenance of a smaller or a larger digit load. In both experiments, the same strictly controlled temporal boundaries were applied across conditions.

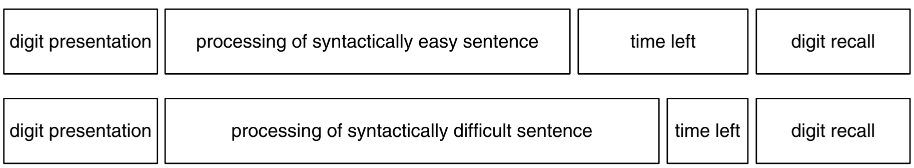


**Figure 1.** Illustration of the hypothesis that processing of a syntactically difficult sentence occupies executive control for a longer time than processing its easier counterpart.

Many studies on the involvement of working memory in sentence processing have investigated the difference between subject- and object-extracted relative clauses (e.g., Fedorenko et al., 2006; Gordon et al., 2002; King & Just, 1991). However, other minimal sentence pairs differ in syntactic difficulty (see the Method section of Experiment 1 for more details). The difficult sentences in these pairs are read slower and less accurately than their easy counterparts (e.g., Chomsky & Miller, 1963). We hypothesise that processing of the syntactic difficulty in these difficult sentences requires the engagement of executive control, leading to longer overall processing times for difficult sentences than for their easier counterparts. To be able to generalise our findings beyond the traditionally studied subject- and object-extracted relative clauses, the present study investigates the involvement of executive control in five different sentence types. As a consequence, we will be able to extend our findings beyond subject- and object-extracted relative clauses.

## EXPERIMENT 1

Experiment 1 investigated whether sentence processing captures executive control, thus impairing the maintenance of digits. We designed an experiment using the time-based resource-sharing procedure in which a sequence of digits had to be maintained in memory during performance of a sentence-processing task. The time within which these two tasks had to be performed was the same for the easy and difficult variant of a sentence. If performance of both tasks requires executive control and if difficult sentences occupy executive control for a longer time than easy sentences, we expect to find worse digit recall after processing of difficult sentences than after processing of easy sentences.

Each trial started with the presentation of six digits, which had to be kept in memory and had to be recalled after a fixed time interval. During this retention interval either two easy or two difficult sentence sequences were presented. The duration of the interval depended on the length of the intervening sentences but was the same for the easy and the difficult variant of a sentence. We presented two sentence sequences instead of one in order to maximise the chances of finding an effect of sentence-processing difficulty on digit recall. Each sentence sequence consisted of a sentence, a comprehension question, feedback to the answer on that question, and a blank screen. First, a sentence was presented that had to be read in silence before a tight time-out. Participants thus had to ensure to process the sentence before it disappeared. Sentence reading was self-paced, so if participants processed the sentence before the tight time-out, they could immediately pace themselves to the yes/no comprehension question about the sentence. In this way, the processed representation of the sentence did not have to be kept in memory during an extra time interval. As a consequence, digit-recall performance would not be affected by the maintenance of this extra memory load, and would merely be affected by the amount of executive control used for sentence processing itself. The total duration of each sequence was fixed by introducing a blank screen with variable duration at the end of the sequence (see Procedure for details). A trial was thus built up as in Figure 2.

### Method

*Participants.* Twenty-four students (18 female, six male) from Ghent University were paid for their participation. The mean age was 21.6 ($SD = 2.1$). All participants were native speakers of Dutch, had normal or corrected to normal

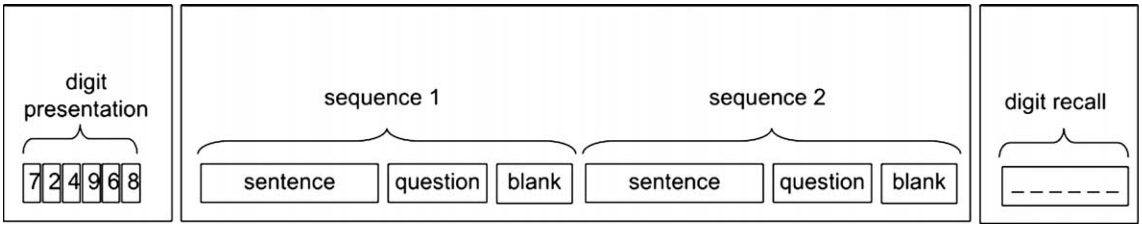


**Figure 2.** Design of the trials in Experiment 1. Separate boxes symbolise separate screens.

vision, had normal reading skills, and were naive to the purposes of the study.

*Design and materials.* We selected five sentence types that have been shown to differ in sentence-processing difficulty. In the following list of the used sentence types, the first-mentioned structure is generally easier to process than the second-mentioned one, also in Dutch: (1) sentences with a subject-extracted relative clause versus sentences with an object-extracted relative clause (Frazier, 1987; Frazier & Flores d'Arcais, 1989; Mak et al., 2002), (2) active versus passive sentences (Ferreira, 2003), (3) sentences with a nonnested relative clause versus sentences with a nested or centre-embedded relative clause (Chomsky, 1957, 1965; Chomsky & Miller, 1963; Miller & Chomsky, 1963; Miller & Isard, 1964; Yngve, 1960), (4) sentences with an unambiguous anaphoric pronoun versus those with an ambiguous anaphoric pronoun (Stewart, Holler, & Kidd, 2007), and (5) sentences in which the direct object (DO) is placed before a heavy indirect object (IO) and sentences in which the DO is placed after the heavy IO (Staub, Clifton, & Frazier, 2006). A further description of the five sentence types and the complete list of sentences can be found in the Appendix.

Within each sentence type, we constructed 20 sentence pairs each containing an easy sentence and its difficult counterpart. Sentences within a pair were built up from the same lexical items and were thus automatically matched in length. Only active and passive constructions intrinsically differ in length (e.g., the active verb phrase "verjaagt [chases]" vs. the passive one "wordt verjaagd door [is chased by]"). The length of these sentence pairs was matched in number of syllables, by selecting longer, but semantically very similar lexical items for the agent and/or patient in the active sentence than in its passive counterpart. For example, in the active sentence "De tovenaar verjaagt de reus. [The wizard chases the giant.]", the longer word "tovenaar [wizard]" was used, whereas in its passive counterpart "De reus wordt door de heks verjaagd. [The giant is chased by the witch.]", the shorter, but semantically related word "heks [witch]" was used. Each participant only saw one sentence of a pair. Thus, each participant saw 50 easy and 50 difficult sentences (10 of each of the five sentence types) and each sentence was presented to only half of the participants.

Each sentence was followed by a comprehension question, to check whether participants fully and correctly processed the sentences. The question concerned the interpretation of the meaning generated by the specific manipulation of the syntactic structure. For example, the question for the subject-extracted relative clause sentence "Ze praat met de patiënten die de dokter bezocht hebben. [She talks to the patients who visited the doctor.]" and for the object-extracted relative clause sentence "Ze praat met de dokter die de patiënten bezocht hebben. [She talks to the doctor who the patients visited.]" was "Hebben de patiënten de dokter bezocht? [Did the patients visit the doctor?]". The question was presented immediately after the sentence. Questions were the same for the easy and difficult sentence within a pair. Half of the comprehension questions required a yes-answer and half of them a no-answer.

The validity of the operationalisation of sentence-processing difficulty was tested in a pilot study with 18 further participants (11 female, seven male; mean age = 25.8, $SD = 3.0$), who read the sentences as quickly as possible and answered the comprehension question immediately after reading the sentence. Both tasks were performed in the absence of any memory load. Reading times were longer for difficult sentences ($M = 4335$ ms, $SD = 1068$ ms) than for easy sentences ($M = 3933$ ms, $SD = 993$ ms), $F(1, 17) = 40.05$, $p < .001$, $\eta_p^2 = .70$, and questions were answered less accurately for difficult sentences ($M = 70\%$, $SD = 11\%$) than for easy sentences ($M = 89\%$, $SD = 9\%$), $F(1, 17) = 40.85$, $p < .001$, $\eta_p^2 = .71$, in all sentence types.

*Procedure and apparatus.* At the beginning of the experiment, the instructions were presented on screen. To accustom to the procedure, participants first performed 5 practice trials. Then, the 50 critical trials were presented, with a self-paced pause after each trial.

On each trial, participants performed two tasks: They were presented six digits which they had to maintain while they processed two sentence sequences consecutively. Each sentence sequence consisted of the presentation of the sentence itself, followed by a comprehension question which had to be answered, feedback to that answer, and a blank screen. The two sentences presented in a trial were always of a different syntactic type, to prevent as much as possible that participants would notice the recurring sentence structures and thus would be able to use processing strategies. On the other hand, the two sentences in a trial were always of the same sentence-processing difficulty (either both were difficult or both were easy), to be able to test the effect of sentence-processing difficulty on digit recall. At the end of the trial, participants had to recall the six digits in the correct order.

To go into more detail, a trial was built up as follows: Each trial started with a fixation cross of 1000 ms. A new set of six different digits ranging from 0 to 9 was sampled for each trial. To discourage chunking (Miller, 1956), each single digit was presented on a separate screen for 1500 ms, followed by a blank screen of 200 ms. After this sequence of digits and blank screens, the first sentence sequence was presented.

A trial thus started with a fixation cross, presented for 1000 ms. Then, the sentence was presented in its full form. To avoid that participants strategically postponed reading in order to rehearse the digits, the sentence was presented during a rather tight time interval. More precisely, the maximum presentation duration varied with sentence length. It was calculated by multiplying the number of characters (spaces included) in the sentence by 65 ms. This measure was defined on the basis of the data of the pilot study in which participants had to read the experimental sentences as quickly as possible without a time-out or secondary load. The number of characters in the sentences was highly correlated with the reading times, $r = .549$, $N = 1710$, $p < .001$. Moreover, two-thirds of all reading times were lower than 65 ms times the number of characters. Basing the presentation duration of the sentences on this measure thus provided us with a tight interval, which forced participants to switch to sentence processing immediately upon presentation of the sentence, in order to be able to process the full sentence completely before the presentation timed out. Duration varied over pairs but not within pairs, as the two sentences within a pair consisted of the same number of characters. There was one exception: The active and passive sentence within a pair consisted of the same number of syllables, not characters. The presentation durations for this sentence type were therefore based on the number of characters in the passive sentence in the pair.

Participants were instructed to press the spacebar on the keyboard as soon as they had completely processed the sentence. After either the registration of this self-paced spacebar press or at the time-out, the comprehension question appeared. Answers to questions were given by pressing a predefined "yes" or "no" button on the keyboard. Answers were self-paced, but had to be performed within 2500 ms. Immediately after detection of the answer, feedback to the answer was presented for 500 ms. Feedback could either be "juist [correct]" for correct answers, "fout [incorrect]" for incorrect answers, or "te laat [too late]" if no answer had been given, encouraging participants to answer more quickly. At the end of the sentence sequence, a blank screen was shown for minimally 1500 ms. However, if the participant had responded to the sentence and/or the question before the respective time-outs of the provided intervals, the time between the actual response and the time-out was added to the duration of the blank screen. That way, the total duration of each sequence was the same for the easy and the difficult sentence within a pair.

After this blank screen, the second sentence sequence was presented in the same way, starting with a fixation cross for 500 ms. After the blank screen at the end of the second sentence sequence, a rectangle was shown in the centre of the screen to cue participants to start recalling the digits. Digits had to be typed in within 10,000 ms on the numerical keyboard in the order in which they had been presented.

Participants were instructed to remember the digits in the order in which they were presented, to read the sentences quickly, but also to ensure that they understood them completely, and to answer the comprehension questions as quickly and accurately as possible. They were instructed not to concentrate on one task (digit recall or sentence processing) more than the other.

Participants were tested individually by means of a Pentium 4 personal computer with a 17-inch monitor running the E-Prime experimentation software (Schneider, Eschman, & Zuccolotto, 2002). All items were presented in white on a black screen. Digits and the preceding fixation cross were presented in the centre of the screen. Digits were presented in bold Courier New 18 font. Sentences, the preceding fixation crosses, and comprehension questions were aligned left on the horizontal axis and in the centre on the vertical axis. Sentences and questions were presented in bold Arial 7 font, so that they would all fit on one line. All fixation crosses were presented in nonbold Arial 14 font.

## Results

Participants constituted the only random factor in the design of the present experiment. Items (or sentences) were not a random factor, as the easy and the difficult sentences within a pair were matched (see earlier) and only differed in sentence-processing difficulty (Erdfelder, 2010; Raaijmakers, Schrijnemakers, & Gremmen, 1999). Therefore, we calculated the effect of sentence-processing difficulty (difficult vs. easy sentences) on digit recall and on sentence-processing performance respectively with repeated measures analyses of variance on the means for participants. Since the two sentences within a trial always belonged to a different sentence type, the effect of sentence type could not be analysed.

*Digit-recall performance.* Digit-recall performance was calculated using a transformation of Kendall's rank correlation coefficient tau ($\tau'$), which reflects the proportion of digits recalled in correct relative order. Values range between 0 and 1. Higher values reflect many recalled items in correct order, whereas low values reflect strongly violated order or few recalled items (for details see Szmalec & Vandierendonck, 2007). In practice, a value of 0.5 corresponds to a recall of the digits in random order. This $\tau'$-measure contrasts with traditional measures of recall (e.g., span), which reflect the proportion of items recalled in correct *absolute* order. If a sequence like "1 2 3 4 5 6" is recalled as "1 3 4 5 6" (some items recalled in correct relative order, but in incorrect absolute order) or as "1 3 2 5 4 6" (items recalled correctly, but some in incorrect order), a traditional span measure would consider this as one item recalled correctly, namely only "1". The $\tau'$-measure we used attributes to these examples the scores 0.81 and 0.76 respectively by using the rank correlation of the recalled digits with the presented order, weighted by the proportion of digits recalled, and rescaled to the range 0–1.

Recall was better when easy sentences had been processed ($M = 0.80$, $SD = 0.08$) than when difficult sentences had been processed ($M = 0.78$, $SD = 0.07$), $F(1, 23) = 4.36$, $p = .048$, $\eta_p^2 = .16$. Although this difference in recall performance seems small when expressed by the $\tau'$-measure, the effect size ($\eta_p^2$) points at a substantial effect of sentence-processing difficulty on recall performance.

*Sentence-processing performance.* Sentence-processing performance was measured by (1) sentence reading times, (2) accuracy,[1] and (3) response times to the comprehension questions. There were 12.8% time-outs in the sentence reading times and 5.5% in the response times to the comprehension questions. The time-out times were included in the analyses of the sentence reading times and of the response times to the comprehension times, respectively.

There was a main effect of sentence-processing difficulty on all measures. Sentence reading times were longer for difficult sentences ($M = 3626$ ms, $SD = 804$ ms) than for easy sentences ($M = 3357$ ms, $SD = 758$ ms), $F(1, 23) = 38.48$, $p < .001$, $\eta_p^2 = .63$. Answers to comprehension questions were less accurate for difficult sentences ($M = 67\%$, $SD = 11\%$) than for easy sentences ($M = 82\%$, $SD = 9\%$), $F(1, 23) = 119.68$, $p < .001$, $\eta_p^2 = .84$. Response times to comprehension questions were longer for difficult sentences ($M = 1601$ ms, $SD = 177$ ms) than for easy sentences ($M = 1524$ ms, $SD = 175$ ms), $F(1, 23) = 22.47$, $p < .001$, $\eta_p^2 = .49$.

## Discussion

Using a time-controlled dual-task paradigm, we found an effect of sentence-processing difficulty on digit-recall performance: Recall performance was worse after processing syntactically difficult sentences than after processing syntactically easy sentences. This suggests that processing difficult sentences taxes executive control for a longer time than processing easy sentences. As a consequence, refreshment of the digit sequence is blocked for a longer time and the memory traces

[1] Answers to comprehension questions on (un)ambiguous pronoun sentences were left out of the analyses of the accuracy data. Questions on this type of sentence checked whether participants had correctly interpreted the pronoun and knew to which of the two persons in the head clause it referred. As the pronoun in sentences with an ambiguous pronoun could refer to either person in the head clause, it could never be misinterpreted and answers to comprehension questions were always correct. On the other hand, the pronoun in sentences with an unambiguous pronoun could only refer to one of the two persons in the head clause and could consequently be misinterpreted. An analysis on the accuracy data for these sentences would thus not be a fair test of performance differences.

of the digits (or the memory traces of the links between the digits and their respective positions in the sequence) decay more. This leads to poorer recall performance after difficult than after easy sentences. We thus found support for the hypothesis that one of the causes for the well-established finding that syntactically difficult sentences are processed slower and less accurately than their easy counterparts, a finding that was replicated in the present study, is the fact that processing difficult sentences occupies executive control for a longer time than processing easy sentences.

## EXPERIMENT 2

In Experiment 1, we presented two sentence sequences instead of one in order to maximise the chances of finding an effect of sentence-processing difficulty on digit recall. In Experiment 2, we investigated whether it is possible to replicate the effect of sentence-processing difficulty on digit recall with only one sentence sequence instead of two. Moreover, apart from manipulating the difficulty of the sentence-processing task (easy vs. difficult sentences, as in Experiment 1), we also manipulated the difficulty of the digit-maintenance task (load size of 5 vs. 6 digits). In short, on the basis of the assumptions of the time-based resource-sharing model (e.g., Barrouillet et al., 2007), we expected a main effect of sentence-processing difficulty as well as a main effect of digit-load size on digit recall performance. On sentence-processing performance, we expected either an additive effect of both factors, or an effect of sentence-processing difficulty but no effect of digit-load size. Crucially, we expected no interaction between both factors on any of the two dependent variables (digit recall or sentence-processing performance).

To explain this in more detail, in working memory theories, components like the phonological loop (Baddeley, 1986) or the direct access area of verbal working memory (Cowan, 2000; Oberauer, 2002) are assumed to have a limited capacity that is shared continuously among the competing processes or tasks. As a consequence, if two tasks tax such a limited capacity component, an increase in the amount of capacity consumed by one task leads to a continuous decrease in capacity available for the other task and thus capacity is traded off between the two tasks, resulting in an interaction of the difficulty of these tasks.

Executive control, on the other hand, is hypothesised to be shared serially on an all-or-none basis and thus not continuously (Barrouillet et al., 2007). There is a considerable amount of evidence that many of the elementary cognitive steps involved in both processing and maintenance tasks can take place only one at a time (through a bottleneck mechanism, Pashler, 1998; Rohrer & Pashler, 2003; Rohrer, Pashler, & Etchegaray, 1998; or through a limited focus of attention, Garavan, 1998; Oberauer, 2002, 2005). Therefore, it is assumed that executive control is shared by switching between tasks (Barrouillet et al., 2007). This also implies that when executive control is available to one task, it is fully available for that task (and not partly, like when it would be shared in parallel) and unavailable for the other task (cf. evidence from task-switching research; Vandierendonck, Liefooghe, & Verbruggen, 2010).

Therefore, as the results of Experiment 1 already suggested that digit maintenance and sentence processing both require executive control, no interaction of the difficulty of these tasks on sentence-processing performance is expected. At most an additive effect of both factors is expected. If participants switch to the refreshment of the digits during sentence processing at all and if the refreshment of memory traces of longer series of digits occupies executive control for a longer time, executive control will be unavailable for sentence comprehension during a longer period when refreshing a higher instead of a lower digit load. In the case of a higher digit load, refreshing operations of the digit load will continue while the sentence is presented, resulting in a shift such that sentence processing starts later but will also end at a later time. This will lead either to longer sentence reading times as measured from the start of sentence presentation, or to exceeding the available reading time (time-out of sentence reading) resulting in a lower answering accuracy to the comprehension questions. However, this effect of digit-load size is only expected if, during the retention interval, participants prefer to use time for the refreshment of the digits rather than for sentence processing. The alternative for the participants is to give priority to the sentence-processing task and to use only the remaining time to refresh the digit load. In the latter case, no effect of the digit-load size on sentence-processing performance is expected.

To wrap up, no interaction of digit-load size and sentence-processing difficulty is expected, and whether there is an effect of digit-load size on sentence-processing performance depends on which of the two tasks is given priority in accessing the serially shared executive control. Finding an interaction between both factors would suggest that executive control (or some other resource) is shared in parallel between sentence processing and digit maintenance.

In Experiment 2, we thus tested the effect of digit-load size on sentence-processing performance. In contrast to Experiment 1, where the load always consisted of six digits, in Experiment 2 we presented two load conditions: Either five or six digits had to be recalled. The choice for these load sizes was based on a number of considerations. First, it was important that the load sizes were not too high. In a pilot study, we observed that with a load size of eight digits, participants just gave up on executing one of both tasks, indicating that the maintenance of a load of eight digits probably demands the permanent involvement of executive control, leaving no room for dual tasking. As seen in Experiment 1, the execution of both tasks was still possible with a load size of six digits. We therefore selected this load size as the highest one in the present experiment. Second, it was important that the load sizes were not too low. Both a load of five digits and one of six digits are close to the span of the average participant and exceed the capacity of the direct access area (four items; cf. Cowan, 2000). It is thus very likely that executive control is required to maintain them. A model like that of Baddeley and Hitch (1974), for example, assumes that lower load sizes can be passively maintained by the phonological loop and thus place little or no demands on executive control. In that case, no dual-task effects are expected with lower load sizes (but see Camos, Lagner, & Barrouillet, 2009). Third, although the load difference of five versus six digits is numerically minimal, it has proven to lead to clear effects. For example, Liefooghe, Barrouillet, Vandierendonck, and Camos (2008) showed that the maintenance of six consonants was impaired more by task switching than the maintenance of five consonants. All these considerations led us to choose a load size manipulation of five versus six digits.

In the present experiment, we also explored the effect of sentence type. Trials in Experiment 1 contained two sentences of a different sentence type. It was thus not possible to assess the individual effects of the various sentence types there. In Experiment 2, we presented only one sentence sequence per trial. This allowed us to explore whether the general effect of sentence-processing difficulty on digit recall is due to some specific sentence types, or whether executive control is involved in the processing of each of the five tested sentence types. This investigation is rather explorative, as we were limited to 20 sentences per sentence type (10 difficult vs. 10 easy sentences), in order to keep testing, which was very demanding for the participants, within the limits of 1 hour. Our sample size might thus not be large enough to yield significant effects.

Everything else in the present experiment was the same as in Experiment 1. Importantly, also here, the time within which the maintenance task and the sentence-processing task had to be performed was kept constant over sentence-processing difficulty and digit-load size conditions, in order to be able to test the subtle effects of the serial sharing of executive control between both tasks (e.g., Barrouillet et al., 2004).

## Method

*Design and materials.* The experiment had a $2 \times 2 \times 5$ mixed design, crossing memory load (five vs. six single digits) with sentence-processing difficulty (easy vs. difficult sentences) with sentence type (five types of syntactic structures). The sentences and questions were the same as in Experiment 1.

*Participants.* Twenty-eight further students (22 female, six male) from Ghent University were paid for their participation. The mean age was 20.2 ($SD = 1.8$). All participants were native speakers of Dutch, had normal or corrected vision, had normal reading skills and were naive to the purposes of the study.

*Apparatus and procedure.* The apparatus and procedure were the same as in Experiment 1, except where indicated otherwise. Participants performed four practice trials and 100 critical trials. Each trial consisted of the presentation of the digits, one sentence sequence, and time for recall of the digits.

The first screen of each trial announced during 1000 ms in words whether ‘‘vijf cijfers’’ (five digits) or ‘‘zes cijfers’’ (six digits) would be presented. We informed the participants about the number of digits that would appear so as not to increase task difficulty by having to keep track of the number of digits. Then, the digits were presented one by one (as in Experiment 1). Subsequently, a fixation cross of 1000 ms announced the sentence sequence. This sequence was built up in the same way as in Experiment 1, except that only one sentence sequence was presented per trial, instead of two. Responses to the sentences and questions were registered by means of a button box.

After the blank screen at the end of the sentence sequence, five or six underscores (according to the number of digits that had to be recalled) were presented in the centre of the screen to cue participants to start recalling the digits. Digits had to be recalled orally in the order in which they had been presented. They were noted down by the experimenter.

## Results

Digit-recall performance and sentence-processing performance (i.e., reading times of the sentences, and response times and accuracy on the comprehension questions) were analysed in 2 (sentence-processing difficulty: easy vs. difficult sentences) $\times$ 2 (memory load: 5 vs. 6 digits) $\times$ 5 (sentence types) analyses of variance. Sentence-processing difficulty and memory load were treated as within-participants and within-items factors, and sentence type was treated as a within-participants and between-items factor. We report the analyses on the means for participants ($F$) for the within-items factors, and we report min $F'$ (as computed with the online tool of Pallier, 1996) for the between-items factor (Clark, 1973; Raaijmakers et al., 1999).

*Digit-recall performance.* Digit-recall performance was calculated in the same way as in Experiment 1. Recall was significantly better when an easy sentence had been processed ($M = 0.78$, $SD = 0.10$) than when a difficult sentence had been processed ($M = 0.76$, $SD = 0.10$), $F(1,\ 27) = 5.06$, $p = .033$, $\eta_p^2 = .16$. As expected, recall of five digits ($M = 0.80$, $SD = 0.10$) was significantly better than recall of six digits ($M = 0.75$, $SD = 0.11$), $F(1,\ 27) = 20.35$, $p < .001$, $\eta_p^2 = .43$. There was a main effect of sentence type (see Figure 3 for means), min $F'(4,\ 200) = 4.87$, $p < .001$, $\eta_p^2 = .09$. However, when introducing sentence length as a covariate in the by-item analysis, the effect of sentence type on digit-recall performance disappeared, $F2 < 1$. Also, the proportion of time the sentence-processing task (sentence reading times and response times to the comprehension questions) occupied the total retention interval correlated negatively with digit-recall performance, $r = -.168$, $N = 2800$, $p < .001$.

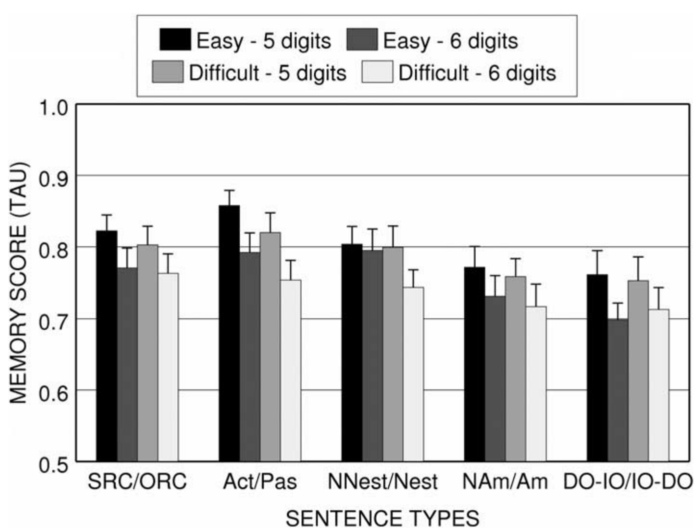


**Figure 3.** Digit recall scores based on a transformation of Kendall's rank correlation coefficient tau ($\tau'$) in Experiment 2, as a function of sentence-processing difficulty (easy vs. difficult), digit-load size (5 vs. 6 digits), and sentence type (SRC/ORC = subject-extracted vs. object-extracted relative clauses, Act/Pas = active vs. passive sentences, NNest/Nest = nonnested vs. nested relative clauses, NAm/Am = unambiguous vs. ambiguous pronoun sentences, DO-IO/IO-DO = sentences with the DO before the heavy IO vs. sentences with the DO after the heavy IO). Means and related standard errors (represented by the error bars) are taken from the participant analyses.

There were no interactions between any of the factors on recall performance (all *F*s and min F′s < 1).

*Sentence-processing performance.* Sentence-processing performance was assessed as in Experiment 1. There were 23.4% time-outs in the sentence reading times and 4.5% in the response times to the comprehension questions. The time-out times were included in the analyses of the sentence reading times and of the response times to the comprehension times respectively.

Sentence-processing difficulty affected all measures of sentence-processing performance. More specifically, reading times on difficult sentences ($M = 3465$ ms, $SD = 633$ ms) were longer than those on easy sentences ($M = 3357$ ms, $SD = 658$ ms), $F(1, 27) = 19.32$, $p < .001$, $\eta_p^2 = .42$. Answers to questions concerning difficult sentences were less accurate ($M = 69\%$, $SD = 8\%$) than answers to questions concerning easy sentences ($M = 81\%$, $SD = 8\%$), $F(1, 27) = 121.09$, $p < .001$, $\eta_p^2 = .82$. Response times to the comprehension questions were longer for difficult sentences ($M = 1560$ ms, $SD = 458$ ms) than for easy sentences ($M = 1500$ ms, $SD = 438$ ms), $F(1, 27) = 14.28$, $p < .001$, $\eta_p^2 = .35$.

The size of the memory load did not influence sentence-processing performance: for neither reading times (load 5: $M = 3430$ ms, $SD = 662$ ms; load 6: $M = 3394$ ms, $SD = 632$ ms), $F < 1$; the accuracy on the comprehension questions (load 5: $M = 76\%$, $SD = 7\%$; load 6: $M = 74\%$, $SD = 8\%$), $F(1, 27) = 2.16$, $p = .153$, $\eta_p^2 = .07$; nor response times to the comprehension questions (load 5: $M = 1533$ ms, $SD = 449$; load 6: $M = 1527$ ms, $SD = 449$ ms), $F < 1$.

There was a main effect of sentence type on the sentence reading times (see Figure 4), min $F'(4, 187) = 85.95$, $p < .001$, $\eta_p^2 = .65$, and on the response times to the questions (see Figure 5), min $F'(4, 114) = 5.45$, $p < .001$, $\eta_p^2 = .16$. The length of the sentences correlated positively with both the sentence reading times, $r = .717$, $N = 2800$, $p < .001$, and response times, $r = .181$, $N = 2800$, $p < .001$. Sentence length also correlated positively with the proportion of time the sentence-processing task (sentence reading times and response times to the comprehension questions) occupied the total retention interval, $r = .167$, $N = 2800$, $p < .001$. In the accuracy of the answers to the questions, there was also a main effect of sentence type (see Figure 6), min $F'(3, 115) = 6.53$, $p < .001$, $\eta_p^2 = .15$, but this factor interacted with sentence-processing difficulty, min $F'(3, 157) = 9.87$, $p < .001$, $\eta_p^2 = .16$. Pairwise comparisons of the effect of sentence-processing difficulty on answer accuracy within the different sentence types (see Figure 6) revealed that questions on active sentences were answered more accurately than questions on passive sentences, min $F'(1, 89) = 24.62$, $p < .001$, $\eta_p^2 = .22$,

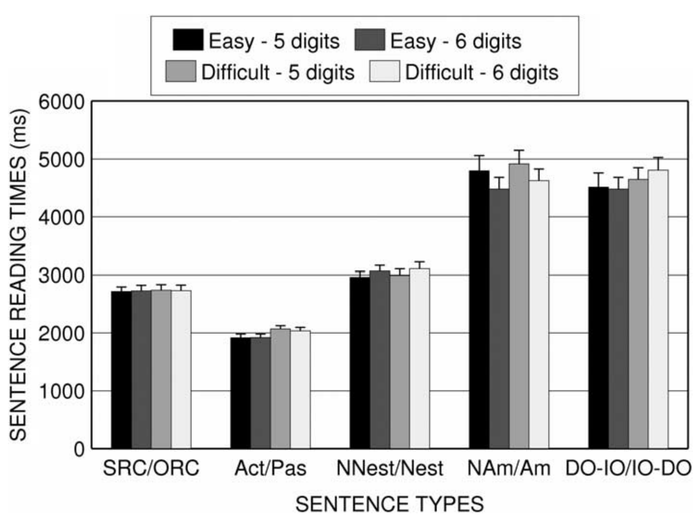


**Figure 4.** Mean sentence reading times in Experiment 2 in milliseconds, as a function of sentence-processing difficulty (easy vs. difficult), digit-load size (5 vs. 6 digits), and sentence type (SRC/ORC = subject-extracted vs. object-extracted relative clauses, Act/Pas = active vs. passive sentences, NNest/Nest = nonnested vs. nested relative clauses, NAm/Am = unambiguous vs. ambiguous pronoun sentences, DO-IO/IO-DO = sentences with the DO before the heavy IO vs. sentences with the DO after the heavy IO). Means and related standard errors (represented by the error bars) are taken from the participant analyses.

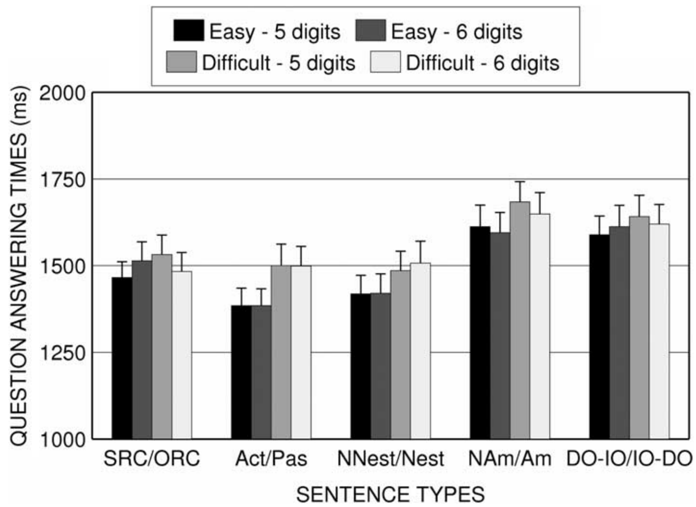


**Figure 5.** Mean response times to the comprehension questions in Experiment 2 in milliseconds, as a function of sentence-processing difficulty (easy vs. difficult), digit-load size (5 vs. 6 digits), and sentence type (SRC/ORC = subject-extracted vs. object-extracted relative clauses, Act/Pas = active vs. passive sentences, NNest/Nest = nonnested vs. nested relative clauses, NAm/Am = unambiguous vs. ambiguous pronoun sentences, DO-IO/IO-DO = sentences with the DO before the heavy IO vs. sentences with the DO after the heavy IO). Means and related standard errors (represented by the error bars) are taken from the participant analyses.

and accuracy on subject-extracted relative clauses was higher than on object-extracted relative clauses, min $F'(1, 61) = 42.66$, $p < .001$, $\eta_p^2 = .41$. Accuracy on the object-extracted relative clauses was even below chance level, $t(1, 27) = -4.16$, $p < .001$. There was no effect of sentence-processing difficulty on (non)nested sentences, nor on heavy IO sentences (min $F'$s $< 1.6$).

There were no interactions between any of the other factors on sentence reading times, accuracy, or response times on the comprehension questions (all $F$s and min $F'$s $< 1.5$).

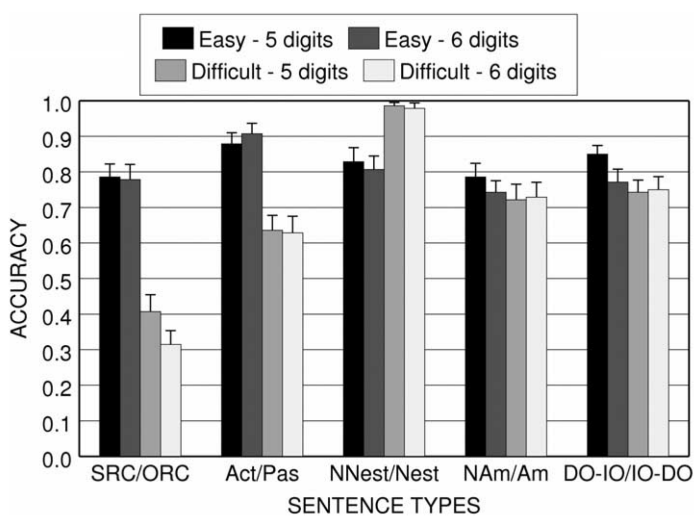


**Figure 6.** Mean accuracy rates of the answers to the comprehension questions in Experiment 2 in percentages, as a function of sentence-processing difficulty (easy vs. difficult), digit-load size (5 vs. 6 digits), and sentence type (SRC/ORC = subject-extracted vs. object-extracted relative clauses, Act/Pas = active vs. passive sentences, NNest/Nest = nonnested vs. nested relative clauses, NAm/Am = unambiguous vs. ambiguous pronoun sentences, DO-heavyIO/heavyIO-DO = sentences with the DO before the heavy IO vs. sentences with the DO after the heavy IO). Means and related standard errors (represented by the error bars) are taken from the participant analyses.

## Discussion

As in Experiment 1, we observed an effect of sentence-processing difficulty on sentence-processing performance: Processing syntactically difficult sentences was slower and less accurate than processing easy sentences. We hypothesised that these effects reflect the fact that processing difficult sentences occupies executive control for a longer time. Hence, we expected that processing difficult sentences would impede the maintenance of the digit loads more than processing easy sentences. Our hypothesis was confirmed by the finding that digit recall was worse after processing of a difficult sentence than after processing of an easy sentence. This tradeoff effect replicates the one found in Experiment 1.

Digit-load size had a clear effect on digit-recall performance: Recall of five digits was better than recall of six digits. As expected, the load-size difference between five and six digits thus proved to be large enough to observe effects. Still, digit-load size did not affect sentence-processing performance. First and foremost, as explained in the introduction of this experiment, this finding is in line with the hypothesis that sentence processing and digit maintenance serially share executive control. As explained in the introduction, no interaction between sentence-processing difficulty and digit-load size on sentence-processing performance was predicted. Rather, either an additive effect of load size or no effect at all was predicted. That last prediction was indeed confirmed by the data: Whereas sentence-processing difficulty affected digit-recall performance, the size of the digit load did not affect sentence-processing performance. This asymmetrical tradeoff effect suggests that as long as the sentence-processing task captured executive control, processes needed for the maintenance of the digit load (e.g., refreshment or reconstruction of the memory traces) were blocked and hence executive control was switched to the digit-maintenance task only after sentence processing was complete. As a consequence, load size could not affect sentence-processing performance.

Besides the effect of digit-load size, we also explored the effect of sentence type in this experiment by presenting only one sentence sequence per trial. First, there was no interaction between sentence-processing difficulty and sentence type on digit recall performance. This suggests that the difficult sentences in each of the five sentence types captured executive control for a longer time than their easy counterparts and that the finding that difficult sentences occupy executive control for a longer time than easy sentences can be generalised beyond the traditionally studied subject- and object-extracted relative clauses.

Second, sentence reading times as well as response times to the comprehension questions correlated positively with sentence length. Processing of longer sentences thus took longer and might hence have occupied executive control for a bigger proportion of the retention time. Indeed, this proportion was larger for longer sentences than for shorter sentences. When following the logic of the time-based resource-sharing model, it is predicted that when the proportion of time the sentence-processing task occupies the retention interval becomes larger, performance on the digit-maintenance task should decrease. This is indeed what is suggested by digit-recall performance, which correlated negatively with the proportion of time the sentence-processing task occupied the total retention interval.

Third, in the accuracy data, there was an effect of sentence-processing difficulty that interacted with sentence type: Accuracy on passive sentences was lower than on active sentences, and accuracy on object-extracted relative clauses was lower than on subject-extracted relative clauses. In the other sentence types, no effect of sentence-processing difficulty was observed on the accuracy data. It has been hypothesised that under a memory load or under tight time limits, two conditions that applied in the present experiment, readers do not always process all information present in the syntax, but apply heuristics instead (e.g., the Garden Path model of Frazier, 1979, or the Good Enough Comprehension model of Ferreira & Patson, 2007). This might have been more detrimental for the understanding of those sentences where the syntactic structure changes the meaning of the sentence, namely sentences with a subject-extracted versus object-extracted relative clause and active versus passive sentences, as opposed to (non)nested sentences and heavy IO sentences. The load and time pressure might have led participants to interpret these sentences according to their canonical word order (as a subject-extracted instead of an object-extracted relative clause sentence and as an active instead of a passive sentence).

## GENERAL DISCUSSION

We investigated whether sentence comprehension requires executive control. To this end, we examined whether there is a dual-task tradeoff between sentence processing and the maintenance of a digit load, which is semantically dissimilar to the material in the sentence. Recently, Barrouillet and colleagues (Barrouillet et al., 2004, 2007; Portrat et al., 2008) demonstrated that in order to be able to capture the subtle effects of a tradeoff of executive control between two simultaneously performed tasks in a dual-task paradigm, it is important to strictly control the time within which these tasks have to serially share executive control. Therefore, in our experiments, we applied the same strictly controlled temporal boundaries across conditions. In Experiment 1, we tested the effect of sentence-processing difficulty on digit recall with two sentences per trial. In Experiment 2, we tested the same effect with only one sentence per trial and additionally tested the effect of the size of the digit load on sentence-processing performance.

In both experiments, we observed an effect of sentence-processing difficulty on digit recall. Recall was worse after participants had processed one (Experiment 2) or two (Experiment 1) difficult sentences than after they had processed one or two easy sentences, respectively. At first sight, this effect seems to resemble the findings of Savin and Perchonock (1965). These authors auditorily presented their participants with a sentence followed by a list of words. Their design was different from ours, as their participants had to first recall the sentence and then recall as many words from the list as possible. Savin and Perchonock found that sentence difficulty affected the number of recalled words. In a follow-up study, however, Epstein (1969) showed that the effect of sentence difficulty on word recall performance in this former study has to be attributed to the sentence-recall phase rather than to the sentence-processing phase per se. More specifically, Epstein demonstrated that when participants had to recall only the word list and not the sentence, or when they had to recall first the word list and then the sentence, sentence difficulty did not affect word recall performance. Also, Foss and Cairns (1970) found evidence that more difficult sentences are more difficult to store or rehearse than their easier counterparts, but not for the hypothesis that they would also be more difficult to process. These early studies thus did not demonstrate a tradeoff between the maintenance of verbal material and sentence processing per se (but rather with sentence recall).

The effect of sentence-processing difficulty on digit recall in the present study suggests that processing syntactically difficult sentences captures executive control for a longer time than processing easy sentences, thereby blocking refreshments of the memory traces of the digits so that these traces decay more and recall is worse. Moreover, the effect suggests that executive control is needed to analyse the syntactic difficulty in the difficult sentences. Whereas Waters et al. (1995) did not find an effect of sentence-processing difficulty on digit recall in a self-paced paradigm, we were able to capture this tradeoff effect in two dual-task experiments with strictly controlled timing.

The time-controlling methodology of the time-based resource-sharing model (e.g., Barrouillet et al., 2007) is thus able to uncover tradeoff effects that are left invisible in a self-paced paradigm. Still, a possible drawback of the methodology in the present study is that sentence comprehension may not always have been performed through a full parse of the sentence, but may sometimes have been based on heuristics (e.g., the Garden Path model of Frazier, 1979, or the Good Enough Comprehension model of Ferreira & Patson, 2007). The finding in Experiment 2 that accuracy on passive sentences was lower than on active sentences, and accuracy on object-extracted relative clauses was lower than on subject-extracted relative clauses may be an indication that under time constraints or memory load participants sometimes strategically choose to not fully parse a difficult sentence, but to apply heuristics instead. This may then lead to an incorrect interpretation of the sentence. If anything, however, the use of heuristics will have reduced the chances of finding an effect of the sharing of executive control between both tasks. Nevertheless, in both experiments, we found an effect of sentence-processing difficulty on digit recall, suggesting that sentence processing—although probably sometimes performed through less-demanding heuristics—competes for executive control with the digit-maintenance task.

We varied sentence-processing difficulty in five different sentence types. Experiment 2 showed that the effect of difficulty on recall did not differ between these sentence types. The lack of an interaction suggests that the results are not due to the peculiarities of the traditionally tested contrast between object-extracted and subject-extracted relative clauses and can be generalised to a large range of syntactic difficulties. Apparently, the analysis of the syntactic difficulty in the difficult sentences in all tested sentence types occupied executive control for a longer time than their easy counterparts.

Also in line with the hypothesis that sentence processing and digit maintenance *serially* share executive control, we found no effect of digit-load size (five vs. six digits) on sentence-processing performance in Experiment 2. This asymmetrical tradeoff effect suggests that as long as the sentence-processing task captured executive control, processes needed for the maintenance of the digit load (e.g., refreshment or reconstruction of the memory traces) were blocked and hence executive control was switched to the digit-maintenance task only after processing was complete. As a consequence, load size could not affect sentence-processing performance.

It is indeed very plausible that executive control was not switched away until sentence processing was complete (cf. Hitch & Baddeley, 1976). Sentence comprehension is a highly cognitively demanding task. Caplan and Waters (1999) argued that in a dual-task procedure where the presentation of the sentence is interrupted with the presentation of the load (e.g., Wanner & Maratsos, 1978), the attentional shifts associated with these interruptions could interfere with sentence processing. As attention or executive control is hypothesised to be shared serially and thus has to be switched between tasks (Barrouillet et al., 2007), this logic could in fact apply to all dual-task situations where executive control needs to be shared. Interrupting sentence comprehension to refresh the digit load would imply that the intermediate processing results of sentence comprehension so far need to be kept in memory, introducing an extra memory load on top of the digit load. Such a strategy would thus hold the risk that the sentence part that was already processed would be (partly) lost, forcing reanalysis. Given the tight computer-paced time-out on the sentence-processing task, such a strategy would presumably lead to a time-out of the presentation of the sentence before sentence processing was completed.

Note that a similar asymmetric pattern of results was observed in the experiments of Liefooghe and colleagues (2008) in the same strictly timed dual-task paradigm. Liefooghe et al. tested the effect of loads of three to eight consonants on task-switching performance and found that recall performance decreased as a function of the number of task switches, but that the task-switching cost remained unaffected by the concurrent memory load. These data are also in line with the assumption that executive control is shared serially between a storage and a processing task.

The present study thus suggests that at least some processes in sentence comprehension involve the domain-general executive control system. Of course, we cannot speak to the question whether sentence comprehension *also* relies on a specialised working memory component, like the one suggested by Caplan and Waters (1999). These authors made a distinction between interpretive processes, namely processes that extract meaning from the linguistic signal, and postinterpretive processes, namely, processes that require the use of the extracted meaning, like reasoning, planning actions, etc. According to their theory, interpretive processing is a largely unconscious process, which relies on a specialised sentence-processing component of working memory, whereas postinterpretive processing is a controlled process, which relies on a more general (but still verbal) working memory (Baddeley, 1986). One of the pieces of evidence for Caplan and Waters to assume that interpretive processing is an unconscious process was the lack of a tradeoff between sentence comprehension and digit maintenance in the self-paced study of Waters et al. (1995). Crucially, in the present study with time-controlled experiments, we showed that such a tradeoff does exist. We thus proved that at least some part of interpretive processing relies on the domain-general executive control system and is a controlled process.

The finding that executive control is required for sentence comprehension is in line with existing evidence. For example, in an individual-differences study, Swets, Desmet, Hambrick, and Ferreira (2007) found that syntactic ambiguity resolution is affected by memory components that are both unique to language and shared with other parts of the cognitive architecture. The present experiments demonstrate that sentence processing indeed captures a domain-general executive control system. A challenge for future research is to pinpoint exactly which processes at what exact moments in the sentences require executive control for a longer time.

To conclude, we found an effect of sentence-processing difficulty on the recall of digits. An effect of digit-load size on sentence-processing performance was not observed. These findings suggest that both sentence processing and the maintenance of a digit load, a load that is semantically dissimilar to the material in the sentence, require executive control. Difficult sentences seem to occupy executive control for a longer time than their easy counterparts, leading to more decay of the memory traces of the digit load.

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## APPENDIX

This appendix further describes the sentence types used in both experiments. Moreover, it lists the sentences, ordered per easy-difficult sentence pair and per sentence type. For each minimal pair, Version a is the easy sentence, and Version b is the difficult sentence. The English translation is given within square brackets.

### Subject-extracted vs. object-extracted relative clauses

For each minimal pair, version a contains the subject-extracted relative clause, version b contains the object-extracted relative clause. Note that in Dutch, the number of the verb and of the object and subject NPs disambiguates between subject-extracted and object-extracted relative clauses.

1a. Ze praat met de patiënten die de dokter bezocht hebben. [She talks to the patients who visited the doctor.]

1b. Ze praat met de dokter die de patiënten bezocht hebben. [She talks to the doctor who the patients visited.]

2a. Ze fotografeert de regisseur die de acteurs begroet. [She photographs the director who is greeting the actors.]

2b. Ze fotografeert de acteurs die de regisseur begroet. [She photographs the actors who the director is greeting.]

3a. Hij lacht met de pianist die de zangers beoordeelt. [He laughs at the pianist who is evaluating the singers.]

3b. Hij lacht met de zangers die de pianist beoordeelt. [He laughs at the singers who the pianist is evaluating.]

4a. Ze verhoort de weduwe die de bejaarden bestolen heeft. [She interrogates the widow who has robbed the elderly.]

4b. Ze verhoort de bejaarden die de weduwe bestolen heeft. [She interrogates the elderly who the widow has robbed.]

5a. Hij herkent de soldaten die de piloot bevrijd hebben. [She recognises the soldiers who have rescued the pilot.]

5b. Hij herkent de piloot die de soldaten bevrijd hebben. [She recognises the pilot who the soldiers have rescued.]

6a. Hij interviewt de diplomaten die de politicus aanvielen. [He interviews the diplomats who had attacked the politician.]

6b. Hij interviewt de politicus die de diplomaten aanvielen. [He interviews the politician who the diplomats had attacked.]

7a. Hij ondervraagt de juweliers die de brillenmaker hielpen. [He interrogates the jeweller who has helped the optician.]

7b. Hij ondervraagt de brillenmaker die de juweliers hielpen. [He interrogates the optician who the jeweller has helped.]

8a. Ze prijst de priester die de rabbijnen toelacht. [She praises the priest who is smiling at the rabbis.]

8b. Ze prijst de rabbijnen die de priester toelacht. [She praises the rabbis who the priest is smiling at.]

9a. Hij filmt de violist die de ballerina's omhelst. [He is filming the violinist who embraces the ballerinas.]

9b. Hij filmt de ballerina's die de violist omhelst. [He is filming the ballerinas who the violinist embraces.]

10a. Ze schrijft naar de studenten die de muzikant ontmoet hebben. [She writes to the students who met the musician.]

10b. Ze schrijft naar de muzikant die de studenten ontmoet hebben. [She writes to the musician who the students met.]

11a. Hij vertelde over de molenaar die de boeren beledigd heeft. [He told about the miller who insulted the farmers.]

11b. Hij vertelde over de boeren die de molenaar beledigd heeft. [He told about the farmers who the miller insulted.]
12a. Ze kent de kruidenier die de agenten aanspreekt. [She knows the grocer who is addressing the policemen.]
12b. Ze kent de agenten die de kruidenier aanspreekt. [She knows the policemen who the grocer is addressing.]
13a. Hij herinnert zich de matrozen die de prostituee vermoordden. [She remembers the sailors who killed the prostitute.]
13b. Hij herinnert zich de prostituee die de matrozen vermoordden. [She remembers the prostitute who the sailors killed.]
14a. Ze begrijpt de bakkers die de slager vervloeken. [She understands the bakers who curse the butcher.]
14b. Ze begrijpt de slager die de bakkers vervloeken. [She understands the butcher who the bakers curse.]
15a. Hij hielp de boswachter die de mijnwerkers vond. [He helped the forester who found the miners.]
15b. Hij hielp de mijnwerkers die de boswachter vond. [He helped the miners who the forester found.]
16a. Ze kijkt naar de knechten die de koetsier wekken. [She watches the servants who are waking up the coachman.]
16b. Ze kijkt naar de koetsier die de knechten wekken. [She watches the coachman who the servants are waking up.]
17a. Hij luistert naar de arbeiders die de bediende pesten. [He listens to the workers who pester the clerk.]
17b. Hij luistert naar de bediende die de arbeiders pesten. [He listens to the clerk who the workers pester.]
18a. Ze staart naar de buurjongen die de kleuters aanmoedigt. [She stares at the boy next-door who is encouraging the toddlers.]
18b. Ze staart naar de kleuters die de buurjongen aanmoedigt. [She stares at the toddlers who the boy next-door is encouraging.]
19a. Ze benijdt de bloemisten die de organisator voorstellen. [She envies the florists who introduce the organiser.]
19b. Ze benijdt de organisator die de bloemisten voorstellen. [She envies the organiser who the florists introduce.]
20a. Hij schildert de herbergier die de bedelaars sloeg. [He paints the innkeeper who hit the beggars.]
20b. Hij schildert de bedelaars die de herbergier sloeg. [He paints the beggars who the innkeeper hit.]

## Active vs. passive sentences

For each minimal pair, version a is the active sentence, version b is the passive sentence.
21a. De tovenaar verjaagt de reus. [The wizard chases the giant.]
21b. De reus wordt door de heks verjaagd. [The giant is chased by the witch.]
22a. De koning verraadt de burgemeester. [The king betrays the mayor.]
22b. De premier wordt door de prins verraden. [The prime minister is betrayed by the prince.]
23a. De bediende verdenkt de barones. [The servant suspects the baroness.]
23b. De baron wordt door de butler verdacht. [The baron is suspected by the butler.]
24a. De grootvader belt de manager. [The grandfather rings the manager.]
24b. De baas wordt door de opa gebeld. [The boss is rung by the grandfather.]
25a. De onderwijzer verzorgt de dichter. [The teacher cures the poet.]
25b. De dichter wordt door de docent verzorgd. [The poet is cured by the professor.]
26a. De keukenmeid haat de buurman. [The kitchen maid hates the neighbour.]
26b. De buur wordt door de kok gehaat. [The neighbour is hated by the cook.]
27a. De kapper gelooft de dominee. [The hairdresser believes the minister.]
27b. De non wordt door de kapper geloofd. [The nun is believed by the hairdresser.]
28a. De aalmoezenier bekijkt de lijkschouwer. [The chaplain watches the autopsist.]
28b. De lijkschouwer wordt door de abt bekeken. [The autopsist is watched by the abbot.]
29a. De bruidegom zoekt de grootmoeder. [The groom searches for the grandmother.]
29b. De oma wordt door de bruid gezocht. [The grandmother is searched for by the bride.]
30a. De schooljuffrouw kust de leerling. [The teacher kisses the student.]
30b. Het kind wordt door de juf gekust. [The child is kissed by the teacher.]
31a. De tuinarchitect prijst de accordeonist. [The landscape architect praises the accordionist.]
31b. De cellist wordt door de architect geprezen. [The cellist is praised by the architect.]

32a. De bazin bespot de winkeljuffrouw. [The manager mocks the saleswoman.]
32b. De kassierster wordt door de chef bespot. [The cashier is mocked by the boss.]
33a. De dierenarts begrijpt de landbouwer. [The veterinarian understands the farmer.]
33b. De boer wordt door de veearts begrepen. [The farmer is understood by the veterinarian.]
34a. De cafébaas begroet de bestuurder. [The barman greets the driver.]
34b. De chauffeur wordt door de barman begroet. [The driver is greeted by the barman.]
35a. De kapitein bezoekt de nonkel. [The captain visits the uncle.]
35b. De oom wordt door de schipper bezocht. [The uncle is visited by the captain.]
36a. De kabouter helpt de reisleider. [The gnome helps the tour guide.]
36b. De gids wordt door de fee geholpen. [The guide is helped by the fairy.]
37a. De dokter herkent de landloper. [The doctor recognises the tramp.]
37b. De zwerver wordt door de arts herkend. [The tramp is recognised by the doctor.]
38a. De banketbakker kwetst de beenhouwer. [The pastrycook hurts the butcher.]
38b. De slager wordt door de bakker gekwetst. [The butcher is hurt by the baker.]
39a. De kunstenaar omhelst de advocaat. [The artist embraces the lawyer.]
39b. De jurist wordt door de artiest omhelsd. [The jurist is embraced by the artist.]
40a. De balletdanser verwent het meisje. [The ballet dancer spoils the girl.]
40b. Het meisje wordt door de danser verwend. [The girl is spoiled by the dancer.]

## Nested vs. nonnested relative clauses

The relative clause (e.g., “die ik begeleidde [that I counseled]” in sentence 41) referring to the subject or object in the superordinate relative clause (e.g., “die de gevangene had veroordeeld [that had the prisoner convicted]”) was either postponed until after the end of the superordinate relative clause (version a, non-nested) or nested into the superordinate relative clause (version b, nested). Only one English translation is given per sentence pair (after the a-version). In Dutch, nesting a relative clause (e.g., “die ongeneeslijk ziek waren [that were incurable]” in sentence 42) into a superordinate relative clause does not change the meaning of the sentence. Sentence 42a and 42b thus have exactly the same meaning, which is represented in the English translation of 42a. In English, though, nesting the relative clause would in most stimuli of this type render an ungrammatical sentence or change the meaning of the sentence.

41a. Gisteren is de rechter gestorven die de gevangene had veroordeeld die ik begeleidde. [Yesterday the judge that had the prisoner convicted that I counselled died.]
41b. Gisteren is de rechter gestorven die de gevangene die ik begeleidde had veroordeeld.
42a. In deze kerk ligt de pater begraven die de leprozen had verzorgd die ongeneeslijk ziek waren. [In this church the father who took care of the lepers that were incurable is buried.]
42b. In deze kerk ligt de pater begraven die de leprozen die ongeneeslijk ziek waren had verzorgd.
43a. Vandaag zal de vakbond staken die voor de arbeiders opkomt die ontslagen dreigen te worden. [Today the labour union that represents the workers who are facing dismissal will go out on strike.]
43b. Vandaag zal de vakbond staken die voor de arbeiders die ontslagen dreigen te worden opkomt.
44a. Morgen zal ik de officier ontmoeten die jonge militairen opleidt die promotie willen maken. [Tomorrow I will meet the officer who trains the young soldiers who want to get promotion.]
44b. Morgen zal ik de officier ontmoeten die jonge militairen die promotie willen maken opleidt.
45a. Gisteren is de verdachte vrijgesproken die zich tegen het vonnis verzette dat de rechter in juli had uitgesproken. [Yesterday the suspect who fought the judgement that the judge had pronounced in July was acquited.]
45b. Gisteren is de verdachte vrijgesproken die zich tegen het vonnis dat de rechter in juli had uitgesproken verzette.
46a. In mei wordt de oude fabriek gesloten die stoffen uitstoot die kanker veroorzaken. [In May the old factory that emits substances that cause cancer will be closed down.]
46b. In mei wordt de oude fabriek gesloten die stoffen die kanker veroorzaken uitstoot.
47a. Vandaag wordt de politicus benoemd die de verkiezingen won die in het voorjaar plaatsvonden. [Today the politician who won the elections that took place in spring was appointed.]

47b. Vandaag wordt de politicus benoemd die de verkiezingen die in het voorjaar plaatsvonden won.
48a. In het journaal worden de soldaten geïnterviewd die van de oorlog terugkomen die in Irak woedt. [The soldiers who return from the war that is raging in Iraq are being interviewed in the news.]
48b. In het journaal worden de soldaten geïnterviewd die van de oorlog die in Irak woedt terugkomen.
49a. De stad zal het kerkje afbreken waarin de artieste trouwde die enkele jaren geleden begraven is. [The city will break down the church in which the artist got married who was buried a few years ago.]
49b. De stad zal het kerkje afbreken waarin de artieste die enkele jaren geleden begraven is trouwde.
50a. In Londen werden de slachtoffers herdacht die bij de aanslag omkwamen die vorig jaar gepleegd werd. [The victims that were killed in the assault that was committed last year were commemorated in London.]
50b. In Londen werden de slachtoffers herdacht die bij de aanslag die vorig jaar gepleegd werd omkwamen.
51a. De Britse band heeft het liedje gecoverd waarmee de zanger bekend werd die onlangs aan een overdosis stierf. [The British band has covered the song that made the singer famous who lately died from an overdose.]
51b. De Britse band heeft het liedje gecoverd waarmee de zanger die onlangs aan een overdosis stierf bekend werd.
52a. De meid zal de blouse wassen die de barones op het feest droeg dat ze gisteren heeft gegeven. [The maid will wash the blouse that the baroness wore on the party that she gave yesterday.]
52b. De meid zal de blouse wassen die de barones op het feest dat ze gisteren heeft gegeven droeg.
53a. De Oostenrijkse auteur heeft een schitterend boek gepubliceerd dat de oorlog beschrijft die jarenlang in Kosovo heeft gewoed. [The Austrian author published a brilliant book that describes the war that raged in Kosovo for years.]
53b. De Oostenrijkse auteur heeft een schitterend boek gepubliceerd dat de oorlog die jarenlang in Kosovo heeft gewoed beschrijft.
54a. Gisteren is de trofee gestolen die de voetbalploeg in de kluis bewaarde die enkel voor de coach toegankelijk is. [The trophy that was kept by the soccer club in the safe that could only be opened by the coach was stolen yesterday.]
54b. Gisteren is de trofee gestolen die de voetbalploeg in de kluis die enkel voor de coach toegankelijk is bewaarde.
55a. De krant heeft de robotfoto gepubliceerd die de commissaris vrijgaf die het onderzoek naar de roofmoord leidt. [The newspaper has published the forensic sketch that was released by the police commissioner who supervises the investigation into the case of robbery with murder.]
55b. De krant heeft de robotfoto gepubliceerd die de commissaris die het onderzoek naar de roofmoord leidt vrijgaf.
56a. De man heeft de villa gekocht waar volgens de legende het spook huisde dat rinkelend door de gangen waart. [The man bought the villa that according to legend is haunted by a ghost that roams around rattlingly.]
56b. De man heeft de villa gekocht waar volgens de legende het spook dat rinkelend door de gangen waart huisde.
57a. Bij een huiszoeking werd de diamantair neergeschoten die zich hevig tegen de agenten verzette die heel zijn huis ondersteboven keerden. [The diamond dealer who reacted vehemently to the policemen who searched his house was shot.]
57b. Bij een huiszoeking werd de diamantair neergeschoten die zich hevig tegen de agenten die heel zijn huis ondersteboven keerden verzette.
58a. Na de voorstelling hebben we de acteur ontmoet die de rol van Odysseus speelde die na de Trojaanse oorlog 10 jaar rondzwierf. [After the performance we met the actor who played the character of Odysseus who wandered around for 10 years after the Trojan war.]
58b. Na de voorstelling hebben we de acteur ontmoet die de rol van Odysseus die na de Trojaanse oorlog 10 jaar rondzwierf speelde.
59a. Vannacht is in het hospitaal de president opgenomen die aan een longziekte lijdt die erg besmettelijk is. [The president who suffers from a pulmonary disease that is very contagious has been hospitalised earlier tonight.]
59b. Vannacht is in het hospitaal de president opgenomen die aan een longziekte die erg besmettelijk is lijdt.
60a. In het chemiebedrijf zijn vijf werknemers gestorven die aan een hoge dosis kwik werden blootgesteld dat uiterst kankerverwekkend is. [In that chemical company five workers that had been exposed to high doses of mercury, which is highly carcinogenic, have died.]

60b. In het chemiebedrijf zijn vijf werknemers gestorven die aan een hoge dosis kwik dat uiterst kankerverwekkend is werden blootgesteld.

## (Un)ambiguous pronoun sentences

The ambiguity of the pronoun in the subordinate clause was manipulated. The pronoun could either refer back to one proper name in the main clause and thus be unambiguous (version a) or it could refer to either of the proper names in the main clause and thus be ambiguous (version b).

61a. Mark leende Lies de CD uit voordat hij op vakantie vertrok. [Mark lent Lies the CD before he went on holiday.]
61b. Mark leende Piet de CD uit voordat hij op vakantie vertrok. [Mark lent Piet the CD before he went on holiday.]
62a. Anna lachte naar Geert toen hij de anekdote vertelde. [Anna smiled at Geert while he was telling the anecdote.]
62b. Otto lachte naar Geert toen hij de anekdote vertelde. [Otto smiled at Geert while he was telling the anecdote.]
63a. Bruno vertelde Karen over de film net voordat hij tegen de auto botste. [Bruno told Karen about the movie just before he hit the car.]
63b. Bruno vertelde Karel over de film net voordat hij tegen de auto botste. [Bruno told Karel about the movie just before he hit the car.]
64a. Esther belde Maarten op toen hij vastzat op de luchthaven. [Esther called Maarten while he was stuck at the airport.]
64b. Thomas belde Maarten op toen hij vastzat op de luchthaven. [Thomas called Maarten while he was stuck at the airport.]
65a. Wim gaf Lotte het briefje voordat hij ging werken. [Wim gave Lotte the letter before he went to work.]
65b. Wim gaf Joris het briefje voordat hij ging werken. [Wim gave Joris the letter before he went to work.]
66a. Leen troostte Tom toen hij in het restaurant aankwam. [Leen comforted Tom as he arrived at the restaurant.]
66b. Kris troostte Tom toen hij in het restaurant aankwam. [Kris comforted Tom as he arrived at the restaurant.]
67a. Paul mailde Sarah voordat hij de roddel had gehoord. [Paul mailed Sarah before he had heard the gossip.]
67b. Paul mailde Felix voordat hij de roddel had gehoord. [Paul mailed Felix before he had heard the gossip.]
68a. Sophie verontschuldigde zich bij Michiel voordat hij het kantoor verliet. [Sophie apologized to Michiel before he left the office.]
68b. Wouter verontschuldigde zich bij Michiel voordat hij het kantoor verliet. [Wouter apologised to Michiel before he left the office.]
69a. Anton wuifde naar Caroline toen hij naar het station liep. [Anton waved to Caroline as he was walking to the station.]
69b. Anton wuifde naar Frederik toen hij naar het station liep. [Anton waved to Frederik as he was walking to the station.]
70a. Kasper glimlachte naar Mieke toen hij de lobby binnenstapte. [Kasper smiled at Mieke as he entered the lobby.]
70b. Kasper glimlachte naar Filip toen hij de lobby binnenstapte. [Kasper smiled at Filip as he entered the lobby.]
71a. Kristof vroeg hulp aan Fien toen hij op het werk was. [Kristof asked Fien for help while he was at work.]
71b. Kristof vroeg hulp aan Bart toen hij op het werk was. [Kristof asked Bart for help while he was at work.]
72a. Matthias schudde Nele de hand toen hij de kamer binnenstapte. [Matthias shook hands with Nele when he entered the room.]
72b. Matthias schudde Arne de hand toen hij de kamer binnenstapte. [Matthias shook hands with Arne when he entered the room.]
73a. Lucas irriteerde Emma toen hij steeds hetzelfde liedje liep te fluiten. [Lucas got on Emma's nerves as he kept on whistling the same song.]
73b. Lucas irriteerde Niko toen hij steeds hetzelfde liedje liep te fluiten. [Lucas got on Niko's nerves as he kept on whistling the same song.]
74a. Niels verraste Amber toen hij het goede nieuws vertelde. [Niels surprised Amber when he told the good news.]
74b. Niels verraste Milan toen hij het goede nieuws vertelde. [Niels surprised Milan when he told the good news.]
75a. Roos prees Ruben nadat hij een erg goede presentatie had gegeven. [Roos praised Ruben after he had given a very good presentation.]
75b. Daan prees Ruben nadat hij een erg goede presentatie had gegeven. [Daan praised Ruben after he had given a very good presentation.]

76a. Britt verdedigde Tim toen hij beschuldigd werd van fraude. [Britt supported Tim when he was accused of fraud.]
76b. Thijs verdedigde Tim toen hij beschuldigd werd van fraude. [Thijs supported Tim when he was accused of fraud.]
77a. Hanne hielp Bert toen hij verdronk in het werk. [Hanne helped Bert when he was drowning in his work.]
77b. Jonas hielp Bert toen hij verdronk in het werk. [Jonas helped Bert when he was drowning in his work.]
78a. Dorien strafte Joost toen hij de vaas brak. [Dorien punished Joost as he had broken the vase.]
78b. Steven strafte Joost toen hij de vaas brak. [Steven punished Joost as he had broken the vase.]
79a. Kaat feliciteerde Dieter nadat hij een fantastisch concert had gespeeld. [Karen congratulated Dieter after he had played a terrific concert.]
79b. Koen feliciteerde Dieter nadat hij een fantastisch concert had gespeeld. [Koen congratulated Dieter after he had played a terrific concert.]
80a. Merel bekritiseerde Floris nadat hij het belangrijke project had verknoeid. [Merel criticised Floris after he had messed up the important project.]
80b. David bekritiseerde Floris nadat hij het belangrijke project had verknoeid. [David criticised Floris after he had messed up the important project.]

## Heavy IO sentences

The place of the direct object (DO) and of the long or ‘heavy’ indirect object (IO) was varied: the DO was either placed immediately after the ditransitive verb and thus before the heavy IO (version a) or at the end of the phrase and thus after the heavy IO (version b).
81a. De verzekering vergoedt de geleden schade aan mensen wiens huis overstroomde tijdens de jongste stormen. [The insurance company reimburses the damaged goods to those clients whose house was flooded during the last storm.]
81b. De verzekering vergoedt aan mensen wiens huis overstroomde tijdens de jongste stormen de geleden schade. [The insurance company reimburses those clients whose house was flooded during the last storm the damaged goods.]
82a. De getuige meldde het ongeval aan een medewerker van het dichtstbijzijnde politiebureau. [The witness reported the accident to a staff member of the nearest police office.]
82b. De getuige meldde aan een medewerker van het dichtstbijzijnde politiebureau het ongeval. [The witness reported to a staff member of the nearest police office the accident.]
83a. De politie geeft de juwelen terug aan de barones die vorige maand bestolen is. [The police returns the jewels to the baroness who was robbed last month.]
83b. De politie geeft aan de barones die vorige maand bestolen is de juwelen terug. [The police returns the baroness who was robbed last month the jewels.]
84a. Het meisje vertrouwt haar geheim toe aan de jongen waarop ze al sinds de lagere school verliefd is. [The girl confides her secret to the boy who she is in love with since primary school.]
84b. Het meisje vertrouwt aan de jongen waarop ze al sinds de lagere school verliefd is haar geheim toe. [The girl confides the boy who she is in love with since primary school her secret.]
85a. Hij geeft zijn blunder toe aan zijn bazin die steeds een blindelings vertrouwen in hem heeft gehad. [He admits his blunder to his boss who had always trusted him implicitly.]
85b. Hij geeft aan zijn bazin die steeds een blindelings vertrouwen in hem heeft gehad zijn blunder toe. [He admits to his boss who had always trusted him implicitly his blunder.]
86a. De journalist deelde zijn ontslag mee aan de cameraman waarmee hij jarenlang reportages had gemaakt. [The journalist announced his resignation to the cameraman with whom he had been collaborating for years on numerous reportages.]
86b. De journalist deelde aan de cameraman waarmee hij jarenlang reportages had gemaakt zijn ontslag mee. [The journalist announced to the cameraman with whom he had been collaborating for years on numerous reportages his resignation.]
87a. De kinesist leende revalidatietoestellen aan de tennisser die op het vorige kampioenschap een ernstige knieblessure opliep. [The physical therapist lent out his rehabilitation equipment to the tennis player who got a serious knee injury at the last championship.]
87b. De kinesist leende aan de tennisser die op het vorige kampioenschap een ernstige knieblessure opliep revalidatietoestellen. [The physical therapist lent out to the tennis player who got a serious knee injury at the last championship his rehabilitation equipment.]

88a. De jonge architect stelt zijn ontwerpen voor aan een jury van gerenomeerde kunstenaars van over heel de wereld. [The young architect presents his project to an international jury of renowned artists.]
88b. De jonge architect stelt aan een jury van gerenomeerde kunstenaars van over heel de wereld zijn ontwerpen voor. [The young architect presents to an international jury of renowned artists his project.]
89a. De staat betaalt kinderbijslag aan de ouder bij wie het kind inwoont. [The state pays out allowance to the parent the child lives with.]
89b. De staat betaalt aan de ouder bij wie het kind inwoont kinderbijslag. [The state pays the parent the child lives with allowance.]
90a. De schepen overhandigt de bloemen aan de prinses die in de stad is voor de opening van de nieuwe Rubens-tentoonstelling. [The alderman gives the flowers to the princess who is in town for the inauguration of the new Rubens exposition.]
90b. De schepen overhandigt aan de prinses die in de stad is voor de opening van de nieuwe Rubens-tentoonstelling de bloemen. [The alderman gives the princess who is in town for the inauguration of the new Rubens exposition the flowers.]
91a. De man zweert trouw aan de vrouw waar hij sinds zijn jeugd verliefd op is. [The man swears allegiance to the woman he has been in love with since his youth.]
91b. De man zweert aan de vrouw waar hij sinds zijn jeugd verliefd op is trouw. [The man swears to the woman he has been in love with since his youth allegiance.]
92a. De man verklapte de schuilplaats aan de journalist die zich sinds het begin van de verdwijning in de zaak heeft vastgebeten. [The man betrays the hiding-place to the journalist who got his teeth into the case since the first hours of the disappearance.]
92b. De man verklapte aan de journalist die zich sinds het begin van de verdwijning in de zaak heeft vastgebeten de schuilplaats. [The man betrays to the journalist who got his teeth into the case since the first hours of the disappearance the hiding-place.]
93a. Hij liet zijn fortuin na aan de zoon van de vrouw met wie hij jarenlang een geheime relatie had. [He left his fortune to the son of the woman who had been his secret mistress for years.]
93b. Hij liet aan de zoon van de vrouw met wie hij jarenlang een geheime relatie had zijn fortuin na. [He left the son of the woman who had been his secret mistress for years his fortune.]
94a. De vereniging schenkt een DVD-speler aan de winnaar van de tombola die plaatsvindt ter gelegenheid van het jaarlijkse dorpsfeest. [The association gives a DVD player to the winner of the tombola taking place on the occasion of the annual fair.]
94b. De vereniging schenkt aan de winnaar van de tombola die plaatsvindt ter gelegenheid van het jaarlijkse dorpsfeest een DVD-speler. [The association gives the winner of the tombola taking place on the occasion of the annual fair a DVD player.]
95a. Hij zendt het formulier aan de gemeentesecretaris waarmee hij de afgelopen week enkele keren gebeld heeft. [He sends the form to the town clerk who he has called a couple of times during the past week.]
95b. Hij zendt aan de gemeentesecretaris waarmee hij de afgelopen week enkele keren gebeld heeft het formulier. [He sends the town clerk who he has called a couple of times during the past week the form.]
96a. De staat kent een premie toe aan werkgevers die personen met een handicap tewerkstellen onder gewone arbeidsvoorwaarden. [The state pays out a subsidy to employers who employ handicapped people under normal terms.]
96b. De staat kent aan werkgevers die personen met een handicap tewerkstellen onder gewone arbeidsvoorwaarden een premie toe. [The state pays out employers who employ handicapped people under normal terms a subsidy.]
97a. Artzen zonder Grenzen verleent humanitaire hulp aan de duizenden slachtoffers van de tsunami in Zuid-Oost-Azië. [Doctors without Borders lends humanitarian aid to the thousands of victims of the tsunami in South-East Asia.]
97b. Artzen zonder Grenzen verleent aan de duizenden slachtoffers van de tsunami in Zuid-Oost-Azië humanitaire hulp. [Doctors without Borders lends the thousands of victims of the tsunami in South-East Asia humanitarian aid.]
98a. De luchtvaartmaatschappij rekent de hoge brandstofprijzen door aan zijn klanten die al maanden geleden hun tickets tegen een promotietarief hebben geboekt. [The airline company charges the high fuel prices to its clients who purchased their tickets months ago for a special early booking price.]
98b. De luchtvaartmaatschappij rekent aan zijn klanten die al maanden geleden hun tickets tegen een promotietarief hebben geboekt de hoge

brandstofprijzen door. [The airline company charges its clients who purchased their tickets months ago for a special early booking price the high fuel prices.]
99a. De schrijver draagt zijn nieuwe dichtbundel op aan zijn buitenechtelijke dochter waarmee hij na jaren van stilte opnieuw contact heeft. [The writer dedicates his new poetry book to his extramarital daughter with whom he got in touch again after years of absolute silence.]
99b. De schrijver draagt aan zijn buitenechtelijke dochter waarmee hij na jaren van stilte opnieuw contact heeft zijn nieuwe dichtbundel op. [The writer dedicates to his extramarital daughter with whom he got in touch again after years of absolute silence his new poetry book.]
100a. De leraar legt het vraagstuk uit aan de student die moeite heeft met wiskunde maar toch erg zijn best doet. [The teacher explains the mathematical problem to the student who has trouble with maths but does his best nevertheless.]
100b. De leraar legt aan de student die moeite heeft met wiskunde maar toch erg zijn best doet het vraagstuk uit. [The teacher explains the student who has trouble with maths but does his best nevertheless the mathematical problem.]

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