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Processing multiple gap dependencies: Forewarned is forearmed

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ABSTRACT

Many studies have shown that when forming a filler-gap dependency, comprehenders attempt to posit a gap site in advance of the input. However, it remains an open question what information they use to determine gap locations. The current study investigates parallelism in coordinate extraction structures, and asks whether comprehenders use parallelism constraints to structure their expectations about upcoming gap sites. Using a filled-gap paradigm, Experiments 1 and 2 show that comprehenders rely on parallelism to restrict the search for upcoming gap sites to specific locations in sentences with coordinate extraction. Experiment 3 shows that this effect cannot be reduced to processing factors, but may be due to a grammatically-based constraint on parallel extraction. Together, these results shed new light on the source and scope of active processing and parallelism effects in comprehension.

Introduction

The ability to project syntactic structure in advance of bottom-up input reflects a tradeoff between efficiency and accuracy: building structure in advance of the input can relieve processing mechanisms later, but only if that structure is accurate. This tradeoff is evident in the processing of filler-gap dependencies. For instance, in sentences like (1), the noun phrase (NP) *which book* (the 'filler') has been displaced from its post-verbal direct object position (the 'gap' indicated by an underscore). In (1), the parser must relate the filler and the gap for thematic interpretation.[1]

(1) **Which book** did the students like the teacher to read ____ in class?

It is well known that comprehenders attempt to complete filler-gap dependencies as rapidly as possible, in advance of bottom-up information that signals the presence of a gap site. This phenomenon is known as 'active gap-filling' (Crain & Fodor, 1985; Fodor, 1978; Frazier & Flores d'Arcais, 1989; Stowe, 1986). In (1), comprehenders' eagerness to resolve the filler-gap dependency as soon as possible leads the parser to posit a gap in the direct object position of the first verb *like*, before direct evidence of a gap site. If the parser's prediction were correct, structure building mechanisms would be temporarily relieved after the verb *like*. However, since the direct object position is filled with the NP *the teacher*, the parser is forced to revise its prediction and posit a gap in a later position.

Over the past several decades, a number of proposals have sought to characterize the mental mechanisms that support active dependency formation in sentence comprehension. However, despite significant advances in our understanding of active processing, several fundamental questions remain. In particular, it is unclear what information about the filler is carried forward to guide active dependency formation, how general processing principles impact this process, and how much structure the parser is willing to project in advance of the input. This paper addresses these questions by investigating active processing in multiple-dependency constructions. Multiple-dependency constructions provide a unique opportunity to track active processing decisions at multiple points throughout a single sentence, maximizing the window into active processing mechanisms.

Active dependency formation in sentence comprehension

Evidence for active dependency formation in sentence comprehension comes from a variety of measures, including reading times (Crain & Fodor, 1985; Frazier & Clifton, 1989; Omaki et al., 2015; Phillips, 2006; Pickering & Traxler, 2001, 2003; Staub, 2007; Traxler & Pickering, 1996; Wagers & Phillips, 2009, 2014), visual world eye-tracking (Sussman & Sedivy, 2003), cross-modal priming (Nicol & Swinney, 1989), speeded acceptability judgments (Frazier & Flores d'Arcais, 1989), and event-related potentials (Garnsey, Tanenhaus, & Chapman, 1989). Active dependency formation is also attested in many languages, including English

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[1] The terms 'gap', 'gap position', and 'gap location' are used theory neutrally in this paper. My argument does not hinge on whether the tail of the filler-gap dependency is or is not treated as an empty category or trace.

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(see aforementioned studies), Dutch (Frazier, 1987), German (Felser, Clahsen, & Münte, 2003), Italian (de Vincenzi, 1991), and Japanese (Aoshima, Phillips, & Weinberg, 2004).

In an early study on active dependency formation, Stowe (1986) compared sentences with a displaced *wh*-phrase, like (2a), with maximally similar sentences that lacked a displaced *wh*-phrase, like (2b). Stowe observed a processing disruption in word-by-word reading times at the direct object *us* in (2a), relative to the same word in (2b). This effect has been termed the 'filled gap effect', and has been widely interpreted as an unambiguous index of active dependency formation. In (2a), the parser posits a gap in the direct object position of the verb *bring*, before it encounters overt evidence of a gap in that position, and processing is disrupted when it discovers that the direct object position is occupied.

(2) a. My brother wanted to know **who** Ruth will bring <u>us</u> home to __ at Christmas.
b. My brother wanted to know if Ruth will bring <u>us</u> home to Mom at Christmas.

Additional evidence for active gap-filling comes from processing disruptions at the verb when the filler is a semantically implausible argument of the verb. For instance, Traxler and Pickering (1996) tested sentences like (3) using eye-tracking while reading, and found increased reading times at the verb for implausible filler-verb combinations, e.g., *garage* ... *shot*, relative to plausible filler-verb combinations, e.g., *pistol* ... *shot*. Garnsey et al. (1989) tested similar sentences using event related potentials, and observed a greater N400 amplitude at the verb for implausible filler-verb combinations, relative to plausible filler-verb combinations. Like the filled-gap effect, this semantic anomaly effect suggests that filler-gap processing is 'active', since the processing disruption precedes any evidence of a gap site.

(3) That's the **pistol / garage** with which the heartless killer <u>shot</u> the hapless man __ yesterday.

Active dependency formation can be viewed as a response to two constraints. First, filler-gap dependencies are unbounded, i.e., the distance between the filler and gap can span a potentially large amount of material. In response, the parser must maintain a representation of the filler in memory until it can be integrated later. Second, the tail of a filler-gap dependency is often signaled only by the absence of a verb's sub-categorized constituent, i.e., a break in the phrase structure. Since the filler must be stored in memory until integration, and since there is a stringent limit on the amount of information that can concurrently occupy working memory (Cowan, 2001; McElree, 2006; McElree & Dosher, 1989), the parser is motivated to close open filler-gap dependencies as soon as possible to reduce the burden on working memory (e.g., Gibson, 1998).

More recently, research on active dependency formation has focused on how grammatical licensing requirements impact active processing. For instance, Yoshida, Dickey, and Sturt (2013) investigated active structure building using constructions that temporarily allow a sluicing interpretation. Sluicing involves a *wh*-phrase and the omission of a full clause. Yoshida and colleagues tested sentences like (4), in which the fronted *wh*-NP is initially compatible with a sluicing parse, e.g., (4a), but the fronted *wh*-PP is not, e.g., (4b). Yoshida and colleagues reasoned that if the parser actively posits a sluicing parse where grammatically possible, and if the parser also attempts to resolve anaphoric relations in real time, then there should be a gender-compatibility effect at the reflexive in (4a), due to the match between the reflexive and the subject of the sluiced clause *grandmother*, but not in (4b). Results from self-paced reading confirmed this prediction, which Yoshida and colleagues interpreted as evidence that comprehenders actively projected a sluicing structure, but only when it was grammatically permissible, and that the projected structure was sufficiently detailed to license the reflexive.

(4) a. Jane's **grandfather/grandmother** told some stories at the family reunion, but we couldn't remember which story about **himself** from the party his brother was so very impressed with.
b. Jane's **grandfather/grandmother** told some stories at the family reunion, but we couldn't remember with which story about **himself** from the party his brother was very impressed.

Phillips (2006) and Wagers and Phillips (2009) also argued that active dependency formation is motivated by grammatical constraints. Phillips (2006) tested parasitic gap constructions, which involve a filler that is linked to two gaps. An important property of parasitic gap constructions is that one gap, typically located inside a syntactic island (i.e., the parasitic gap) must be licensed by a gap in the main clause (i.e., the licensing gap) under specific structural conditions. In the sentences that Phillips (2006) tested, the parasitic gap ($\_\__{pg}$) was located in a complex subject NP, and the licensing gap ($\_\__{lg}$) was located in the main clause verb phrase (VP) following the subject NP, as in (5a). The contrast between (5a) and (5b) shows that the parasitic gap is licensed only when the subject NP involves an infinitival clause.

(5) a. The school superintendent learned **which schools/students** [$_{\text{Subject NP}}$ the proposal to expand $\_\__{pg}$ upon the current curriculum] would overburden $\_\__{lg}$ during the following semester.
b. *The school superintendent learned **which schools/students** [$_{\text{Subject NP}}$ the proposal that expanded $\_\__{pg}$ upon the current curriculum] would overburden $\_\__{lg}$ during the following semester.

Parasitic gaps present a challenge for incremental processing. Upon encountering a potential parasitic gap, the parser cannot know in advance whether there will be a licensing gap in the main clause. Using a plausibility manipulation as a probe of active processing, Phillips (2006) observed slower reading times at the infinitival verb, e.g., *expand* in (5a), in the implausible condition, e.g., *which students*, relative to the plausible condition, e.g., *which schools*. No such contrast was found in the corresponding finite clause conditions. This contrast suggests that the parser posits a parasitic gap only when it is licensed in a subject NP that involves an infinitival clause. Phillips argued that for this to be achieved, the parser must predict the upcoming main clause structure to decide that a parasitic gap is grammatically licensed.

Wagers and Phillips (2009) tested the hypothesis that active processing is driven by the need to satisfy grammatical constraints as rapidly as possible during real-time comprehension using sentences with across-the-board (ATB) extraction. ATB extraction involves a single filler that participates in multiple dependencies, as shown in (6). ATB extraction in coordinate phrase constructions like (6) is subject to a structural licensing requirement known as the Coordinate Structure Constraint (CSC; Ross, 1967), which requires that each coordinate contain a gap, as illustrated in (7).

(6) The **wines/cheeses** which the gourmets were energetically discussing __ or slowly sipping __ during the banquet were rare imports from Italy.

(7) a. *The wines which the gourmets were discussing __ or sipping the beer were imported.
b. *The wines which the gourmets were discussing the beer or sipping __ were imported.

Wagers and Phillips reasoned that if grammatical constraints, such as the CSC, guide active processing, then they should find evidence that a second gap is actively posited in the second coordinate. By contrast, if active processing is driven by memory demands to resolve the filler-gap dependency as quickly as possible, then active search should be terminated after the filler is integrated in the first coordinate, and no evidence of active search should be found in the second coordinate. Word-by-word reading times showed a plausibility effect, reflected in a processing disruption shortly after encountering the implausible filler-verb combination in the second conjunct, e.g., *cheese* ... *sipping*, relative to its plausible counterpart, e.g., *wines* ... *sipping*. Wagers and Phillips interpreted these findings as evidence that the grammatically-based requirement for multiple gap sites in coordinate structures, i.e., the CSC, drives active gap-filling across both coordinates (see also Aoshima et al., 2004; Phillips, 2006; Pritchett, 1992).

Revisiting previous conclusions about active dependency formation

A problem for existing theories of active dependency formation is that the evidence for grammatically-driven filler-gap processing is inconclusive. For instance, a concern with the findings reported by Wagers and Phillips (2009) is that the processing disruption observed in the second coordinate in sentences like (6) might reflect general processing principles, rather than application of grammatical constraints. It is well-known that in coordinate structures, the parser strongly prefers syntactically and semantically parallel conjuncts, as evidenced by facilitated reading times when the structure of the second conjunct parallels the structure of the first conjunct (Apel, Knoeferle, & Crocker, 2007; Carlson, 2001; Frazier & Clifton, 2001; Frazier, Munn, & Clifton, 2000; Frazier, Taft, Roeper, Clifton, & Ehrlich, 1984; Knoeferle, 2014; Knoeferle & Crocker, 2009; Sturt, Keller, & Dubey, 2010). These findings have led to the proposal that parallelism in coordinate structures is simply an instance of predictability, e.g., the facilitation observed in coordinate structures reflects the fact that predictable structures are processed more rapidly than unpredictable ones (e.g., Frazier et al., 2000). Under this view, parallelism may be cast in terms of general processing principles, such as template reuse, priming of the construction process, or even a special parallelism mechanism (see Knoeferle, 2014, for discussion). This proposal motivates a plausible alternative explanation of the findings reported by Wagers and Phillips (2009): the active search for multiple gap sites in sentences with coordinate phrase ATB extraction is not driven by grammatical licensing requirements, e.g., the CSC, but rather the expectation of parallel conjuncts derived from general processing principles. If parallelism is to be treated as a form of prediction, as previously suggested (Frazier et al., 2000), then parallelism might be expected to impact active structure building decisions in coordinate structures. Under this account, encountering the implausible verb in the second conjunct in (6), e.g., *sipping*, signals that a parallel structure is not possible because the filler cannot have the same function in both conjuncts, e.g., as the semantic object, leading to the observed processing disruption.

The present study attempts to resolve this debate by investigating whether the parser uses parallelism to guide active dependency formation in sentences with coordinate ATB extraction. Experiments 1 and 2 used self-paced reading to test whether parallelism can prompt active dependency formation and help structure comprehenders' expectations about upcoming gap locations in ATB sentences. To preview the results, Experiment 1 shows that encountering the conjunction in sentences with ATB extraction from coordinated VPs does in fact trigger the expectation of parallel gap sites. Experiment 2 shows that this effect extends to more complex clausal coordination. These results suggest that active dependency formation in coordinate extraction structures cannot be due to the CSC alone, favoring an account based on parallelism. Finally, Experiment 3 compares the stimuli used in Experiment 2 against the corresponding non-ATB structures to determine whether the parallelism effect observed for ATB sentences reflects general processing factors or a grammatically-based constraint that strongly encourages parallel gaps. This design was first used by Sturt and Martin (2016), and was used in the current study to provide an experiment-internal test for the role of a grammatically-based parallelism constraint. Results confirmed previous findings reported by Sturt and Martin (2016), revealing a larger parallelism effect in ATB coordinates than in the corresponding non-ATB structures. These results suggest that parallelism in ATB coordinates cannot be reduced to processing factors, motivating a new argument for a grammatical account of active dependency formation.

Experiment 1

The goal of Experiment 1 was to test whether the search for multiple gap sites in sentences with coordinate ATB extraction is driven by the expectation for parallel conjuncts. To achieve this, Experiment 1 used a modified version of the filled-gap design devised by Lee (2004). Lee (2004) compared displaced noun phrases (NP filler) with displaced prepositional phrases (PP filler), as shown in (8) (see Wagers & Phillips, 2014, for a similar design).

(8) a. **The chemicals which** the technician sprayed <u>the equipment</u> with ___ ...
b. **The chemicals with which** the technician sprayed <u>the equipment</u> ___ ...

In both (8a) and (8b), the filler is semantically compatible as the direct object of the verb *sprayed*. Lee reasoned that if comprehenders actively posit a direct object gap in (8a), then encountering the overt object NP *the equipment* should lead to a processing disruption, i.e., a filled-gap effect. By contrast, the PP category of the filler in (8b) should prevent comprehenders from positing a direct object gap, in which case no disruption is expected. These predictions were borne out, as Lee observed a filled-gap effect, such that the processing of the direct object was more difficult in (8a) than in (8b).

Experiment 1 extended the design in (8) to coordinate ATB constructions, and introduced a manipulation for gap parallelism. In the sample set of materials provided in Table 1, the PP filler must be interpreted after the direct object in both coordinates. This configuration allows the direct object in the second coordinate to serve as a baseline for measuring the filled-gap effect in the same regions in the ±parallel conditions involving an NP filler. In the +parallel condition, both coordinates involve a late-arriving prepositional gap. In the −parallel condition, the first coordinate involves an early-arriving direct object gap, but this position is filled in the second coordinate, violating parallelism between the conjuncts.

Importantly, the grammatical account of active processing based on the CSC (e.g., Wagers & Phillips, 2009) and the competing account based on processing factors make divergent predictions for the NP-filler conditions. If active dependency formation in coordinate extraction structures is driven by general processing factors, specifically the preference for coordinate parallelism, then the location of the first gap in the first conjunct should determine where comprehenders expect to find the second gap in the second conjunct. Specifically, the parsing preference for coordinate parallelism should lead comprehenders to predict a late-arriving prepositional gap in the second coordinate for the NP +parallel condition and a direct object gap in the second coordinate for the

Table 1
Sample materials set for Experiment 1. Filler phrases are indicated in bold. The primary active-filling region is indicated by double underlining. The gap is indicated by an underscore.

Filler category	Gap parallelism	Sentence
PP	+parallel	The harsh chemicals **with which** the technician sprayed the sensitive equipment ___ and prepared the sterile beakers ___ were manufactured in China
NP	+parallel	The harsh chemicals **which** the technician sprayed the sensitive equipment with ___and prepared the sterile beakers with ___ were manufactured in China
NP	−parallel	The harsh chemicals **which** the technician sprayed ___ and prepared the sterile beakers with ___ were manufactured in China

NP −parallel condition. Since the expectation for a direct object gap in the –parallel condition is violated due to the presence of the overt NP object, processing in this region is predicted to be more difficult in the −parallel condition than in the +parallel conditions, giving rise to a filled-gap effect. By contrast, if the CSC alone drives active dependency formation in coordinate extraction structures, as previously claimed (e.g., Wagers & Phillips, 2009), then we expect identical profiles in the second conjunct for the NP ±parallel conditions, since the CSC is satisfied in both of these conditions. This prediction should manifest in the test items exemplified in Table 1 as a filled gap effect at the direct object in the second conjunct in both the NP +parallel and –parallel conditions, since this is the first place the CSC could be satisfied.

Participants

Participants were 18 native speakers of English from the College of William & Mary (8 female and 10 male undergraduate students), and all were naïve to the purpose of the experiment. Each participant received credit in an introductory psychology or linguistics course. The experiment lasted approximately 30 min.

Materials

Eighteen sets of the form shown in Table 1 were constructed. All sentences involved ATB extraction from coordinated verb phrases (VPs), which were joined with the coordinating conjunctions *and* or *but* to ensure natural discourse coherence relations between the coordinates. The experiment manipulated filler category (PP- vs. NP-filler) and gap parallelism in sentences with an NP filler (+-parallel vs. −parallel). In the +parallel condition, both gaps occurred in a prepositional object position, satisfying parallelism. In the -parallel condition, the gap in the first coordinate occurred in direct object position, and the gap in the second coordinate occurred in prepositional object position, violating parallelism. The direct object NP in the second coordinate constituted the critical region because it is where the effect of gap parallelism on active processing can first be detected. Direct object NPs were always three word sequences of the form *determiner-adjective-noun*. Filler phrases were selected such that they were always semantically plausible as direct objects of the second coordinate verb to prevent biases against dependency formation at that position.

The 18 target sentences were distributed in a Latin Square design across 3 lists. Within each list, the 18 target sentences were combined with 36 grammatical filler sentences of similar length and complexity, for a total of 54 sentences. Across all items, comprehension questions addressed various parts of the sentence to ensure that participants would not adopt superficial reading strategies that would allow them to answer the question without reading the sentences in full. The full materials list for all experiments is given in the Supplementary materials.

Procedure

Sentences were presented on a desktop PC using the Linger software package (Rhode, 2003) in a moving window, self-paced reading display. Sentences were initially masked by dashes with white spaces and punctuation intact. Participants pushed the space bar to reveal each word. Presentation was non-cumulative, i.e., the previous word was replaced with a dash when the next word appeared. Each sentence was followed by a 'yes/no' comprehension question, and onscreen feedback was provided for incorrect answers. The order of presentation was randomized for each participant.

Analysis

Only data from participants with at least 85% accuracy on the comprehension questions for the test items were used in the analysis. One participant was removed from the data analysis due to poor comprehension accuracy. Self-paced reading times for experimental sentences were examined region-by-region, with sentences aligned word-for-word in each conjunct. Four regions of interest were defined. The first two regions of interest consisted of the verb and direct object NP in the first conjunct. All accounts of active processing predict a filled-gap effect in the direct object position in the first conjunct of +parallel NP-filler condition, and this region served as a baseline measure to show that comprehenders were engaged in active processing. The primary regions of interest were the corresponding regions in the second conjunct. In the second conjunct, the direct object NP region was used to examine the impact of parallelism on active processing, and is labeled as the "active filling" region in the data figures.

The Box-Cox procedure (Box & Cox, 1964) was used to determine that a natural log would be the appropriate transformation to obtain normally distributed residuals. Statistical analyses were carried out over the untrimmed, log-transformed reading time data using linear mixed-effects models. Models were estimated using the *lme4* package (Bates, Maechler, & Bolker, 2011) in the R software environment (R Development Core Team, 2014). Four orthogonal contrasts (C1-4) were defined: C1: the effect of filler type: PP vs. NP, C2: the effect of parallelism within NP fillers:+parallel vs. -parallel, C3: the filled-gap effect for parallel structures:+-parallel NP vs. baseline PP, and C4: the filled-gap effect for -parallel structures: -parallel NP vs. baseline PP. Items and participants were crossed as random effects, following Baayen, Davidson, and Bates (2008) and Barr, Levy, Scheepers, and Tily (2013). To determine whether inclusion of random slopes was necessary, a model that included random by-participant and by-item intercepts was compared with a model that included a fully specified (i.e., maximal) random effects structure with random intercepts and slopes for all random effects by-participant and by-item (Baayen et al., 2008; Barr et al., 2013). A log likelihood ratio test at the critical active-filling region revealed that the maximal model did not provide a better fit to the data in the critical region ($\chi^2_{(4)}$ = 5.41, p = 0.24). Therefore, the intercept-only model was adopted, and for consistency, the same model was applied to all regions of interest. For all statistical analyses reported in this paper, an effect was considered significant if its absolute t-value was greater than 2 (Gelman & Hill, 2007).

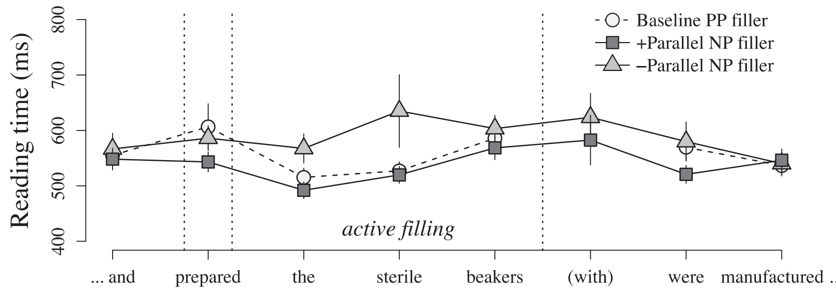

Fig. 1. Word-by-word reading times from the onset of the second VP to three regions beyond the active-filling region for Experiment 1. Error bars indicate standard error of the means.

Results

Fig. 1 presents the word-by-word condition means for the aligned second coordinate. The word-by-word condition means for the full sentences are reported in the Supplementary materials. No effects were observed at the first critical region in the first conjunct, i.e., the verb, ($\hat{\beta}$ = 0.02, SE = 0.03, t = 0.55). A filled-gap effect was observed at the direct object NP in the first conjunct, reflecting a slowdown for the +parallel NP-filler sentences relative to the baseline PP-filler condition ($\hat{\beta}$ = 0.08, SE = 0.03, t = 2.33). This effect indicates that participants were engaged in active processing. In the second conjunct, no effects were observed at the pre-critical verb region (C1: $\hat{\beta} = -0.02$, SE = 0.04, $t = -0.45$; C2: $\hat{\beta}$ = 0.01, SE = 0.04, t = 0.34; C3: $\hat{\beta} = -0.04$, SE = 0.04, $t = -1.12$; C4: $\hat{\beta} = -0.05$, SE = 0.03, $t = -1.46$). A filled-gap effect was observed for –parallel NP-filler sentences at the active filling region, carried by a slowdown for the –parallel NP-filler condition relative to the baseline PP-filler condition. This effect was statistically significant at the first two words of the active-filling region (*determiner*: $\hat{\beta} = 0.06$, SE = 0.03, t = 2.03; *adjective*: $\hat{\beta} = 0.09$, SE = 0.03, t = 2.74). No such effect was observed for +parallel NP-filler sentences, as reading times patterned with the PP-filler condition in the active-filling region (*determiner*: $\hat{\beta}$ = –0.04, SE = 0.03, $t = -1.28$; *adjective*: $\hat{\beta}$ = –0.01, SE = 0.03, $t = -0.30$; *noun*: $\hat{\beta} = -0.01$, SE = 0.03, $t = -0.17$). This difference was matched by a significant effect of parallelism within NP-filler sentences in the active-filling region at the active filling region, carried by a slowdown for the –parallel NP-filler condition relative to the +parallel NP-filler condition (*determiner*: $\hat{\beta} = 0.10$, SE = 0.03, t = 3.36; *adjective*: $\hat{\beta} = 0.11$, SE = 0.03, t = 3.05).

Discussion

Experiment 1 was designed to show that the search for multiple gap sites in sentences with coordinate extraction is driven by the expectation for coordinate parallelism. Results revealed that parallelism has a direct and immediate impact on active processing across conjuncts. A reading disruption associated with active object gap creation was observed at the filled-gap region ('active-filling' region) in the -parallel NP-filler condition relative to the control PP-filler condition, indicating that comprehenders anticipated parallel direct object gaps. No such effect was observed for the +parallel NP-filler condition, which suggests that comprehenders did not actively search for a direct object gap, as that gap assignment would violate parallelism.

A concern with the results of Experiment 1 is that the contrast between the ±parallel NP-filler conditions could reflect decay of the filler in the +parallel condition due to the increased length between the filler and second coordinate gap site, relative to the –parallel condition. It is unlikely that the observed contrast is due to decay for four reasons. First, in both conditions, the filler is reactivated at the first gap site immediately before the conjunct. From this point, the distance to the critical active filling region in the second coordinate is the same for both conditions, and decay should impact processing in the second coordinate similarly for both conditions. Second, if the observed contrast was due to decay of the filler, we would expect a difference between the +parallel NP and PP baseline conditions, which also differed in distance with respect to the filler-gap dependency. Yet, no differences between these conditions were observed in the second conjunct (ts < 2). Third, previous efforts to find direct evidence for decay in short term working memory have uncovered little or no effects (Badecker & Lewis, 2007; Berman, Jonides, & Lewis, 2009; Lewandowsky, Oberauer, & Brown, 2009). Fourth, previous studies using computational simulations have shown that decay cannot explain differences in memory-based dynamics during dependency formation for a range of syntactic dependencies, including reflexive-antecedent dependencies, negative polarity item licensing, and predictive processing for subject-verb agreement dependencies (Dillon, Mishler, Sloggett, & Phillips, 2013; Parker & Phillips, 2016), and there is no reason to believe that filler-gap dependencies should pattern differently with respect to these findings.

Another concern with the results of Experiment 1 is that the experimental items might have an alternative syntactic analysis involving V-level coordination, rather than ATB extraction. For instance, the string *sprayed and prepared* in the -parallel NP-filler condition could be initially analyzed as coordinated verbs with a single direct object, e.g., ... *the technician [[sprayed and prepared] the sterile beakers]* (see Boškovic & Franks, 2000, for an analysis of ATB involving head-level coordination). Although such structures are not permitted in prominent syntactic theories, such as X-bar theory (see Kayne, 1994 for arguments against V-level coordination), many grammatical frameworks, including Combinatory Categorical Grammar (Steedman, 2000), Head-driven Phrase Structure Grammar (HPSG; Pollard & Sag, 1994), and Lexical Functional Grammar (LFG; Bresnan, 2001), assume head-level coordination. Under this view, the processing disruption observed in the active filling region in the -parallel NP-filler condition might reflect disconfirmation of a syntactic analysis involving V-level coordination, rather than a filled-gap effect. This issue is addressed in Experiment 2.

Experiment 2

Experiment 2 had two goals. The first goal was to show that the effect of parallelism observed for phrasal coordination in Experiment 1 extends to more complex clausal coordination. Such findings would provide additional support for the claim that active dependency formation in coordinate extraction sentences is driven by the expectation for coordinate parallelism. The second goal was to confirm that the processing disruption observed in the –parallel NP-filler condition in Experiment 1 was due to active dependency formation, rather than disconfirmation of an alternative syntactic analysis involving V-level coordination. To this end, Experiment 2 attempted to replicate the results of Experiment 1 using ATB constructions with clausal (IP) coordination, which cannot be analyzed as V-level coordination. If the processing disruption observed in Experiment 1 reflects active processing, then the same processing disruption should be observed under similar conditions with clausal coordination. However, if the processing disruption reflects disconfirmation of a V-level coordination analysis, then no processing disruption is expected in the -parallel condition under clausal coordination, and all conditions should show the same processing profile in the second conjunct.

Participants

Participants were 69 native speakers of English who were recruited using Amazon's Mechanical Turk web service (37 Female, 33 Male, mean age = 37, education: high school degree or higher). Participation required an IP address in the United States, and each participant was screened for native speaker abilities. The screening probed participants' knowledge of the constraints on English tense, modality, morphology, ellipsis, and syntactic islands. The experiment lasted approximately 30 min, and each participant received $5 for participating in the experiment. Previous studies on filler-gap processing have shown that data received from lab-based and web-based participant samples are comparable (Wagers & Phillips, 2014). Nonetheless, several steps were taken to ensure that the web-based experiment would yield interpretable results. Participants were required to meet the following qualifications: location was restricted to the United States, HIT approval rate for all requesters' HITs was greater than or equal to 98, the number of HITs approved for each participant was greater than or equal to 5000, and participants were assigned a qualification after they completed the study that would prevent them from participating in the experiment more than once.

Materials

Eighteen item sets of the form shown in Table 2 were constructed. Experimental materials followed the same filled-gap design used in Experiment 1, but included coordinated clauses rather than coordinated VPs. The key difference between the materials used in Experiments 1 and 2 is that the materials used in Experiment 2 included a subject NP in the second coordinate to establish clausal coordination. The subject NP was held constant across conditions, and was syntactically parallel with the subject NP in the first conjunct.

The 18 target sentences were distributed in a Latin Square design across 3 lists, such that each participant read six sentences per condition. Within each list, the 18 target sentences were combined with 36 grammatical filler sentences of similar length and complexity, for a total of 54 sentences. Across all items, comprehension questions addressed various parts of the sentence to ensure that participants would not adopt superficial reading strategies that would allow them to answer the question without reading the sentences in full.

Procedure and analysis

Experiment 2 used self-paced reading, following the same procedure used in Experiment 1, with the exception that sentences were presented phrase-by-phrase. Phrase-by-phrase presentation was used to help ensure that any reading time effects would be

Table 2
Sample materials set for Experiment 2. Filler phrases are indicated in bold. The primary active-filling region is indicated by double underlining. The gap is indicated by an underscore. Slashes indicate phrasing used in the self-paced reading presentation.

Filler category	Gap parallelism	Sentence
PP	+parallel	The harsh chemicals/ **with which**/ [$_{IP}$ the technician/ sprayed/ the sensitive equipment/___] and/ [$_{IP}$ the scientist/ prepared/ <u>the sterile beakers/</u> ___] were/ manufactured/ in China/
NP	+parallel	The harsh chemicals/ **which**/ [$_{IP}$ the technician/ sprayed/ the sensitive equipment/ with/___] and/ [$_{IP}$ the scientist/ prepared/ <u>the sterile beakers/</u> with/ ___] were/ manufactured/ in China/
NP	−parallel	The harsh chemicals/ **which**/ [$_{IP}$ the technician/ sprayed/ ___] and/ [$_{IP}$ the scientist/ prepared/ <u>the sterile beakers/</u> with/ ___] were/ manufactured/ in China/

observed at the critical region, preventing variable spill-over effects due to potential artifacts from the web-based presentation. The phrasing used in Experiment 2 is indicated with slashes in Table 2. The experiment was conducted using the online experiment platform Ibex (Drummond, 2010), which allows self-paced reading experiments to be deployed in a standard web browser. To ensure that participants completed the task as directed, an instructional manipulation check was used (Oppenheimer, Meyvis, & Davidenko, 2009). Instructional manipulation checks ensure that participants are completing the task as directed by asking them to ignore the standard response format and provide a confirmation that they have read the instructions. Three participants were excluded from the analysis due to failure to respond correctly to the instructional manipulation check. In addition, 16 participants were excluded from analysis due to comprehension accuracy below 85%, yielding a total of 50 participants for analysis. Beyond these steps, data analysis followed the same steps as in Experiment 1.

Results

Fig. 2 presents the word-by-word condition means for the aligned second coordinate. The word-by-word condition means for the full sentences are reported in the Supplementary materials. No effects were observed at the first critical region in the first conjunct, i.e., the verb, ($\hat{\beta}$ = 0.01, SE = 0.02, t = 0.47). A filled-gap effect was observed at the direct object NP in the first conjunct, reflecting a slowdown for the +parallel NP-filler sentences relative to the baseline PP-filler condition ($\hat{\beta} = 0.08$, SE = 0.03, t = 2.21). This finding indicates that participants were engaged in active processing. In the second conjunct, no effects were observed at the pre-critical verb region (C1: $\hat{\beta} = -0.01$, SE = 0.04, t = −0.31; C2: $\hat{\beta} = -0.01$, SE = 0.03, t = −0.32; C3: $\hat{\beta} = -0.01$, SE = 0.02, t = −0.30; C4: $\hat{\beta} = 0.00$, SE = 0.02, t = 0.13). A filled gap effect was observed for –parallel NP-filler sentences at the active filling region, reflecting a slowdown for –parallel NP-filler conditions relative to the baseline PP-filler condition ($\hat{\beta} = 0.12$, SE = 0.03, t = 3.08). No such effect was observed for +parallel NP-filler sentences, as reading times patterned with the PP-filler condition in the active-filling region ($\hat{\beta} = -0.01$, SE = 0.03, t = −0.20). This effect was matched with a significant effect of parallelism within NP-filler sentences at the active filling region, carried by a slowdown for the –parallel NP-filler condition relative to the +parallel NP-filler condition in the active-filling region ($\hat{\beta} = 0.12$, SE = 0.03,

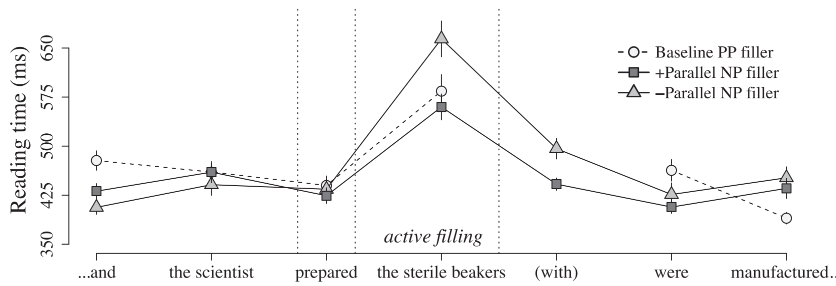

Fig. 2. Word-by-word reading times from the conjunction to three regions beyond the active-filling region for Experiment 2. Error bars indicate standard error of the means.

$t = 3.08$). This effect persisted into the following region ($\hat{\beta} = 0.06$, SE = 0.02, $t = 2.29$). No other effects were observed.

Discussion

Experiment 2 was designed to show that the effect of parallelism observed for phrasal coordination in Experiment 1 extends to more complex clausal coordination, and that the processing disruption observed in the –parallel NP-filler condition in Experiment 1 was due to active dependency formation, rather than disconfirmation of an alternative syntactic analysis involving head-level coordination. Experiment 2 replicated the findings for Experiment 1. The -parallel NP-filler conditions showed a filled-gap effect in the active-filling region, which suggests that comprehenders expected parallel direct object gaps. No such effect was observed for the +parallel NP-filler condition, which suggests that comprehenders did not expect a gap in the direct object position, as this would violate parallelism. These results favor a view in which the processing disruption in the –parallel NP-filler condition in Experiment 1 was an index of active processing, rather than the result of re-analysis, since the same filled-gap profile was observed when a single-gap analysis was not possible.

Taken together, the results of Experiments 1 and 2 show that parallelism has a direct and immediate impact on active dependency formation for both phrasal and clausal coordination. Specifically, the current results suggest that based on the expectation for coordinate parallelism, the parser uses the location of the gap in the first conjunct to narrow down the search for the second gap site in the second conjunct. These findings provide the first evidence of its kind that comprehenders use parallelism to guide active dependency formation.

On the view that parallelism reflects a general processing factor, e.g., template reuse, syntactic priming, etc. (Frazier et al., 2000; Knoeferle, 2014; Knoeferle & Crocker, 2009), the results from Experiments 1 and 2 suggest that active dependency formation for coordinate extraction is not driven by grammatical constraints, at least not by the CSC alone (e.g., Wagers & Phillips, 2009), but rather by general processing factors governing coordinate parallelism. Recall that the CSC predicts identical profiles for the ±parallel NP-filler conditions, but this is not what Experiments 1–2 showed. Instead, a filled gap effect was observed at the direct object only in the–parallel NP-filler condition, as predicted by a processing account based on parallelism.

However, the current results do not license the sweeping generalization that grammatical accounts play no role in active dependency formation for coordinate extraction. Although it is typically assumed that the internal structure of conjuncts is not grammatically regulated (Frazier & Clifton, 2001; Frazier et al., 2000), formal syntactic accounts argue that coordinate extraction is subject to a parallelism licensing constraint, which requires that the gap sites be in parallel positions (Hornstein & Nunes, 2002; Kasai, 2004; Pesetsky, 1982; Williams, 1978). Arguments for a grammatically-based parallelism constraint are based, in part, on the observation that in languages with overt morphological case marking, a single filler cannot be linked to conflicting case values simultaneously in each conjunct (Borsley, 1983; Dyła, 1984). Under this view, active processing might be driven by a grammatically-based constraint that strongly encourages parallel gaps. Importantly, this account is compatible with previous proposals that active dependency formation relies on grammatical licensing requirements (e.g., Wagers & Phillips, 2009). This issue is addressed in Experiment 3.

Experiment 3

Experiments 1 and 2 showed that parallelism provides a strong constraint on active processing in sentences with coordinate extraction. However, the source of this effect remains unclear. On the one hand, the effect could reflect a general processing preference for parallelism (Frazier & Clifton, 2001; Frazier et al., 2000). On the other hand, it could be attributed to a grammatically-based constraint that strongly encourages parallel extraction (Borsley, 1983; Dyła, 1984; Hornstein & Nunes, 2002; Kasai, 2004; Pesetsky, 1982; Williams, 1978). Experiment 3 was designed to test whether the parallelism effect observed in Experiments 1–2 can be reduced to processing factors. To determine the effect of parallelism independently, the stimuli used for Experiment 2 were compared against the corresponding non-ATB sentences, which involved separate fillers in each conjunct, but were still subject to a parallelism contrast. This design was first used by Sturt and Martin (2016) in an eye-tracking experiment to determine whether the preference for ATB extraction from positions with parallel grammatical functions in sentences like (9) is due to processing factors or a grammatical constraint on parallel extraction.

(9) a. +Parallel, +ATB: The surgeon who James tricked ___, and Richard annoyed ___, scrubbed up for surgery.
b. –Parallel, +ATB: The surgeon who ___ tricked James, and Richard annoyed ___, scrubbed up for surgery.
c. +Parallel, −ATB: The surgeon who ___ tricked James, and who Richard annoyed ___, scrubbed up for surgery.
d. −Parallel, −ATB: The surgeon who ___ tricked James, and who Richard annoyed ___, scrubbed up for surgery.

Sturt and Martin reasoned that if parallelism is due to general processing factors, then the parallelism effect for ATB and non-ATB sentences should be comparable, i.e., of equal magnitude. On the other hand, if parallelism is due to grammatical constraints, then the parallelism effect for ATB sentences might be stronger than the baseline parallelism preference revealed by the corresponding non-ATB sentences. Sturt and Marin observed different profiles for ATB and non-ATB sentences: both ATB and non-ATB sentences showed an effect of parallelism, but the effect was larger in the ATB sentences. Based on these findings, Sturt and Martin

Table 3
Sample materials set for Experiment 3. Filler phrases are indicated in bold. The active-filling region is indicated by double underlining. The gap is indicated by an underscore. Slashes indicate phrasing used in the self-paced reading presentation.

Parallelism	Sentence
+ATB, +parallel	The harsh chemicals/ **which**/ [$_{IP}$ the technician/ sprayed/ the sensitive equipment/ with/___] and/ [$_{IP}$ the scientist/ prepared/ the sterile beakers/ with/ ___] were/ manufactured/ in China/
+ATB, −parallel	The harsh chemicals/ **which**/ [$_{IP}$ the technician/ sprayed/ ___] and/ [$_{IP}$ the scientist/ prepared/ the sterile beakers/ with/ ___] were/ manufactured/ in China/
−ATB, +parallel	The harsh chemicals/ **which**/ [$_{IP}$ the technician/ sprayed/ the sensitive equipment/ with/___] and/ **which**/ [$_{IP}$ the scientist/ prepared/ the sterile beakers/ with/ ___] were/ manufactured/ in China/
−ATB, −parallel	The harsh chemicals/ **which**/ [$_{IP}$ the technician/ sprayed/ ___] and/ **which**/ [$_{IP}$ the scientist/ prepared/ the sterile beakers/ with/ ___] were/ manufactured/ in China/

argued that parallelism for grammatical functions in ATB sentences cannot be reduced to processing factors, and instead may be due to grammatical constraints. Experiment 3 used the same design to provide a study-internal test for the role of a grammatically-based parallelism constraint, and to determine whether the contrast that Sturt and Martin observed for grammatical functions extends to grammatical categories, as tested in Experiments 1 and 2.

Participants

Participants were 80 native speakers of English who were recruited using Amazon's Mechanical Turk web service (37 Female, 43 Male, mean age = 36, education: high school degree or higher). Each participant received $5 for participating in the experiment, and was screened for native speaker abilities.

Materials

Experimental materials consisted of the same ±parallel NP-filler items from Experiment 2, combined with the corresponding non-ATB sentences, as shown in Table 3. The –ATB sentences involved a filler for each conjunct, and hence did not involve ATB extraction, but included a parallelism contrast that was used to determine the baseline effect of the parallelism preference for the coordinated IPs used in Experiment 2. The 18 target sentences were distributed across 4 lists. This method does not result in a fully balanced Latin Square design. However, the goal of Experiment 3 was to determine the baseline parallelism preference in the specific items from Experiment 2, motivating the current design. Within each list, the 18 target sentences were combined with the same 36 filler sentences from Experiment 2, for a total of 54 sentences.

Procedure and analysis

Experiment 3 used self-paced reading, following the same procedure and analysis methods as in Experiment 2. Linear mixed-effects modeling included orthogonally coded fixed effects for parallelism (+parallel vs. –parallel) and sentence type (+ATB vs. –ATB) and their interaction, as well as random intercepts for participants and items (Baayen et al., 2008). As in Experiments 1–2, all analyses were carried out over the untrimmed, log-transformed reading time data.

Results

Fig. 3 presents the word-by-word condition means for the second coordinate of the –ATB sentences, and Fig. 4 presents the word-by-word condition means for the aligned second coordinate of the +ATB sentences. The word-by-word condition means for the full sentences are reported in the Supplementary materials. No effects were observed at the pre-critical verb region, e.g., *prepared*, (parallelism: $\hat{\beta} = 0.01$, SE = 0.00, $t = 1.11$; sentence type: $\hat{\beta} = 0.01$, SE = 0.00, $t = 1.65$; interaction: $\hat{\beta} = -0.00$, SE = 0.00, $t = -0.50$). In the critical active-filling region, a main effect of parallelism was observed, carried by a slowdown in reading times for the −parallel conditions relative to the +parallel conditions ($\hat{\beta} = 0.06$, SE = 0.01, $t = 6.34$), and a main effect of sentence type ($\hat{\beta} = 0.02$, SE = 0.01, $t = 2.25$). Crucially, there was also an interaction of parallelism and sentence type ($\hat{\beta} = 0.02$, SE = 0.01, $t = 2.12$). Planned pairwise comparisons revealed that the parallelism effect was larger for +ATB sentences than –ATB sentences (mean effect sizes: +ATB 172 ms vs. –ATB 58 ms; +ATB: $\hat{\beta} = 0.09$, SE = 0.01, $t = 6.25$; −ATB: $\hat{\beta} = 0.05$, SE = 0.01, $t = 3.32$).

Discussion

The goal of Experiment 3 was to determine whether the parallelism effect observed in Experiments 1–2 could be reduced to a general processing preference for coordinate parallelism. To achieve this, the ATB stimuli from Experiment 2 were compared against the corresponding non-ATB sentences to obtain a baseline measure of the processing preference for parallelism. The results from Experiment 3 showed that the stimuli used in the current study are in fact subject to a basic parallelism preference, indicated by a significant effect of parallelism in the non-ATB sentences. However, the magnitude of the parallelism effects differed by sentence type. The parallelism effect observed in ATB sentences was significantly larger than the baseline parallelism effect shown in the corresponding non-ATB sentences. These results replicate those reported by Sturt and Martin (2016), who also found a larger parallelism effect for ATB sentences than for the corresponding non-ATB sentences. One critical difference between the two studies is that Sturt and Martin (2016) examined the effect of parallel grammatical functions, whereas the current study examined the effect of parallel grammatical categories. Thus, the current findings demonstrate that findings reported by Sturt and Martin extend to a wider range of ATB configurations. Taken together, these data suggest that the parallelism effect observed for ATB sentences cannot be reduced to general processing factors, and instead, may reflect a grammatically-based constraint that strongly encourages parallel extraction from coordinate structures. This proposal is developed further in the General Discussion.

General discussion

Summary of results

The goal of the present study was to investigate the source and scope of active dependency formation in sentences with coordinate

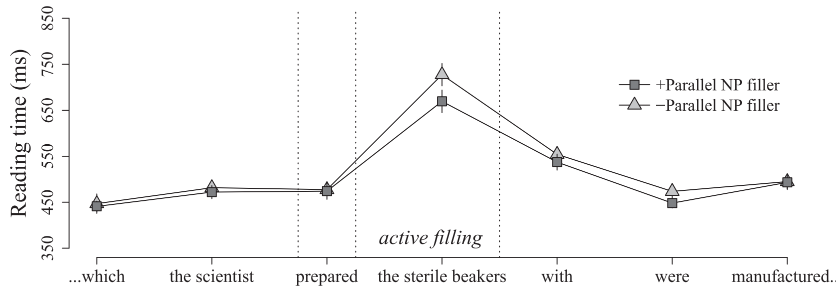

Fig. 3. Word-by-word reading times from the filler to three regions beyond the active-filling region for the –ATB conditions from Experiment 3. Error bars indicate standard error of the means.

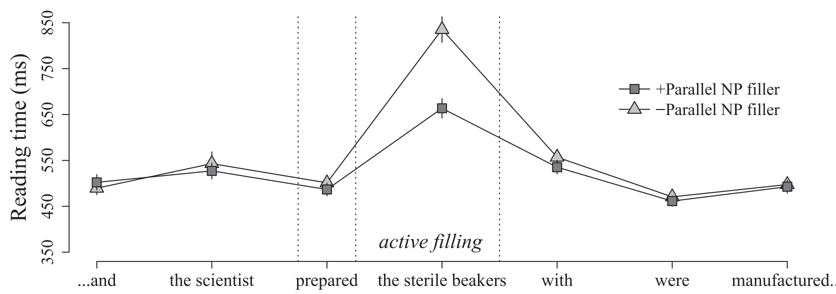

Fig. 4. Word-by-word reading times from the conjunction to three regions beyond the active-filling region for the +ATB conditions from Experiment 3. Error bars indicate standard error of the means.

ATB extraction. Previously, it has been claimed that active dependency formation in ATB sentences is driven by the need to satisfy grammatical constraints, such as the CSC, as rapidly as possible during real-time comprehension (Wagers & Phillips, 2009). An alternative account suggests that active processing in ATB sentences is motivated by general processing considerations, such as the expectation for coordinate parallelism. Experiments 1 and 2 addressed this debate by testing whether parallelism can prompt active dependency formation across ATB conjuncts. Experiment 1 showed that encountering the conjunction in ATB sentences involving coordinated VPs does in fact trigger the expectation of parallel gaps, demonstrating that parallelism has a direct and immediate impact on active dependency formation at the phrasal level. Experiment 2 replicated the findings from Experiment 1, by showing that the parallelism effect extends to more complex clausal coordination. These results confirm that the parser uses parallelism to structure its expectations about upcoming gap locations in sentences with coordinate extraction.

Experiment 3 examined the source of the parallelism effect. It is typically assumed that the internal structure of conjuncts is not grammatically regulated, and that parallelism effects in coordinate processing are the product of general processing principles (Frazier & Clifton, 2001; Frazier et al., 2000). However, some formal syntactic accounts argue that coordinate extraction is subject to a parallelism licensing constraint, which requires that the gap sites be in parallel positions (Borsley, 1983; Dyła, 1984; Hornstein & Nunes, 2002; Kasai, 2004; Pesetsky, 1982; Williams, 1978). To distinguish these accounts, Experiment 3 compared the stimuli from Experiment 2 against the corresponding non-ATB structures to obtain an independent baseline measure of the preference for parallelism in the current materials. Results from Experiment 3 revealed that the parallelism effect for ATB sentences is larger than the parallelism preference revealed by the corresponding non-ATB sentences. These results suggest that the parallelism effect observed for ATB sentences cannot be reduced to general processing principles, favoring a grammatical account of parallelism in ATB sentences.

The source and scope of active dependency formation

The results of the current study have important implications for existing theories of active dependency formation. In particular, the current study is the first of its kind to show that comprehenders use parallelism to guide active dependency formation. It has been argued that parallelism in coordinate structures is an instance of prediction, since parallel structures are most predictable in coordinate structures (Frazier & Clifton, 2001; Frazier et al., 2000; Knoeferle & Crocker, 2009), and it has been shown that the expectation of parallelism in coordinate structures impacts incremental structure-building operations during real-time comprehension (Knoeferle & Crocker, 2009). The results of the current study extend previous findings by showing that parallelism also has a direct and immediate impact on active dependency formation, and that the parser uses parallelism to structure its expectations about the location of upcoming gap sites in sentences with coordinate extraction.

In addition, the results of the current study help us better understand how much structure the parser is willing to project in advance of the input. Many studies have shown that the parser generates local predictions about the syntactic, semantic, and phonological properties of the next word or phrase in the input based on previously processed material (e.g., Altmann & Kamide, 1999; DeLong, Urbach, & Kutas, 2005; Federmeier & Kutas, 1999; Kamide, Altmann, & Haywood, 2003; Kimball, 1975; Meyer & Federmeier, 2007; Van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005; Wlotko & Federmeier, 2007). Several studies have also shown that comprehenders can reliably anticipate the syntactic category of the second conjunct in sentences with coordinated phrases (e.g., Staub & Clifton, 2006), and actively project a clausal skeleton (e.g., Yoshida et al., 2013). The results of the current study extend previous findings by showing that the parser is capable of actively projecting a fully-fledged clausal skeleton upon encountering the coordinating conjunction, and can use parallelism to accurately predict the specific position of a gap within this skeleton, e.g., [S [NP] [VP [V NP] [PP [P __]]]].

These results imply that predictive structure building mechanisms are more flexible and powerful than assumed by existing theories of structure building, e.g., left-corner parsers or recursive descent procedures that permit top-down prediction (e.g., Johnson-Laird, 1983; Lewis & Vasishth, 2005). In a left-corner parser, encountering the first constituent of a phrase in the bottom-up input triggers a prediction of the subsequent constituents of that phrase. For instance, given a context free rule like VP → V NP, a left-corner parser will project the upcoming NP node upon detecting a transitive verb. However, the structural details of the NP cannot be specified until the bottom-up input for that constituent is encountered. This strategy thus allows for some degree of syntactic prediction. But, it cannot capture the structural predictions observed in Experiments 1 and 2. As just noted, Experiments 1 and 2 suggest that the parser can accurately predict a prepositional object gap upon encountering the preceding verb, if not earlier, based on the expectation for gap parallelism. Even if we assume an expanded context free rule like VP → V NP PP, the structural details of the PP, such as the object gap, cannot be projected at the verb until further bottom up input is received. Furthermore, it is not clear how to ensure that the left corner parser will predict the correct gap location in the second conjunct, since the prediction for the prepositional object gap is based on non-local information from the first conjunct, which is no longer available to guide left-corner parsing routines at the point of the second conjunct. It may be possible to capture the current findings by expanding the memory and control state of a left corner parser to track outstanding predictions, such as open filler-gap dependencies, and the expectation of parallelism. However, this functionality is not available in current left-corner parsing models.

The source and scope of parallelism effects in sentence comprehension

The current findings also have important implications for existing theories of parallelism processing. First, the current results help us better understand what aspects of parallelism are carried forward after a conjunct is encountered. Existing accounts have shown that rather coarse-grained information about general constituent order guides parallelism processing (see Knoeferle & Crocker, 2009, for discussion). The results of Experiments 1 and 2 extend previous results by showing that the parser maintains detailed information about the grammatical features of the filler, such as the syntactic category, e.g., PP vs. NP, as well as detailed information about verb subcategorization frame from the first conjunct, e.g., *spray NP* vs. *spray NP with NP*, to guide predictive structure-building decisions. These results present a challenge for current memory-based accounts of sentence comprehension that assume a stringent limit on the amount of information that can be actively maintained in working memory over the span of the sentence (McElree, 2001; Nicol, Fodor, & Swinney, 1994; Nicol & Swinney, 1989). An important task for future research would be to determine what other types of information under parallelism are maintained across a sentence, and whether there is a privileged role for parallelism with regards to the types of information that are maintained.

Second, the results of the current study suggest that parallelism effects do not solely reflect processing factors, at least in the case of coordinate extraction. Existing accounts of coordinate processing have attributed parallelism effects to general processing principles, such as structural priming, template re-use, or a special parallelism mechanism (Frazier & Clifton, 2001; Frazier et al., 2000; Knoeferle, 2014; Knoeferle & Crocker, 2009). In contrast, the results from Experiment 3 revealed that the parallelism effect observed for ATB sentences is larger than the baseline parallelism preference revealed by the corresponding non-ATB sentences, as shown in Fig. 5 (see also Sturt & Martin, 2016, for similar findings).

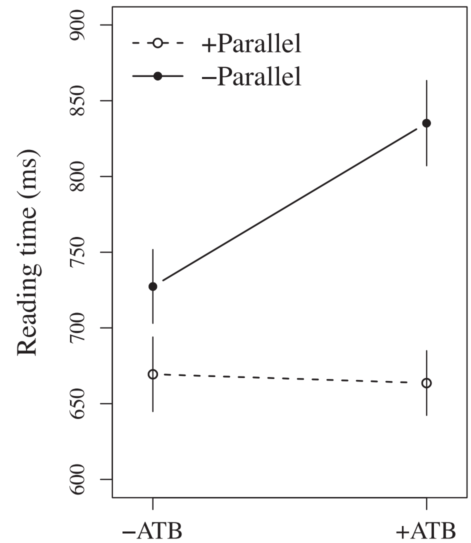

Fig. 5. Direct comparison of the parallelism effects for +ATB and −ATB sentences from Experiment 3. Error bars indicate standard error of the means.

The finding that the parallelism effect for ATB sentences is larger than the baseline parallelism preference revealed by the non-ATB sentences suggests that additional factors beyond processing principles are likely responsible for the parallelism effect in ATB sentences. I argue that the parallelism effect observed in ATB sentences reflects a grammatically-based constraint that strongly encourages parallel extraction in coordinate structures (see also Sturt & Martin, 2016, who make the same argument based on a related set of findings). This account can be grounded in the formal syntactic literature, where it is argued that coordinate extraction is subject to a parallelism licensing constraint that requires parallel gaps in coordinate extraction structures (Borsley, 1983; Dyła, 1984; Hornstein & Nunes, 2002; Kasai, 2004; Pesetsky, 1982; Williams, 1978). The motivation for this constraint comes from languages with overt case marking, where a single filler cannot be linked to conflicting case markings simultaneously in each conjunct (Borsley, 1983; Dyła, 1984). Although there are exceptions to this rule (see de Vries, 2017, for discussion), some form of this constraint is likely deployed to guide initial predictive structure building processes in coordinate extraction structures.

Taken together, the results of Experiments 1–3 extend existing grammatical accounts of active processing (e.g., Aoshima et al., 2004; Phillips, 2006; Pritchett, 1992; Wagers & Phillips, 2009; Yoshida et al., 2013) by showing that grammatical licensing requirements provide a stronger constraint on active dependency formation than previously assumed. For instance, Wagers and Phillips (2009) argued that the CSC drives the active search for multiple gap sites in coordinate extraction structures. However, a grammatical account based on CSC alone cannot explain the current results, as this account incorrectly predicts identical profiles for the NP ±parallel conditions, contrary to what was shown in Experiments 1–2. The current results show that the parser not only actively searches for multiple gap sites in coordinate structures, in accordance with the CSC, but also uses grammatical licensing requirements on parallelism to actively search for gap sites in specific positions. In particular, the results from Experiments 1–3 showed that active dependency formation can be suspended in the search for a late-arriving prepositional gap to satisfy the grammatically-based constraint on parallelism, leading the parser to ignore potential gap sites in earlier positions that would normally be considered if parallelism was not involved. Under this view, grammatically-based parallelism constraints allow the parser to fine tune its expectations, leading to more precise predictions than shown in previous work. These results, along with the previous findings, motivate a strong argument that grammatical constraints play a prominent role in active processing.

Lastly, the current proposal opens several lines of inquiry for future research. One question concerns the linguistic properties of coordination that are carried forward after the conjunct is encountered. For instance, it remains unclear what other types of linguistic information beyond filler category and verb subcategorization frame are maintained to satisfy parallelism. A related question concerns the relationship between ATB structures and other structures that are subject to a grammatical parallelism constraint. For instance, it is well known that for ellipsis, the antecedent and the ellipsis site must be parallel, though there are competing proposals regarding how to formulate this parallelism requirement and how it might impact real-time sentence processing (see Phillips & Parker, 2014, for discussion). One task for future research would be to determine whether parallelism impacts active processing in ellipsis sentences like it does in ATB sentences. Crucially, the current proposal predicts a contrast between cases where parallelism reflects a processing preference, such as in basic coordination and subordinate clause contexts (e.g., Sturt et al., 2010), and cases where parallelism reflects a grammatical constraint, such as in ATB and ellipsis contexts.

Conclusion

The current study investigated whether the parser uses parallelism to structure its expectations about upcoming gap locations in sentences with coordinate extraction. Experimental findings showed that parallelism has a direct and immediate impact on active dependency formation, restricting the search for upcoming gap sites down to specific locations. Importantly, such effects cannot be reduced to processing factors or a preference for parallelism, but may be due to a grammatically-based constraint that strongly encourages parallel extraction. Together, these results contribute to the growing body of literature showing that the parser makes detailed predictions, and strengthen existing arguments that grammatical constraints play a prominent role in parallelism processing and active dependency formation.

A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jml.2017.08.003.

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