Information Compression via Eliding Verb Phrase: A Dependency-Based Study

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Abstract

Verb Phrase Ellipsis (VPE) is an anaphoric construction in which a verb phrase has been elided. It is a common linguistic feature that we use to facilitate effective communication. The current research has adopted a quantitative method that combines dependency grammar and information theory, trying to figure out the quantitative features of the form-meaning mismatch caused by VPE. The current research found that: (1) VPE simplifies the sentence structure, and the simplification process is demonstrated by the decrease of dependency distance after ellipsis; (2) VPE facilitates language communication by retaining the information content. Overall, VPE simplifies the language form but not the information to be transmitted, and the effort-saving effect promotes the trade-off between language form and information content. The current research strengthens the idea that the function of VPE is to ease human communication through compressing information. Together, these results provide important insights into the effect of the least-effort principle that though VPE has achieved simplification in dependency structure, and the language adaptive system nonetheless remains the fidelity of information to be transmitted.

1 Introduction

The ellipsis is a common linguistic feature in human natural language. Most studies on the ellipsis mechanism were carried out empirically from the aspect of psycholinguistic experiments. They are concerned with the ellipsis effect on human language comprehension by utilizing a wide range of experimental techniques, including speed-accuracy trade-off (Martin and McElree, 2008, 2009, 2011), reading time (Yoshida et al., 2012), event-related potentials (Kaan et al., 2004; Martin et al., 2012), and so on. Among the previous studies, most of them investigated factors (e.g., the size of the ellipsis antecedent, the distance to the antecedent) to the effort of resolving ellipsis (i.e., language comprehension). There are also some studies that explore the role of ellipsis mechanism itself. Some consider ellipsis as a tool for discourse construction. It may, for example, disambiguate discourse structure (Hendriks and Spenader, 2005) and improve discourse coherence (Halliday and Hasen, 1976). Overall, ellipsis is one of the mechanisms that human beings utilized to facilitate more effective communication. The essence of human communication is information exchange. As Merchant claims (2019), ellipsis structures have a form-meaning mismatch due to the absence of expected syntactic components. In other terms, the relationships that underpin the trade-off between ellipsis structure and information transmission deserve exploration. Nonetheless, few previous studies have focused on the function of ellipsis on information exchange. A considerable amount of literature with qualitative analysis has been published on discussing such form-meaning mismatch, such as the classification of ellipsis (Merchant, 2010; Quirk et al. 1985), the generation mechanism of ellipsis (Chomsky and Lasnik, 1993; Merchant, 1999; Sag, 1976), the resolution of ellipsis (Hardt, 1993; Nielsen, 2005), etc. Nevertheless, a quantitative understanding of such a phenomenon is still lacking. To this end, the current research attempts to figure out the quantitative features of ellipsis from an information-theoretic perspective.

Methodologically, the present study adopted a text-based approach which is purely conducted from the perspective of texts with ellipsis

constructions. The research was based on the investigation into the elided sentences and their full-form counterparts in natural human language. Our small-scale treebank is annotated using the Dependency Grammar (DG) theoretical framework (Tesnière, 2015). DG is a syntactic theoretical framework that focuses on the close but uneven syntactic relationships that exist between words (Liu, 2009). This paper examines the mismatch of form and meaning quantitatively, in the aspect of the information-theoretic approach which measures the entropy of sentences as a representation of information content (Bentz and Alikaniotis, 2016). Intuitively, the rationale for such application underpins some common interests between information theory and linguistics (Dębowski and Bentz, 2020). We proposed that due to the effort-saving trend in language use, ellipsis mechanism has taken the role of facilitating information transmission through simplifying the sentence structure while still retaining the information content. Consequently, the study aims to answer two questions:

Question 1: How does VPE influence the sentence structure?

Question 2: How does the information content vary comparing the elided sentences and their full form counterpart?

The organization of the paper is as follows: section 2 introduces the text materials, the methodology, and the theoretical framework. Section 3 describes the statistical results of the comparison between language form and information content of elided sentences and their full-form counterparts. Section 4 presents the concluding remarks.

2 Materials and Methods

2.1 Preliminaries: VP Ellipsis

Among the elliptical mechanisms, the verb phrase ellipsis is one of the most extensively studied omission phenomena in linguistics (Sag, 1976; Williams, 1977), indicating a kind of constituent ellipsis where the omitted element is a complete verb phrase (Schäfer, 2021). The term demonstrates the anaphoric process where a verbal constituent is partially or totally unexpressed but can be restored through its verb phrase (VP) antecedent in the context. The

elliptical vacancy is the target of ellipsis, while the context being the ellipsis antecedent is the source of ellipsis. VPE does not occur freely and manifests itself in English when verb phrases are abbreviated to an auxiliary verb (do, be, have, modal verbs) or deleted in an infinite clause (Bos, 2012). These constitute different licensing conditions for VPE. See case (1) for illustration, and the sentence in case (1) was extracted from Wall Street Journal Corpus (WSJ).

(1) *Sounds great*, or **does** it [*sound great*]? (WSJ_1574)

In case (1), the auxiliary verb escorting the elided VP is typeset in boldface, and the antecedent is in italic. Besides, the antecedent was "replicated" and then moved to brackets, namely the ellipsis target site. Necessary adjustments were made according to the syntactic domain of the auxiliary verb for making the non-elliptical counterpart grammatical.

2.2 Materials

In this paper, we took the Wall Street Journal Corpus (WSJ) in the Penn Treebank as the material source. To ensure recall precision and accuracy, the present study built the VPE collection based on Bos and Spenader (2011)'s stand-off annotations to VPE in WSJ. For practical reasons, we detected 343 sentences with VPE structures from WSJ altogether. Within the scope of this article, the detection principle goes as follows:

a. Avoid cases that are morphologically similar to VPE. Structures like *do-it*[1], *do-so* and *do-the-same*, etc. would be excluded from our collection. Such structures are argued as being principally different from VPE (Nielsen, 2005). See case (2) with the *do-anaphora* structure.

(2) The banks have 28 days to *file an appeal against the ruling* and are expected to **do so** [*file an appeal against the ruling*] shortly. (WSJ_0117)

b. Each identified sentence has only one VPE occurrence.

c. The source and target of ellipsis are in the same sentence instead of two different sentences. Examples like (3) where the source and target of

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[1] Some may argue that "do-it" is the same as the "does it" in the case (1). However, "it" in "do-it" presents the object, while in "does it", "it" functions as the subject.

ellipsis are separated into two complete sentences would be removed from our collection as well.

(3) I *owe that contractor*. I really **do** [~~owe that contractor~~]. (WSJ_0766)

In the end, we identified 5 kinds of auxiliary types, namely *do*, *be*, *have*, *modal* and *to*. The closest VP that occurs before the elided VP was considered as the antecedent. Besides, we adjusted the verb inflection in the target of VPE within various syntactic domains. See case (1) for further illustration. We took the nearest VP *sounds great* as the antecedent of the target of VPE. Within the syntactic domain of the ellipsis licensor *does*, we changed the verb of the antecedent VP into the original form, that is, *sound great*.

2.3 Methods

Both the VPE and its counterpart collections are parsed and analyzed under the theoretical framework of Dependency Grammar (DG). According to DG, one of the two words acts as the governor and the other as the dependent. Figure 1 graphically depicts the major features of a syntactic dependency relation: a binary and asymmetrical relation between two linguistic units; the type of a dependency relation is usually indicated through a label on top of a connected directed arc linking the two units (Liu, 2009).
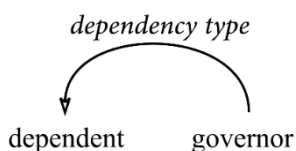

Figure 1: Three elements of dependency

The syntactic structure or dependency structure of case (1) can be represented as a connected directed acyclic graph shown in Figure 2. The dependency structures are labeled with Penn Treebank part-of-speech tags and phrasal labels (de Marneffe and Manning 2008).
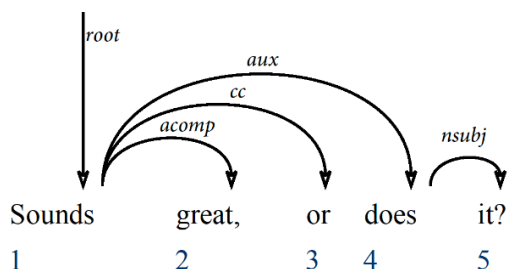

Figure 2: Dependency structure of case (1).

Dependency distance (DD) refers to the linear distance between two linguistic units with a syntactic relationship (Heringer et al., 1980; Hudson, 1995; Liu et al., 2017; Liu, 2022). It may reflect the syntactic complexity as well as the memory burden of language processing (Hudson, 1995; Liu, 2008). The correlation between linear order and comprehension difficulty, mostly examined in response time in psycholinguistics, has been widely discussed among cognitive domains (Gibson, 1998, 2000; Grodner and Gibson, 2005). Hudson (1995) defines DD as "the distance between words and their parents (or heads), measured in terms of intervening words." Liu et al. (2009) propose a more formalized method for calculating the DD of sentences or texts. In a word string $W_1...W_i...W_n$, the dependency distance between a governor W_a and its dependent W_b can be defined as their position difference: 'a-b'. Therefore, adjacent words have a DD of 1. In this study, we adopt the absolute value of DD in this study.

Entropy, which originated from information theory, was developed as a measure of randomness and uncertainty in a text by Shannon (Shannon, 1948, 1951). As an indicator of information content, entropy includes the frequency information of words, for Daller et al. (2007) suggested that the word frequency distribution is an important feature to examine language and language use.

The entropy reflects the average information content of words. We here adopted the definition of word in Bentz et al. (2016), where they define a word as a unigram: a string of alpha-numeric Unicode characters delimited by white spaces. Let T be a text that is drawn from a vocabulary of word types $V = \{w_1, w_2, ..., w_v\}$ of size V = $|V|$. The estimation of entropy of a text T is calculated with the formula (1) as follows:

$$H(\text{T}) = -\sum_{i=1}^{V} \text{P}_i \log_2 \text{P}_i \qquad (1)$$

where V is the total number of word types in a text, P_i stands for the probability of each type in the text (estimated by its relative frequency), $-\log_2 P_i$ refers to the self-information for each type, and $-P_i\log_2 P_i$ is its mathematical expectation. The entropy of a text is the sum of mathematical expectations of all types.

Each VPE sentence together with its non-elliptical counterpart was annotated in CoNLL-U format according to DG through the Stanford Parser (version 3.4) with the annotation scheme of Stanford Typed Dependencies (SD) (de Marneffe and Manning, 2008). SD is adopted because it is

more congruent with dependency syntactic analyses than Universal Dependencies (Osborne and Gerdes, 2019; Yan and Liu, 2019). Following the methods, 343 pairs of sentences are annotated automatically and then manually checked by the authors.

Tables 1 and 2 demonstrate the dependency analyses of the sample sentence case (1) and its non-elliptical counterpart, respectively.

Table 1: Simplified CoNLL-U version of the sample sentence case (1)

Word Order	Word	POS	Head	DEP REL	DD
1	Sounds	VERB	0	root	0
2	great	AMOD	1	acomp	1
3	,	PUNCT	/	/	/
4	or	CC	1	cc	3
5	**does**	**AUX**	**1**	**aux**	**4**
6	it	PRON	5	nsubj	1
7	?	PUNCT	/	/	/

Table 2: Simplified CoNLL-U version of the counterpart of sample sentence case (1)

Word Order	Word	POS	Head	DEP REL	DD
1	*Sounds*	*VERB*	*0*	*root*	*0*
2	*great*	*AMOD*	*1*	*acomp*	*1*
3	,	PUNCT	/	/	/
4	or	CC	1	cc	3
5	**does**	**AUX**	**7**	**aux**	**2**
6	it	PRON	5	nsubj	1
7	***sound***	***VERB***	***1***	***advcl***	***6***

|					
8	*great*	*AMOD*	*7*	*acomp*	*1*
9	?	PUNCT	/	/	/

Based on the dependency annotated structures, we would quantify the changes in sentence structure. Since the sentence length of VPE sentences and their counterparts vary, we did not choose mean value of DD of each sentence due to the sentence length effect (Jiang and Liu, 2015). The DD difference value (DDD) between the ellipsis sentences and their non-elliptical counterparts would be captured, showing the syntactic complexity discrepancy between them. Given that non-elliptical counterparts are simply full forms of elliptical sentences, the DDD is purely caused by ellipsis. Thus, this indicator may well capture the features of ellipsis resolution efficiency. The value of DDD between VPE sentences and their counterparts can be calculated as follows:

$$DDD = SUM\ (DD_{non\text{-}elliptical\ counterpart}) - SUM\ (DD_{VPE}) \quad (2)$$

3 Results and Discussion

The dependency distance distribution of each VPE group was demonstrated in figure 3, from which the resultant effort-saving mechanism of VPE is clear: the line indicating DD distributions of VPE sentences are lower than that of their counterparts.

In order to get a more precise result, we have calculated the difference of syntactic complexity between the elided sentences and their counterparts with the DDD which are computed in dependency distance. The mean value of DDD is 11.503 and the standard deviation is 9.659, indicating a large difference between our VPE sentences and their non-elliptical counterparts. The positive value of DDD confirmed the simplification effect of VPE on sentence structure.
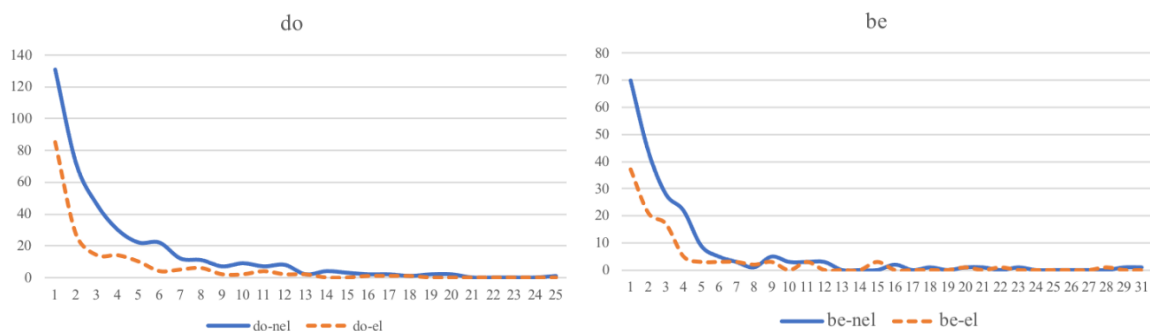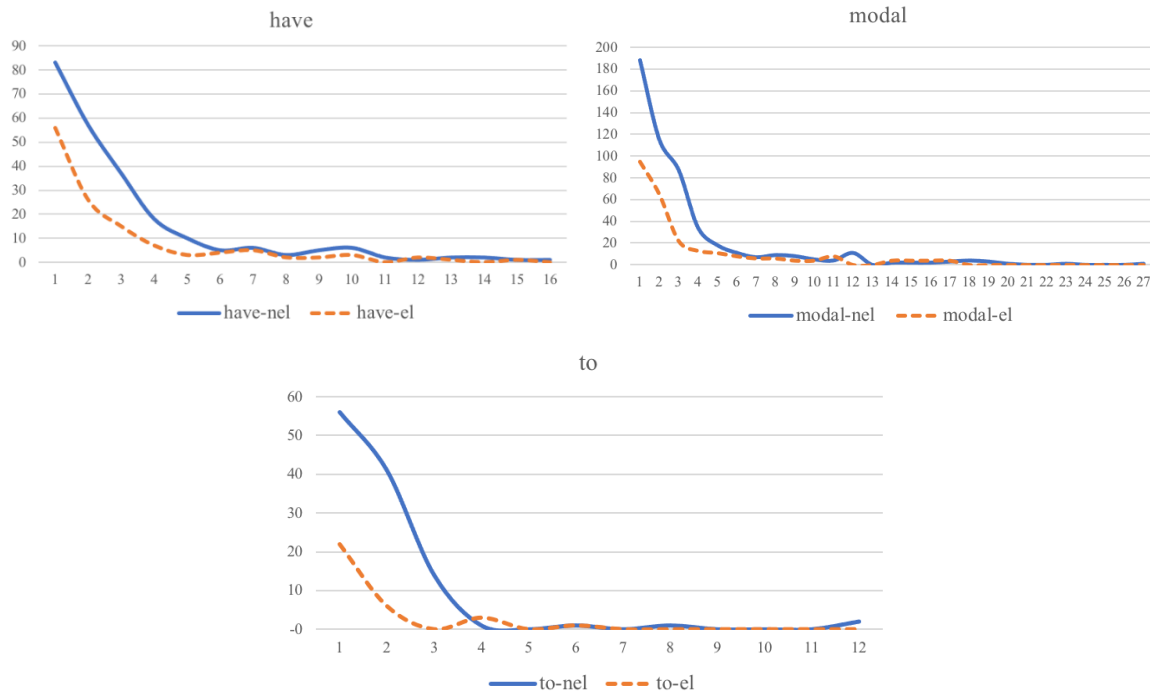
Figure 3: DD distribution of VPE sentences and their non-elliptical counterparts licensed by auxiliary verbs

In terms of information content in each VPE group, figure 4 illustrates the distribution of information content between VPE and its counterpart. To analyze whether there exists a significant difference in information content between these two groups, we have conducted a paired-samples T-test for each pair of ellipsis group. First, we found that for all the VPE type and all the *do* type of VPE, the information content between elided sentences and non-elided counterparts are not significantly different (Sig. of all = .723, df = 342; Sig. of do = .927, df = 171). The fact suggested that VPE can facilitate language communication with simplification of language form but still retains the information content in the non-elided sentences. Ellipsis simplifies sentence structure but not the information content. The result confirmed that one of the functions of ellipsis is compressing the information to be transmitted. According to Zipf (1949), it is the human instinctive inclination to reduce one's efforts in language expression. To put it another way, the concept of economy in speaking or writing language might be seen as the driving force behind ellipsis. Therefore, we supposed the least-effort principle guides the VPE in language communication. Since the result of DDD indicated the effort-saving mechanism in

dependency structure, the results reconfirmed that VPE simplifies the language form by compressing the information. According to information theory, there is a trade-off between the degree of compression and the fidelity of the recovered signal (Norris and Kalm, 2021). For instance, the most familiar examples of lossy compression are MP3 encoding of audio signals and JPEG encoding of images. We apply compression algorithm to save file storage on a computer disk. Likewise, we may utilize ellipsis mechanism to decrease the burden of cognition. Consequently, the rationale for studying ellipsis, on the other hand, is the preconceived notion that ellipsis is regulated by the "principle of least effort" (Bîlbîie, 2011). This point of view is now widely accepted as the mainstream explanation for ellipsis (Hendriks and Spenader, 2005). Language is a human-driven complex adaptive system (Liu, 2018) and also an important tool for information transmission. The effort-saving effect promotes the trade-off between language form and information content. Together, these results may provide important insights into the effect of the least-effort principle that though VPE has achieved simplification in dependency structure, language adaptive system nonetheless remain the fidelity of information to be transmitted.
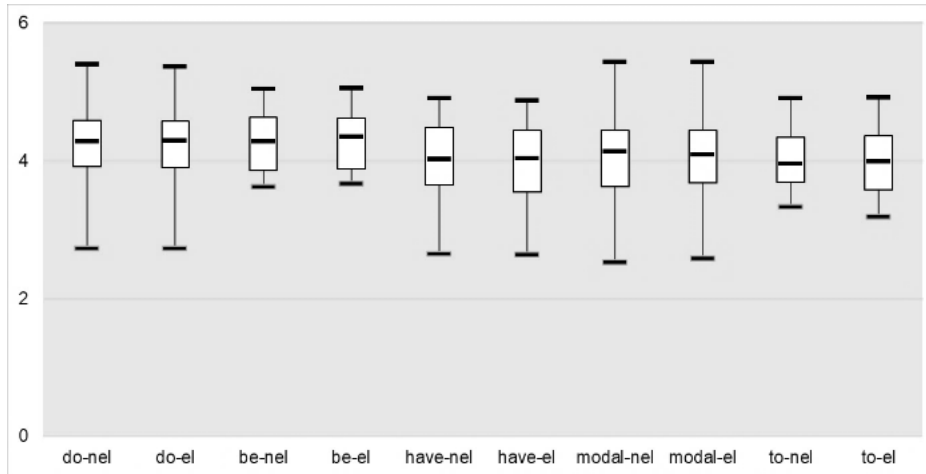
Figure 4: Box-plot of information content of each VPE group and their non-elliptical counterparts

In order to further investigate the different VPE strategies, we conducted a more fine-grained analysis of information content shift in different VPE groups. Consequently, paired samples T-tests have been performed to different VPE strategies and their counterparts. The fine-grained analysis got some interesting results that though most VPE strategies remain the information content unchanged, two strategies could significantly influence the information content. The T-test result in VPE *be* group and *to* group demonstrated significant difference (Sig. of *be* = .000, df = 30; Sig. of *to* = .021, df = 23). We found that the information content in *be* group is significantly increased while in *to* group decreased after the VPE process. Bos and Spenader (2011) annotated and found over 480 instances of VPE in the Wall Street Journal. They indicated VPE *be* group and VPE *to* group are two prominent types of ellipsis. Kenyon-Dean (2016) followed a similar annotation scheme and investigated the distinctive features of these VPE forms. We suggested that the distinction of information content in these two groups is caused by the different ellipsis processes. We noticed that in VPE *be* group, the source of ellipsis is always presented in the form of participle. The process of ellipsis in VPE *be* group is homogenous: as simple as directly deleting the to-be omitted verb phrase in the ellipsis site, without altering other parts of the sentences. Hence, the eliding process of VPE *be* group implies a significant compression of information content by directly flattening the word frequency distribution, causing more uncertainty in language comprehension. Consequently, the result demonstrated a significant increase in information content after the eliding process of VPE *be* group. By contrast, the VPE *to* group performs a distinct ellipsis process. It is noteworthy that most of the verb phrases in VPE *to* group endure inflection in the source of VPE. As we mentioned in section 2, with a "to" indicating an infinitive, the source of ellipsis should be adjusted the inflection to fulfill the syntactic constraint in the target of VPE. Therefore, the ellipsis process in VPE *to* group is not as direct as the one in VPE *be* group. The eliding process of VPE *to* group combines not only the deletion of verb phrase but also the inflectional adjustment of that. Due to most cases in VPE *to* group have experienced the inflection, the influence of ellipsis may help to avoid performing inflections of verb phrases in VPE *to* group. The process decreases the uncertainty in sentence comprehension, thereby help to reduce the information content. However, in other VPE mechanisms, we found the two processes, as a pair of opposite forces, both take effect, making the difference between the elliptical sentences and their counterparts not significant.

4 Conclusion

In this paper, we adopted an information-theoretic approach to quantitatively investigate the effect of VPE on both language form and information content. The current research found that: (1) through the difference between the dependency distance of elided sentences and their counterpart, we demonstrated that ellipsis simplifies the sentence structure; (2) the function of VPE is to facilitate language communication through compressing the information to be transmitted; (3) two kinds of VPE mechanism would cause significant variation in information content due to distinct ellipsis process. However, it should be pointed out that the comparatively small sample size of VPE *be* group and VPE *to* group may possibly limit the generalizability of the two

distinct ellipsis processes. Overall, this study strengthens the idea that ellipsis simplifies sentence structure but not the information content. The findings in the current research may provide insights into the functions of ellipsis and try to establish a preliminary application of information theory to a linguistic study.

Acknowledgments

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