

Discourse Rules: The Effects of Clause Order Principles on the Reading Process

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ARTICLE HISTORY

Compiled April 11, 2022

ABSTRACT

In an eye-tracking-while-reading study, we investigated adult monolinguals' (N=80) processing of two-clause sentences embedded in short narratives. Three principles theorized to guide comprehension of complex sentences were contrasted: one operating at the clause level, namely clause structure (main clause - subordinate clause or vice versa), and two operating at the discourse-level, namely givenness (given-new vs. new-given) and event order (chronological vs. reverse order). The results indicate that clause structure mainly affects early stages of processing, whereas the two principles operating at the discourse level are more important during later stages and for reading times of the entire sentence. Event order was found to operate relatively independently of the other principles. Givenness was found to overrule clause structure, a phenomenon that can be related to the grounding function of preposed subordinate clauses. We propose a new principle to reflect this interaction effect: the grounding principle.

KEYWORDS

Text comprehension; eye tracking; clause order; discourse; processing

1. Introduction

Discourse comprehension includes not only the processing of the individual words that form sentences, but also the processing of crucial structural, semantic, and pragmatic relationships that together convey meaning. These relationships must be inferred by the reader in order to establish a coherent mental representation of the discourse. One of the factors that affect this process is sentence structure. Previous literature has identified various principles governing the processing of clauses. The most well-studied principles are the *event order principle* (also known as the *iconicity* principle; e.g., Blything, Davies, & Cain, 2015; E. Clark, 1971; Givón, 1985; Münte, Schiltz, & Kutas, 1998; Pyykkönen & Järvikivi, 2012) , the *clause structure principle* (also known as the *frame structure* principle, Diessel, 2005, 2008; Fodor, Bever, Garrett, et al., 1974; Gibson, 1998; Holmes, 1973; Jansen, 2008; Troost, Jansen, & Sanders, 2008) and the *givenness principle* (also known as the *information structure* principle; Chafe, 1976; Chen, Li, & Yang, 2012; H. Clark & Haviland, 1977; Haviland & Clark, 1974).

Even though the three individual principles have been the topic of many research efforts, they have mainly been studied in isolation, thereby ignoring any possible interactions that they might have with each other (but see de Ruiter, Lieven, Brandt, & Theakston, 2020). Moreover, most literature focuses on their effect on offline comprehension rather than online processing, and studies children rather than adults. The current study bridges this gap by investigating how clause order influences adults' online processing of two-clause sentences joined by the temporal connectives *before* and *after*, embedded in short texts, to test three different principles for how to structure sentences.

The studies we review below provide the context for investigating the effects of the three principles on online sentence processing. We first review studies that focused on the effects of the principles in isolation, followed by studies investigating the principles in interaction.

1.1. *Principles in isolation*

The *event order* principle (termed *iconicity* by Givón, 1985) is based on the notion that “the structure of language reflects in some way the structure of experience” (Croft, 2002, p. 102), which means that utterances are more likely to relate events in the order in which they occurred (Jansen, 2008). This is the case when the order of clauses is chronological: the first clause describes the first occurring event and the second clause describes the second event as they occurred in real time, as in (1) and (2). Clauses can also be organized in reverse chronological order as in (3) and (4).

- (1) Gary adjusted the flower arrangements before he carefully positioned the antique candlesticks.
- (2) After Gary carefully positioned the antique candlesticks, he adjusted the flower arrangements.
- (3) Before Gary carefully positioned the antique candlesticks, he adjusted the flower arrangements.
- (4) Gary adjusted the flower arrangements after he carefully positioned the antique candlesticks.

Research on adults’ (e.g., Münte et al., 1998) and children’s comprehension (Blything et al., 2015; E. Clark, 1971; Pyykkönen & Järvikivi, 2012) confirms that two-clause sentences joined by *before* and *after* are easier to process when the events are presented in chronological order (as in (1) and (2)) than in reverse order. ERP studies have shown that adults experience temporary difficulties for sentences in which events are expressed in reverse order (Münte et al., 1998; Politzer-Ahles, Xiang, & Almeida, 2017; see also Ye et al., 2012 for an fMRI study with a similar conclusion). Taken together, the literature indicates that reverse order complicates the reading process.

The *clause structure* principle refers to the syntactic properties of the clauses: sentences are proposed to be harder to process if the main clause follows the subordinate clause (S-M), as in examples (2) and (3), than when the main clause precedes the subordinate clause (M-S), as in (1) and (4) (Gibson, 1998). In support of this, analyses of written and spoken corpora show that S-M order is less frequent in natural

language (Diessel, 2005, 2008; Jansen, 2008; Troost et al., 2008). S-M order also results in poorer sentence recall and lower ratings of sentence comprehensibility (Fodor et al., 1974; Holmes, 1973).

The third principle examined in this study is the *givenness* principle, also known as the *information structure* principle. This principle refers to the information status of the clauses (Chafe & Tannen, 1987). Information that has already been introduced in the discourse is given information; information that is being introduced into the discourse is new information. Sentences are proposed to be easier to integrate with the existing mental representation of the text if their clauses are ordered according to their information status, with given information before new. This order allows readers to search their memory for a direct antecedent of the given information before new information is encountered, benefiting from the still relatively high activation level of these antecedents. The new information can then be integrated into memory by attaching it to the antecedent (H. Clark & Haviland, 1977; Prince, 1981). In support of this, adults are faster to comprehend sentences for given-new structures (Haviland & Clark, 1974; see also Chen et al., 2012).

Table 1 summarizes the three principles and the predictions they make about the difficulty of clause orders when considered alone. The facilitative effect of the preferred order in each principle can be explained in terms of a memory capacity constraint-based theoretical account (e.g., Just & Carpenter, 1992), which predicts processing difficulties for various sentence structures in terms of the demand these sentences make on comprehenders' working memory (see, e.g., Blything & Cain, 2016; Karlsson, Jolles, Koornneef, van den Broek, & Van Leijenhorst, 2019). In relation to event order, a memory account would predict that reverse order sentences are more difficult because the information expressed must be manipulated to construct a veridical mental representation when processing the sentence meaning. Memory mechanisms can also explain why S-M order is dispreferred: when a subordinate clause appears first (S-M order), the clause must be stored in working memory until the corresponding main clause has been processed and the two can be integrated (Gibson, 1998). Finally, in relation to givenness, a memory account predicts that sentences with a given-new order are easier, because these allow readers to search memory for a direct antecedent

Table 1.: Principles for ordering clauses and subsequent predictions. “<” = “is preferred over”.

Principle	Prediction	Interpretation
Event order	Chronological order < reverse order	Complex sentences with clauses presented in the same order as the events they represent are easier to process than those that are presented in reverse chronological order.
Clause order	Main-subordinate < subordinate-main	Complex sentences with the main clause first are easier to process than complex sentences with the subordinate clause first.
Givenness	Given-new < new- given	Complex sentences in which the first clause presents given information and the second clause presents new information are easier to process than sentences in which the order of information is new-given (regardless of the syntactic status of the clauses).

of the given information before new information is encountered. This allows readers to benefit from the still relatively high activation level of these antecedents. We will return to this memory capacity constraint-based account in the Discussion.

1.2. Principles in interaction

As reviewed, a range of experimental work and corpus studies have provided evidence for the relevance of the three principles individually. Critically, there have been very few studies examining whether these principles operate independently or interact with one other. Studies that have looked into combinations of these principles in adults have mainly studied possible interactions between the event order and the clause structure principles (H. Clark & Clark, 1968; Jou & Harris, 1990; Politzer-Ahles et al., 2017). For example, H. Clark and Clark (1968) studied college students’ written sentence recall, including complex sentences marked by *before* or *after*. The results indicated that the event order principle took precedence over the clause structure principle: sentences presented in chronological order were recalled significantly better than those in reverse order, and this was apparent in comparisons within both M-S structures and S-M structures. There was no main effect of clause structure, nor an interaction between clause structure and event order.

Similar findings have been reported in an ERP comprehension study by Politzer-

Ahles et al. (2017). This method measures processing costs (e.g., of semantic or syntactic violations) by recording changes in the electric potentials (ERPs) that occur whilst reading the sentence. Politzer-Ahles et al. (2017)'s results showed that, regardless of clause structure, reading of reverse order sentences resulted in increased processing costs compared to chronological sentences. It should be noted that H. Clark and Clark (1968) and Politzer-Ahles et al. (2017) presented the sentences in isolation and did not consider the givenness principle – these factors may modulate whether clause structure effects occur or interact with event order effects on comprehension.

Few studies to date have examined all three principles simultaneously (but see Prideaux, 1989 for a corpus analysis investigating sentence order in three books). A recent study of four- to five-year-olds' sentence comprehension accuracy by de Ruiter et al. (2020) is an exception. Their stimuli comprised two-clause sentences linked either by *before* or *after*, and provides preliminary support for a combinatory role for the three principles (de Ruiter et al., 2020; see also Karlsson et al., 2019). Their findings suggest that the given-new order improves children's understanding for sentences containing temporal connectives, but only when the given information is in a preposed subordinate clause. It is an open question whether similar findings would be found for the processing of these sentences by adults, for whom language and memory skills are more fully developed.

The interaction between givenness and clause structure found by de Ruiter et al. (2020) is interesting, as it denies a main effect of clause structure. The interaction indicates that a preposed subordinate clause is not more complex per se; its complexity is modulated by the information status (i.e. givenness) of that clause and that of the main clause. S-M and M-S clause structures are hypothesized to serve different discourse pragmatic functions (see, e.g., Chafe, 1984). In S-M sentences, the preposed subordinate clause frequently contains given information to provide a thematic ground or orientation for the next clause – referred to as the grounding function of preposed subordinate clauses. By contrast, M-S clause structures have a final subordinate clause that typically serves to add new information to the assertion made by the main clause or modify part of what is stated in this clause Chafe (1984). S-M sentences with the given information in the subordinate clause are therefore hypothesized to facilitate

processing of the main clause (Chafe, 1994; Diessel, 2005; Ford & Ford, 1993; Ramsay, 1987; Thompson, 1985; Ward & Birner, 2004). The grounding function of preposed subordinate clauses has received support from corpus data (see, e.g., Diessel, 2005), and de Ruiter et al. (2020) have shown that it affects children’s sentence comprehension. The current study will evaluate whether adults’ online sentence processing is also affected by grounding.

In sum, a range of previous studies have shown evidence for the relevance of the three individual principles in isolation. Experimental studies that examined a combination of principles with adults (e.g., H. Clark & Clark, 1968; Politzer-Ahles et al., 2017) did not reveal clear evidence for interactive effects of event order and clause structure, but rather emphasized the dominance of event order. The de Ruiter et al. (2020) child study suggests that the principles do interact with each other in intricate ways. Importantly, no study to date has directly compared the individual and combined effects of event order, clause structure, and givenness on the real time processing of the sentence stimuli among adults; such methods are critical to determine the locus of processing difficulty for complex syntactic structures. Hence, it is unclear which principle or combination of principles are most beneficial for readers. The current study therefore addressed the following research question: what is the effect of different ordering principles on adults’ on-line reading processes, and do they exert a unique or combined influence? In what follows, we first present the methodology, along with a more detailed account of our hypotheses, for investigating the effect of different ordering principles on reading processes. We then present the results and provide a critical reflection on the results in the discussion.

2. Method

We investigated the effects of three ordering principles (event order, clause structure, and givenness) on adults’ on-line processing of two-clause sentences linked by a connective that signaled a temporal coherence relation. Eye-tracking-while-reading was used to enable us to identify the locus of any processing difficulties. Participants’ word reading and working memory capacity were measured because individual differences in

Table 2.: Example of experimental item. G-N = given-new order; N-G = new-given order; Chron = chronological order; Reverse = reverse chronological order; M-S = main-subordinate clause order; S-M = subordinate-main clause order.

Context 1	Nico was a renowned pizza chef working at Jamie’s restaurant. His specialty was a [tomato sauce] _{G-N} / [fluffy dough] _{N-G} .
a. Chron – M-S	He prepared the sauce before he kneaded the dough.
b. Reverse – M-S	He prepared the sauce after he kneaded the dough.
c. Chron – S-M	After he prepared the sauce, he kneaded the dough.
d. Reverse – S-M	Before he prepared the sauce, he kneaded the dough.
Context 2	Nico refused to tell anyone his secret to making the perfect pizza.

each may influence performance (Perfetti, 2007; Shah & Miyake, 1996; but see Staub, 2021). We controlled for these individual characteristics (decoding, working memory) by including the scores as covariates in the analyses, since our primary motivation was to identify the individual and combined effects of the three ordering principles.

2.1. *Participants*

Eighty native speakers of English participated in this experiment (age range 18-41 years; mean age 20 years; 63 female). Participants were recruited from the Lancaster University student community and received either course credit or monetary compensation for participation. All participants had normal or corrected-to-normal vision and were unaware of the purpose of the experiment. Data of four participants could not be used due to problems with the eye tracker. These data were removed before analysis.

2.2. *Materials*

The target materials comprised 64 passages, each containing a complex temporal sentence in a $2 \times 2 \times 2$ (event order \times clause structure \times givenness) experimental design.¹ An example item is presented in Table 2. Each target item consisted of two introduction sentences (Context 1) that provided the context and presented the main character and event, followed by one of the four versions of the target sentence, and then a final wrap-up sentence (Context 2). Event order was varied by the order of mention of

¹All experimental items are available in an online repository, accessible via https://osf.io/j3kf6/?view_only=30a74f44c5314e7babfdc24c4e1982f0.

events in a target sentence (a, c = chronological; b, d = reverse order). Each target sentence included two events for which the order in the real world is arbitrary, to ensure that participants had no basis for predicting the event order without taking the connective into account. Clause structure was manipulated by the clause structure of the target sentences (a, b = main-subordinate; c, d = subordinate-main).

Givenness was manipulated by naming a noun in the context sentences from Context 1, and then referring to it in either the first or the second clause of the target sentence. Note that we opted to operationalize givenness as words that are lexically identical. In some items, as in the item in Table 2, the new information could also be primed by bridging (e.g., ‘dough’ might be primed by the mentioning of ‘pizza’ in the context). This was not the case for all items. Consider the following example.

- (5) Jenny had just got home from her holidays with her parents. She had missed her pet bunny a lot. She cuddled up to her pet bunny before she called her best friend. Jenny was looking forward to sleeping on a proper mattress again.

Coming home from holidays does not necessarily prime cuddling with a pet bunny and calling a friend. In other items, the list of possible inferences that readers can make is much longer than for the item in Table 2 (e.g., the possible things to do when visiting your grandmother), and so a potential priming effect is much less likely to occur. In all items, however, whether the new item could be primed by bridging or not, the new item will be less activated than the given item because the given item is explicitly mentioned.

Fifty passages for two unrelated experiments were included as fillers. These filler items were of a length and structure similar to those of the experimental items but did not systematically contain the connectives *before* and *after*. Their inclusion was to minimize participants detecting the nature of the experimental manipulations and engaging in strategic processing. The stimuli were counterbalanced across eight lists, with each passage appearing in a different condition in each list. All participants saw each story in only one condition. Participants were randomly assigned to one of the lists, and for each participant the list was presented in a unique, random order.

Word reading ability Participants completed the Test of Word Reading Efficiency – Second Edition (TOWRE-2: Wagner, Torgesen, & Rashotte, 2011) to assess efficiency of sight word recognition and phonemic decoding. The test requires participants to read aloud as many real words from a list as possible in 45 seconds; the same procedure was followed for a list of non-words. The words and non-words are of increasing length and difficulty. The raw score is the number of items read correctly in the allotted time.

Working memory Participants completed a backwards digit span test to assess working memory. They listened to strings of digits read aloud by the experimenter at a pace of 1 digit per second, starting with string lengths of three digits. Their task was to recall the string in backwards order. There were three items at each level of difficulty and participants completed all items at a given level. If they completed two or more items correctly, they advanced to the next level, which contained an additional digit. Credit of .33 points was awarded for each correctly recalled string of digits. Two practice items of three digits were completed before the experimental items, with feedback if necessary. The items were selected from the Psychology Experiment Building Language (PEBL) backwards digit task (Mueller & Piper, 2014). This programme generates two items at each string length, with the digits in each string selected randomly. We ran the PEBL digit span task and randomly selected three strings generated, for three through to ten digit length strings.

2.3. Procedure

Participants were tested individually in a quiet laboratory. Eye movements were recorded with an SR Research Eyelink 1000 at a sampling rate of 500 Hz. Viewing was binocular, but only the participant’s dominant eye, as determined by a parallax test prior to the experiment, was recorded. Participants were seated at a distance of approximately 60 cm from the monitor and rested their head on a chin-rest. Each session started with an explanation of the task, after which the eye-tracker was adjusted if necessary. A brief nine-point calibration and validation procedure was then performed, during which the participants had to fixate a random sequence of nine dots at various locations on the screen.

Upon successful calibration, two practice trials were completed. The participant was instructed to read the passage at a natural pace and to press the space bar after reading the entire story. Before presentation of each passage, a fixation mark appeared at the position of the first word of the first sentence. The stories were presented in their entirety on the screen, in a randomized order. The target sentence was always presented on a single line, preceded by one or two words from the previous sentence. For every item, the placement of the target sentence on the screen was identical across conditions. To encourage reading for meaning, participants were presented with a verification statement about story content following 25% of the texts (target and filler). Participants indicated whether the statement was correct or incorrect by pressing a button on a button box.

After completing half of the items, participants had a short break and then performed the word reading and working memory tasks. These did not involve a computer. Upon finishing these tasks, participants returned to the monitor, were recalibrated, and finished the eye tracking experiment. On average, the whole session took approximately an hour.

2.4. Analysis procedure

Two regions of interest were identified for the analyses: the full target sentence, and the second clause of the target sentence (from here on referred to as C2). For the full target sentence, *total reading time* (TT) was calculated. This is the total time spent in a region, including regressions to that region, and was used to compare overall processing time for the target sentence amongst conditions. For C2, two reading times were calculated: *first pass duration* and *regression path duration*. First pass duration (FP) is the time spent in a region before moving on or looking back. This measure reflects the immediate processing difficulties a reader has when reading a region for the first time (Rayner, 1998). Regression path duration (RP) is the summed fixation duration from when the current region is first fixated until the eyes enter the next region on the right. This measure includes regressions to regions to the left of the current region. Regression path duration can be seen as reflecting the process of integrating the linguistic material with the previous context (Rayner, 1998). FP and RP

provide a comparison of processing ease (or difficulty) involved in the integration of the information contained in C2 with the preceding clause.

Prior to all analyses, skipped regions were treated as missing data. Additionally, fixations shorter than 80 ms and within one degree of a consecutive longer fixation were merged with the longer fixation. Any remaining reading times shorter than 80 ms were removed (0.4% of the data) (Staub & Clifton, 2006). Outliers were removed by replacing reading times of more than two standard deviations from both the participant's and the condition's mean by the value that corresponded to either two standard deviations below or above the mean, depending on the direction of the outlier (3.5% of the data for FP, 4.3% for RP, and 1.0% for TT).

Reading times were modeled using linear mixed-effect regression models (LMER; Baayen, Davidson, & Bates, 2008), with subjects and items as crossed random effects. Models were evaluated using the *lme4* package within the statistical software R (Bates & Sarkar, 2007; R Development Core Team, 2008). In constructing the models, we always started with all interactions between the three fixed effects, which were deviation-coded, as well as a maximal random effect structure. We reduced random effects only in cases of non-convergence of the full model (Barr, Levy, Scheepers, & Tily, 2013). Full models including interactions within the random effect structure did not converge, which is why all models started without these interactions (lmer model: $RT \sim X*Y*Z + (1 + X+Y+Z | \text{item}) + (1 + X+Y+Z | \text{subject})$). In case of non-convergence with these reduced models, we simplified the model by removing the correlation between the slope and the intercept of the random effect with the lowest explained variance (e.g.: $RT \sim X*Y*Z + (1 + X+Y | \text{item}) + (0 + Z | \text{item}) + (1 + X+Y+Z | \text{subject})$). To help interpret interaction effects, we broke down all significant interactions using pairwise comparisons, which were conducted using subsets of the data that only included the observations for the relevant pairs of conditions.

In addition to the three experimental predictors (event order, clause structure, and givenness), three additional fixed effects were included in the models to account for additional variance: the *trial index*, which indicates the order in which items were presented, the TOWRE scores, and the working memory test scores.

2.5. Hypotheses

The experimental design allowed us to investigate the individual effects of each ordering principle, as well as any interactions between them. Several hypotheses were generated for the two regions of interest: the full target sentence (e.g., sentences a-d in Table 2), and the second clause of the target sentence (e.g., *he kneaded the dough* in the example in Table 2). Given that the significance of all strategies has been shown in prior research, we formulate our hypotheses based on the premise that each strategy will affect online processing, both individually and in combination with other strategies. Figure A1 in the Appendix provides an illustration of the possible effect types (i.e. a main effect versus interaction effect).

Based on evidence from prior research showing effects of the individual principles, we would expect to find main effects of all three principles, with chronological, M-S and given–new orders being more easily processed than their counterparts. The effects of clause structure and givenness should be expected to affect reading times in both regions of interest, but the effect of event order is expected to be evident only in the processing times of the full sentence, not in those of C2. This is because the connective location differs between the conditions: in some conditions it immediately precedes C2, in others it precedes the first clause. Crucially, participants reading a preposed *before*-clause (“*before S, M*”) know immediately on encountering the connective at the beginning of the first clause that the information is presented in reverse chronological order, and were therefore not expected to show processing difficulties at C2.

In line with the grounding principle of preposed subordinate clauses, we expected to find a cross-over interaction between clause structure and givenness in both regions of interest. If evident, sentences with clauses in S-M order should be processed faster than those with clauses in M-S order when the information structure is given-new (i.e. sentences a and b, preceded by *fluffy dough* in Table 2), and more slowly when the information structure is new-given (i.e. sentences a and b, preceded by *tomato sauce* in Table 2). It follows for the C2 prediction that the C2 in an S-M constellation that presents given information (i.e. sentences c and d, preceded by *fluffy dough* in Table 2) should be read more slowly than the C2 in an S-M constellation presenting new information (i.e. sentences c and d, preceded by *tomato sauce* in Table 2).

Apart from this cross-over interaction, the principles could potentially have an additive effect (i.e. the more preferred orders a sentence adheres to, the easier the sentence is to process, or the inverse: the fewer preferred orders a sentence adheres to, the more difficult the sentence is to process). This would predict ‘boost’ interactions between event order and clause structure, as well as event order and givenness. If such interactions are found, in both the full sentence and C2, the condition with chronological order and M-S order (example a should be easiest (note, however, that the condition with reversed order and S-M order (example d) is not expected to be extra complex, see the explanation accompanying the discussion of the main effect of event order above). In addition, in the full sentence, the difference between the given-new and the new-given conditions (i.e., target sentences preceded by *tomato sauce* versus *fluffy dough*) should be larger in chronological relations than in reverse order relations. No effect would be expected on C2 for the same reason no main effect of event order on C2 is expected, see explanation above.

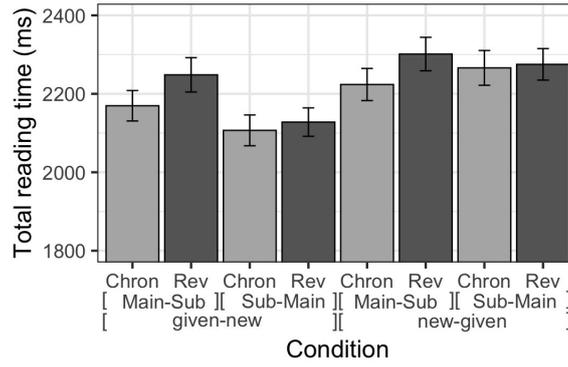
3. Results

Figure 1 shows the mean reading times per condition, reading time measure and region of interest, also reported in Table A1 in the Appendix. The results will be discussed per region (first the full sentence, then C2) and, for C2, per measure (FP and RP).

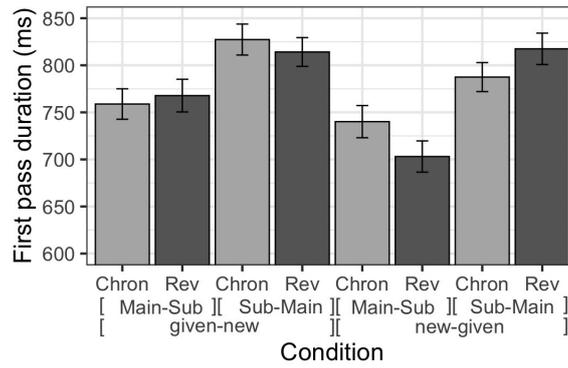
Descriptive statistics for the working memory and word reading ability tests are reported in Table A2 in the Appendix. Working memory capacity did not significantly affect reading times (all $ps > .09$), whereas word reading ability as measured by the TOWRE did affect reading times in the majority of the models ($.01 < p < .09$). In addition, participants’ reading pace tended to speed up as the experiment progressed (all ps for Trial index $< .001$).

3.1. Full sentence – Total reading times

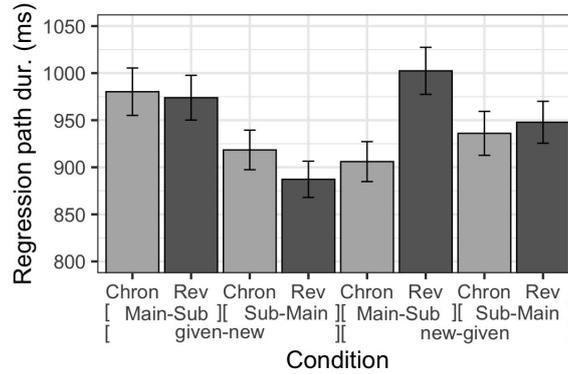
Table 3 presents a summary of the model for the total reading time of the full sentence. As expected, there was a main effect of event order: the target sentences were read faster when the clauses were presented in chronological order compared to reverse



(a) Total reading time of the full sentence



(b) First pass reading time of C2



(c) Regression path duration of C2

Figure 1.: Mean reading times and standard error for the three reading time measures. Lighter shades indicate the chronological conditions, darker shades the reverse conditions.

order. There was also a significant main effect of givenness. Givenness furthermore occurred in a significant two-way interaction with clause structure. This is depicted in Figure 2.

To help interpret this interaction effect, we conducted pairwise comparisons split-

Table 3.: Regression coefficients and test statistics for the effect of event order, clause structure and givenness on the total reading time of the full sentence.

	β	SE	t	p
(Intercept)	3369.06	567.74	5.93	
Trial index	-4.79	0.37	-12.85	<.001
TOWRE	-12.52	5.67	-2.21	<.05
WM	56.31	47.95	1.17	.24
Event order	51.96	25.54	2.04	<.05
Clause structure	-37.80	28.72	-1.32	.19
Givenness	89.32	24.86	3.59	<.001
Event order:Clause structure	-65.97	44.95	-1.47	.14
Event order:Givenness	1.85	44.91	0.04	.97
Clause structure: Givenness	111.54	44.94	2.48	<.01
Event order:Clause structure:Givenness	30.49	89.89	0.34	.73

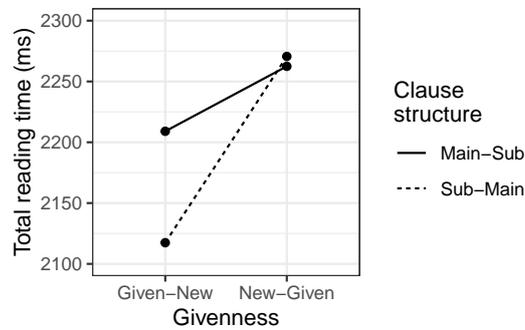


Figure 2.: Interaction effect of clause structure*givenness in the total reading time of the full sentence.

ting up the data by givenness. These comparisons revealed a main effect of clause structure for sentences with a given-new order ($\beta=-93.18$, $SE=35.34$, $t=-2.64$, $p<.01$) but not for sentences with a new-given order, supporting the expectation that in given-new sentences, total reading time would be shorter for sentences in S-M order than for sentences in M-S order. In other words: processing of the full sentence was facilitated specifically when given information was presented in a preposed subordinate clause.

3.2. C2 – First pass duration

Table 4 presents a summary of the model for the first pass duration of C2. As expected, for the first pass duration of C2, there was no main effect of event order, but there were significant main effects of clause structure and givenness. The results also revealed an

Table 4.: Regression coefficients and test statistics for the effect of event order, clause structure and givenness on the first pass duration of C2.

	β	SE	t	p
(Intercept)	1240.00	191.90	6.46	
Trial index	-0.96	0.16	-5.93	<.001
TOWRE	-4.97	1.91	-2.60	<.01
WM	10.79	16.19	0.67	.51
Event order	-2.19	10.78	-0.20	.84
Clause structure	69.56	12.50	5.57	<.001
Givenness	-31.87	11.99	-2.66	<.01
Event order:Clause structure	22.21	19.44	1.14	.25
Event order:Givenness	0.00	19.43	0.00	1.00
Clause structure: Givenness	28.60	19.44	1.47	.14
Event order:Clause structure:Givenness	96.71	38.89	2.49	<.01

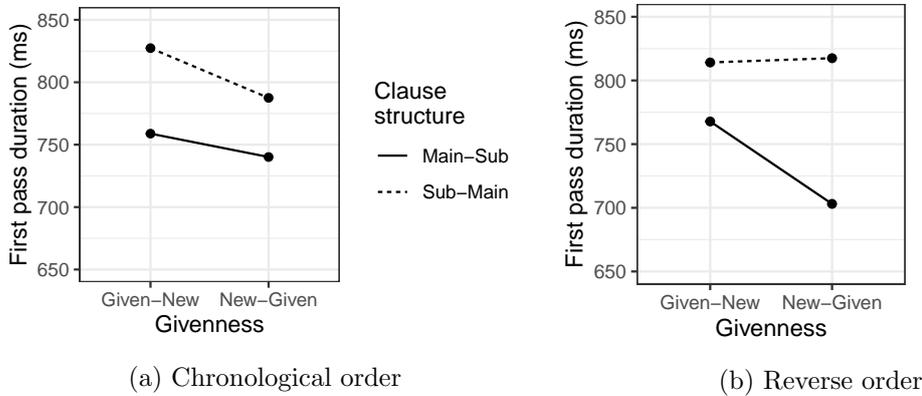


Figure 3.: Interaction effect of clause structure*givenness in the first pass duration of C2, for chronological and reverse order sentences.

unexpected three-way interaction between event order, clause structure, and givenness. This interaction effect was further explored for chronological and reverse order items separately, and is visualized in Figure 3.

For the chronological sentences, there was only a main effect of clause structure ($\beta=-59.33$, $SE=14.47$, $t=4.10$, $p<.001$), with faster first pass duration when the second clause was a subordinate clause. Given this main effect and the absence of an overall two-way interaction between event order and clause structure, there is only partly a ‘boost’ interaction: there is a difference between M-S and S-M orders only for chronological sentences, but not between chronological and reverse ordered sentences in M-S constellations.

For the reverse order sentences, there were main effects of clause structure

Table 5.: Regression coefficients and test statistics for the effect of event order, clause structure and givenness on the regression path duration of C2.

	β	SE	t	p
(Intercept)	1387.94	227.20	6.11	
Trial index	-1.89	0.24	-8.00	<.001
TOWRE	-4.85	2.26	-2.14	<.05
WM	23.11	19.16	1.21	.23
Event order	20.89	19.22	1.09	.28
Clause structure	-42.02	18.21	-2.31	<.05
Givenness	4.27	16.30	0.26	.79
Event order:Clause structure	-57.39	28.38	-2.02	<.05
Event order:Givenness	74.56	28.36	2.63	<.01
Clause structure:Givenness	70.06	28.38	2.47	<.01
Event order:Clause structure:Givenness	-43.59	56.77	-0.77	.44

($\beta=80.61$, $SE=17.75$, $t=4.54$, $p<.001$) and givenness ($\beta=-31.55$, $SE=15.55$, $t=-2.03$, $p<.05$). Different from the pattern of reading times found for chronological sentences, there was also an interaction between clause structure and givenness ($\beta=76.12$, $SE=27.86$, $t=2.73$, $p<.01$). Pairwise comparisons, conducted by splitting up the reverse order data by givenness, revealed that the first pass duration of C2 in S-M sentences differed significantly from that of M-S sentences only when C2 contained given information ($\beta=119.85$, $SE=22.04$, $t=5.44$, $p<.001$), which is also illustrated in Figure 3: for reverse order sentences, C2 was processed faster when it was a subordinate clause containing given information than when it was a main clause containing given information. This lends further support to the grounding principle, according to which the combination of subordinate clauses and given information is a preferred one.

3.3. C2 – Regression path duration

Table 5 displays the summary of the model for regression path duration of C2. As expected, the main effect of event order was not significant in the regression path duration of C2, whereas the main effect of clause structure was significant. Contrary to our expectations, there was no main effect for givenness. The three two-way interactions were all significant; they are described below and visualized in Figure 4.

The two-way interaction between event order and clause structure was significant

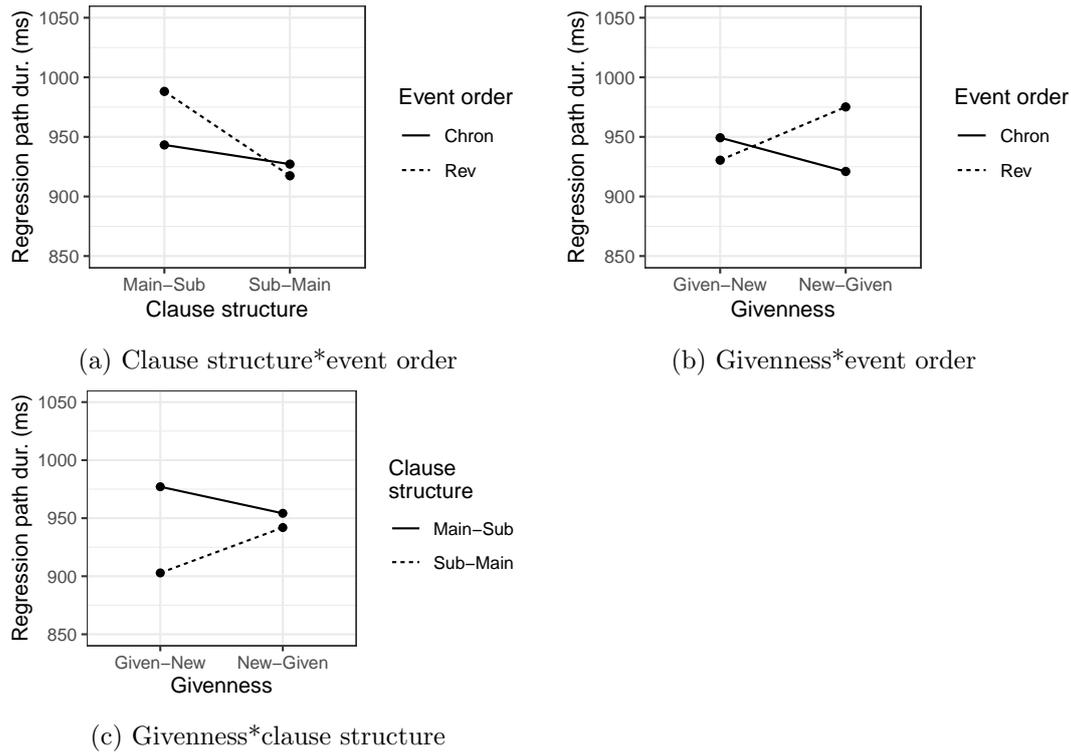


Figure 4.: Interaction effects in the regression path duration of C2.

($\beta=-57.39$, $SE=28.36$, $t=-2.02$, $p=.04$), but we did not find the boost effect that would be expected if the principles have an additive effect. Figure 4a illustrates the pattern of results. A boost effect would predict C2 reading to be facilitated in chronological M-S sentences compared to reverse order M-S sentences. However, this advantage did not reach conventional levels of statistical significance ($p=.07$). In contrast, the pairwise comparisons splitting the data by event order revealed a main effect of clause structure only for reverse order sentences ($\beta=-71.92$, $SE=23.95$, $t=-3.00$, $p<.01$): in reverse order sentences, C2 was read faster in S-M sentences than in M-S sentences, even though two principles are violated. Note, however, that in M-S conditions, the connective immediately precedes the C2, and therefore spillover effects onto C2 are more likely to occur in M-S conditions than in S-M conditions, where readers have had more time to process the connective.

The results also revealed a significant two-way interaction between event order and givenness ($\beta=74.58$, $SE=28.35$, $t=2.63$, $p<.01$), which was predicted for full sentence processing only, not for C2. This interaction is shown in Figure 4b. Pairwise

comparisons, splitting the data by givenness, revealed a main effect of event order only in new-given relations ($\beta=58.18$, $SE=25.61$, $t=2.27$, $p<.05$): the regression path duration of C2 in a new-given order sentence was longer in reverse order sentences than chronological sentences. This might be caused by the fact that two principles are violated in such cases. Other pairwise comparisons did not reach significance.

Finally, the expected cross-over interaction between clause structure and givenness was significant ($\beta=70.08$, $SE=28.36$, $t=2.47$, $p<.01$). This is shown in Figure 4c. We expected an interaction effect whereby a new main C2 (i.e. with the given information in a preposed subordinate clause) would be read faster than a main C2 containing given information. In line with this hypothesis, pairwise comparisons splitting the data by givenness revealed that there was a main effect of clause structure only in given-new order sentences ($\beta=-76.74$, $SE=23.12$, $t=-3.32$, $p<.001$): for sentences with a given-new order, C2 was read faster when it was a main clause compared to when it was a subordinate clause.

3.4. C2 – Follow up analysis

The mean reading times per condition suggest that there might be a trade-off between first pass duration and regression path duration (see also Rayner, 1998, p. 376-377). Such a potential trade-off can obscure the true nature of the reading difficulty: it is assumed that a faster first pass duration reflects faster initial processing, but in reality it might reflect greater difficulty, which in turn prompts earlier regressions out of the region. Consider, for example, the reading times for the condition reverse M-S new-given ('given after new'): first pass duration is shortest in this condition compared to other conditions, but regression path is, in fact, longest. We conducted an exploratory analysis of this potential trade-off by repeating the C2 analysis with a "new" reading time measure: RP–FP. This new measure thus reflects the regression path duration minus the first pass reading times.

Table 6 presents the model results for this measure. The main effect of event order was, again, not significant in the regression path duration of C2, whereas the main effect of clause structure was, again, significant. Contrary to the RP results and in line with our hypothesis, there now was a significant main effect for givenness. Similar to

Table 6.: Regression coefficients and test statistics for the effect of event order, clause structure and givenness on RP–FP of C2.

	β	SE	t	p
(Intercept)	122.98	105.20	1.17	.25
Trial index	-0.90	0.22	-4.12	<.001
TOWRE	0.41	1.04	0.40	.69
WM	11.75	8.81	1.33	.19
Iconicity	22.55	16.90	1.33	.19
Clause structure	-111.88	17.23	-6.49	<.001
Givenness	36.00	16.51	2.18	<.05
Event order:Clause structure	-79.73	27.19	-2.93	<.001
Event order:Givenness	75.49	27.19	2.78	<.01
Clause structure:Givenness	42.26	27.20	1.55	.12
Event order:Clause structure:Givenness	-141.86	54.42	-2.61	<.01

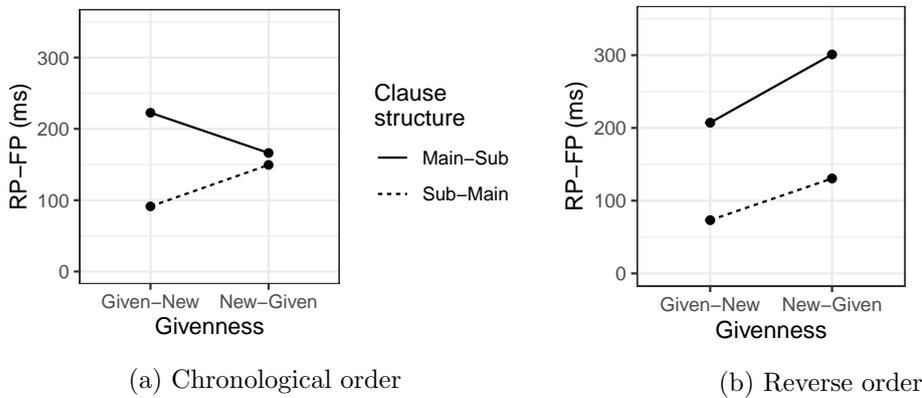


Figure 5.: Three-way interaction effect in RP–FP of C2, split by event order.

the RP results, there was a significant two-way interaction between event order and clause structure, as well as clause structure and givenness. The results also revealed a three-way interaction between event order, clause structure, and givenness. This was further explored for chronological and reverse order items separately, and is visualized in Figure 5.

For the chronological order sentences, there was a main effect of clause structure ($\beta=-72.43$, $SE=22.48$, $t=-3.22$, $p<.01$), as well as an interaction between clause structure and givenness ($\beta=113.32$, $SE=38.37$, $t=2.95$, $p<.01$). Pairwise comparisons revealed that RP-FP reading times of C2 in S-M sentences differed significantly from that of M-S sentences when C2 contained given information ($\beta=-128.99$, $SE=35.04$, $t=-3.68$, $p<.001$). As visualized in Figure 5, for chronological sentences only, C2 was

processed faster when it was a main clause containing new information (given-new and sub-main). This supports the hypothesis that given-new and S-M together form a preferred combination of clause orders.

For the reverse order sentences, there was a main effect of clause structure ($\beta=-152.59$, $SE=23.43$, $t=-6.51$, $p<.001$), with faster reading times when C2 was a main clause. There was also a main effect of givenness ($\beta=74.43$, $SE=19.54$, $t=3.80$, $p<.001$), with faster reading times when C2 was new (corresponding to a given-new clause order).

Taken together, these results continue to support the grounding principle: reading times are faster when the given information is presented in a preposed subordinate clause (i.e., S-M and given-new order).

4. Discussion

We set out to investigate how different ordering principles (event order, clause structure and givenness) affect the online processing of reading complex sentences for meaning. In line with previous studies, there were clear effects of each principle. This confirms their influence on the processing of complex sentences containing temporal connectives. Critically though, the results indicate that none of the three ordering principles stand out in the sense that they facilitate reading irrespective of the other two ordering principles (i.e. none of the principles generate solid main effects). Rather, they function in relationship with each other to influence sentence processing. The most notable interaction between principles seems to correspond to the grounding function of given information in subordinate clauses. There were few indications that the effects work additively; that is, a combination of multiple preferred clause orders did not consistently result in faster processing.

In line with previous adult studies (H. Clark & Clark, 1968; Politzer-Ahles et al., 2017), event order appears to be an influential principle with a significant main effect on total reading times for the full sentence. As expected, event order did not seem to have a large effect on the processing of C2.

Clause structure influenced the initial phases of processing, but this facilitative

effect did not carry over to the later stages of processing. A likely explanation is that the effect of clause structure is modulated by a cross-over interaction with givenness (as discussed in more detail below).

Givenness influenced sentence processing as well: information in given-new order sentences was generally easier to process than information in new-given order. More importantly, the results revealed a cross-over interaction between givenness and clause structure. Reading times were faster when given information was presented in a subordinate clause (as S-M rather than M-S order). This fits with theories on the grounding function of preposed subordinate clauses: they provide the context to support understanding of subsequent information (Chafe, 1984; Ford & Ford, 1993; Thompson, 1985).

The results also showed a significant three-way interaction in first pass duration. This interaction indicated that a combination of all preferred orders does not result in fastest processing times and suggested that instead, in reverse order sentences only, the second clause was easier to process when it presented given information in a subordinate clause. We do not have an explanation for why this effect would appear in reverse order sentences only. What we can conclude from this, however, is that clause structure appears to be most influential in early processing measures. We would be interested to see whether this finding replicates in future research.

All in all, the results indicate that parsing the individual words and the grammatical structure of the clause mainly affects early processing stages. Presenting familiar, given words in C2 and a subordinate clause in C2 resulted in shorter initial processing times. When looking at the full sentence as well as the later stages of processing C2, it appears that discourse factors are more important. First, event order is a rather strong principle, which operates relatively independently of the other two principles. Second, during the later stages of processing, the benefits of a relatively easy grammatical structure can be overruled by an ordering principle that also functions at the level of the discourse: the givenness of the segments. The results demonstrate that S-M structures are preferred when given information is presented in the preposed subordinate clause. This phenomenon can be related to the grounding function of preposed subordinate clauses. Given the persistence of this interaction effect, as well as the

abundance of corpus-based evidence for presenting given information in preposed subordinate clauses, we suggest promoting this interaction effect to a separate principle: *the grounding principle*.

These findings and our proposal of a grounding principle provide new theoretical insights in complex-sentence processing by considering both linguistic and cognitive processes. Specifically, the grounding principle emphasizes comprehenders' sensitivity to discourse factors and the discourse pragmatic functions that clauses serve. In natural language, sentences are generally not processed in isolation, and so models of language processing must take into account the role that discourse factors play in comprehension, as well as the interplay between discourse and syntactic constraints. In other words, sentence processing research should assess the impact of discourse and syntactic constraints simultaneously to be able to contribute towards a comprehensive theory of language processing.

Open questions and suggestions for future research Further research is needed to examine the source of the effects found in the current study. The data might be explained by a working memory-based account. However, the working memory data were not predictive of participants' reading times. This could be due to a lack of variability in the population that was tested (adult university students), insufficient power to obtain meaningful variability in working memory capacity, or a lack of sensitivity in our dependent measure (reading times) for detecting individual differences (see Staub, 2021). Another possibility is that the constraints that a text places on working memory should be decoupled from operationalized working memory measures, and that we should instead focus on the memory demands that discourse places on comprehenders irrespective of individual differences in working memory capacity.

An alternative account to explain the results is based on statistical learning: because readers frequently encounter certain clause orders, they show more ease when processing such clause orders compared to other orders. This account is based on prior research showing that syntactic computations may rely on statistical information about the relative frequencies with which different syntactic structures occur in the language (see, e.g., Conway, Bauernschmidt, Huang, & Pisoni, 2010; Misyak & Christiansen,

2012). In relation to the grounding principle, a statistical account would predict that readers learn that preposed subordinate clauses tend to contain given information, and so they would come to expect this information structure when encountering S-M sentences.

Additional research will be needed to assess to what extent the results from the current study are generalizable across populations. We opted to test adult readers because the experiment was fairly long – one hour in total. Our findings do fit a recent study of children’s comprehension accuracy (de Ruiter et al., 2020). An important extension of the current findings would be to examine online language processing from a developmental perspective. This could provide interesting insights into the source of the effects reported here, as children show more variability in reading ability and working memory.

Similarly, an open question is whether less-skilled readers benefit from the same clause ordering principles. Such readers are known to experience more difficulties in comprehending texts than skilled readers (McNamara, Kintsch, Songer, & Kintsch, 1996; Sanders, Land, & Mulder, 2007) and may therefore not be affected by clause ordering principles in the same way as skilled readers. Examining both skilled and non-skilled readers is crucial for providing concrete evidence to inform educational practice. At present, recommendations for producing comprehensible texts are often based on experience with the target group and/or common-sense logic. Some recommendations such as ‘keep sentences short’ are inherent in most readability formulae (Bailin & Grafstein, 2001), but empirical research does not support this position (see, e.g., Cain & Nash, 2011; van Silfhout, Evers-Vermeul, Mak, & Sanders, 2014). Writing advice must be evidenced-based and these studies, together with the current findings, emphasize the need for more empirical research.

Finally, we reflect on the experimental design. Although care was taken to keep the target clauses as identical as possible between the eight conditions, syntactic restrictions created a difference between M-S and S-M conditions: C2 in the S-M conditions was directly preceded by a comma, whereas C2 in the M-S conditions were not. This confound is related to a literature showing that adult readers appear to process subsequent words after a comma faster (Hill & Murray, 2000), and they are

more likely to initiate a regression for nouns in a clause-final position than for those in a nonfinal position (Rayner, Kambe, & Duffy, 2000; see also Rayner, Sereno, Morris, Schmauder, & Clifton Jr, 1989). These factors must be kept in mind when interpreting the results of the current study. Nevertheless, the clauses were presented as they would occur in real texts; that is, sentences can occur in S-M structures with a comma, or M-S structures without a comma. Any possible increased reading time or decrease in regressions that was related to the presence of absence of a comma would therefore be reflective of processing difficulties similar to what would occur in real-world language processing situations.

Another point of consideration is what the chosen reading time measures actually reflect. Total time is a useful gross measure of sentence processing difficulty, and its interpretation is relatively straightforward. This is less so the case for the other two measures. First pass duration is a useful measure of momentary difficulty in syntactic or semantic analysis. However, multi-word first pass duration can be affected by the probability of regressing out of the region, thereby making it more difficult to interpret. Regression path duration can also be difficult to interpret, as it does not provide detailed insight into where any processing difficulty lies and can reflect different reading processes: probability of regressing out of a region, time spent rereading earlier regions, and time spent rereading the target region after regressing out of it. To further explore the robustness of the effects found on C2, we conducted a post-hoc analysis of regression path durations minus the first pass durations. In future studies, this should be addressed by studying the probability of a regression out of a region, which can reflect similar effects.

5. Conclusion

Principles governing the processing of clauses have been studied in isolation with insufficient attention to how they may interact to influence processing. This contribution fills that gap, showing that clause structure mainly affects early stages of processing, whereas the two principles operating at the discourse level – event order and givenness – are more important during later stages and for reading times of the entire sentence.

Further, the current study codifies the interactions between clause structure and givenness into a new principle, called the grounding principle, which provides a frame for understanding potential cognitive processes involved in language processing and opens an avenue to future testing of these interactions.

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Appendix A.

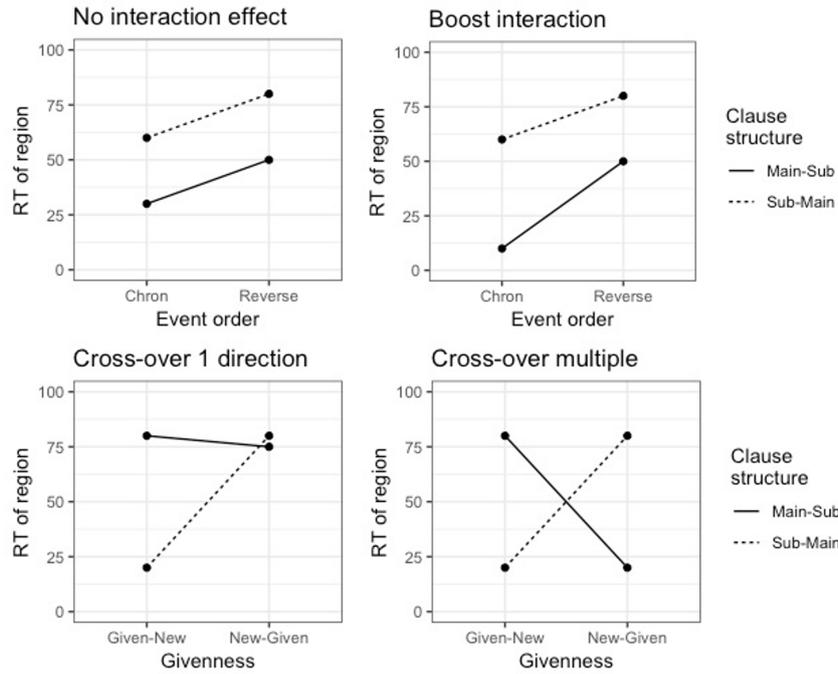


Figure A1.: Illustration of possible effects. The top two panels illustrate a possible main-effect only and boost interaction for event order * clause structure; the bottom two panels represent the possible cross-over interactions for givenness * clause structure.

Table A1.: Mean reading times and standard deviations per condition, measure and region.

Condition			FP C2		RP C2		TT full sentence	
			Mean	SD	Mean	SD	Mean	SD
Chron	M-S	given-new	759	395	980	615	2170	948
Rev	M-S	given-new	768	422	974	578	2248	1070
Chron	S-M	given-new	827	403	918	514	2107	960
Rev	S-M	given-new	814	373	887	470	2128	887
Chron	M-S	new-given	740	416	906	516	2224	1002
Rev	M-S	new-given	703	403	1002	607	2301	1042
Chron	S-M	new-given	787	375	936	567	2266	1083
Rev	S-M	new-given	817	405	948	541	2275	982

Table A2.: Descriptive statistics for the TOWRE and WM measures.

Variable	Possible range	Observed range	Mean	SD
TOWRE	0-167	44-108	92.86	10.72
WM	0-8	3-8	4.94	1.30