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Processing correlates of verb semantic complexity in argument realization

Tun Hao, The Hong Kong University of Science and Technology (Guangzhou), China, haotun@hotmail.com

Predicate decomposition and construction grammar are two competing approaches to verb semantic representation. Both are syntactically useful in argument realization, but they make contradictory predictions of verb semantic complexity. The predicate decomposition approach hypothesizes that accomplishment verbs (e.g., *break*) are conceptually more complex than activity verbs (e.g., *sweep*). In contrast, the constructional approach hypothesizes that three-participant-role verbs (e.g., *sweep*) are more complex than two-participant-role verbs (e.g., *break*). To test these hypotheses, two experiments are reported in this paper. Experiment 1 investigates the activation of verb representation in lexical access by a lexical decision task. The results show that three-role verbs take significantly longer reaction times than two-role verbs, whereas there is no significant difference between accomplishment verbs and activity verbs. Experiment 2 examines the access and use of verb semantics in sentence processing by a self-paced reading task. The results show that three-role verbs yield significantly longer reading times than two-role verbs, whereas there is no significant reading time difference between accomplishment verbs and activity verbs. The above findings jointly suggest that the participant role is a better indicator of verb semantic complexity and, thus, is more likely to be stored in verb representation and accessed during language processing.

1 Introduction

Verbs exhibit a varied but restricted range of argument realization. The variation and restriction involve not only the number and type of arguments but also the possible combinations of arguments. Take the verb *sweep* for example. It can take one argument (1a), two arguments (1b) and three arguments (1e, f); it can take an agent, a patient, a result, a theme, and a goal argument (1a, b, e, f); and it can take a theme preceding a preposition and a goal (1f), but not the inverse (1g), or separately (1c, d).

(1) a. Pat swept.
b. Pat swept the floor.
c. *Pat swept the crumbs.
d. *Pat swept onto the floor.
e. Pat swept the floor clean.
f. Pat swept the crumbs onto the floor.
g. *Pat swept onto the floor the crumbs.

To generalize such variation, most linguistic models assume that argument structure can be predicted from verb meaning, although to varying degrees. Such assumptions are explicitly specified in, for example, the Principles and Parameters framework (Chomsky 1981: 29, 38), Lexical-Functional Grammar (Kaplan & Bresnan 1995: 65), Role and Reference Grammar (Foley & Van Valin 1984: 183), and Construction Grammar (Goldberg 1995: 50). Extensive research has therefore focused on verb sematic representation. In previous studies, verb meaning has been argued to be represented by semantic roles (Gruber 1965; Fillmore 1968; Jackendoff 1972; 1976) and their variants (Dowty 1991; Van Valin & LaPolla 1997), and more recently, by decomposed predicates (Jackendoff 1983; Croft 1991; Rappaport Hovav & Levin 1998) and by participant roles (Goldberg 1995).

Questions then have been raised about what kind of information is exactly encoded in verb meaning to predict argument structures. Even though these various theoretical approaches to verb semantic representations may successfully generalize the linguistic reality in argument realization, it remains unclear what speakers and comprehenders actually know and use about verb meaning in language processing. Thus, this paper explores the psychological reality of two mainstream theories of verb semantic representation in theories of argument realization by testing their hypotheses about verb semantic complexity.

In this paper, I first summarize the predicate decomposition approach and the constructional approach to verb semantic representation. I demonstrate that both approaches serve to predict argument structures, but they make distinct hypotheses on verb semantic complexity. Then, I examine these hypotheses in the real-time processing of verbs (Experiment 1) and sentences containing those verbs (Experiment 2). Finally, I discuss the theoretical implications of these experiments.

1.1 The predicate decomposition approach to verb semantics

Predicate decomposition is a dominant approach to verb semantics, and it is widely adopted in generative theories. The predicate decomposition approach assumes that verb meaning can be decomposed into primitive predicates and constants. Primitive predicates are the structural part of verb meaning, and they represent the grammatically relevant aspects of verb meaning. Verbs that share the same primitive predicate are supposed to behave syntactically and morphologically alike. Constants, also known as roots (Pesetsky 1995), are the idiosyncratic part of verb meaning. They differentiate one verb from the others that share the same structural meaning. Under such an assumption of verb meaning, instantiations of predicate decomposition theory differ mainly in which aspect of events is emphasized in constructing the grammatically relevant part of meaning. The localist approach focuses on the motion and location in events (Jackendoff 1972; 1976; 1983; 1987; 1990); the causal approach highlights the causal relation and the transmission of force between event participants (Langacker 1987; 1991; 1994; Croft 1991; 1994; 1998; 2012); and the aspectual approach centers on the temporal properties of events (Vendler 1957; Tenny 1994; Van Valin & LaPolla 1997; Rappaport Hovav & Levin 1998; Van Valin 2005). Among these approaches, the localist approach is meant to provide an account of certain instances of systematic polysemy and preposition distribution, and it does not aim to account for argument realization per se. In contrast, the causal approach and the aspectual approach are designed to solve the problem of argument realization. Since the transfer of force and the temporal order can both be represented by the notion of precedence, these two approaches often end up using quite similar semantic representations for verbs. However, as will be argued shortly in Section 1.2, the aspectual approach makes explicit predictions of verb semantic complexity, so the rest of this section focuses on this specific approach.

The aspectual approach to verb semantics can be dated back to the long tradition of categorizing verbs based on lexical aspect (also known as *Aktionsart*) in both linguistics and philosophy. The current study does not try to cover the full richness and depth of the vast literature on lexical aspect, but rather discusses the aspectual approach with a special emphasis on its applications in argument realization. The aspectual predicate decomposition approach to verb semantics generalizes verb meaning by the aspectual properties that were developed primarily based on Vendler's (1957) four verb aspectual classes – states, activities, achievements, and accomplishments. Generally, states describe events that do not involve change (e.g., *know, believe*); activities describe events that have no inherent temporal endpoints (e.g., *run, laugh*); achievements describe events that are punctual and have inherent temporal endpoints (e.g., *realize, discover*); and accomplishments describe events that are durative and have inherent temporal endpoints (e.g., *build, fix*). According to this classification, verbs are represented by lexical semantic templates, as shown in (2).

(2) a. state: $[\text{x} < \mathit{STATE} >]$
b. activity: $[\text{x ACT}_{<\mathit{MANNER}>}]$
c. achievement: $[\text{BECOME} [\text{x} < \mathit{STATE} >]]$
d. accomplishment: $[[\text{x ACT}_{<\mathit{MANNER}>}] \text{ CAUSE } [\text{BECOME } [\text{y} < \mathit{STATE} >]]]$
$[\text{x CAUSE } [\text{BECOME } [\text{y} < \mathit{STATE} >]]]$
(Rappaport Hovav & Levin 1998: 108)

Primitive predicates are represented by nonitalics. The combinations of primitive predicates in a language constitute a fixed inventory of lexical semantic templates. Additionally, because these combinations often define the ontological types of events, they are also referred to as event structure templates. Constants are represented by the capitalized italics in angle brackets. The set of constants in a language is open-ended, but each constant can be categorized into a fixed set of ontological types (e.g., manner, state). Constants determine the basic association with event structure templates and the number of event participants of verbs. A variety of other aspectual classifications have been proposed since Vendler (1957). They either superimpose a different organization on these classes or further subdivide them into smaller categories. For example, Smith (1991) and Engelberg (1999) proposed a fifth class, the semelfactives, and Van Valin and LaPolla (1997) and Van Valin (2005) subdivided each of the four basic categories into a noncausative version and a causative version. However, none of these are radically different from Vendler (1957).

The aspectual representation of verb meaning has an important consequence in argument realization. Consider the following examples:

(3) a. John swept.
b. John swept the floor.

(4) a. *John broke.
b. John broke the dishes.

Sweep is an activity verb, and is represented as (5) under the aspectual approach.

(5) sweep: $[\text{x ACT}_{<\mathit{SWEEP}>} \underline{\text{y}}]$

This event structure has one subevent. There are two participants in this subevent: a structural participant, the *sweeper* (marked as ‘x’), which is defined as licensed by both the constant and the event structure, and a content participant, the *swept* (marked as ‘$\underline{\text{y}}$’), which is defined as licensed by the constant only. To map this representation to the argument structure, the aspectual approach proposes two well-formedness conditions on syntactic realization: the Subevent Identification Condition (6) and the Argument Realization Condition (7).

(6) Subevent Identification Condition (SIC): Each subevent in the event structure must be identified by a lexical head (e.g., a V, an A, or a P) in the syntax (Rappaport Hovav & Levin 1998: 112).

(7) Argument Realization Condition (ARC): There must be an argument XP in syntax for each structure participant in the event structure (Grimshaw & Vikner 1993: 144; van Hout 1996: 201; Kaufmann & Wunderlich 1998: 25; Rappaport Hovav & Levin 1998: 113).

The SIC aligns predicates with subevents, and the ARC aligns subevents with arguments. In example (3), the verb *sweep* identifies one subevent ensuring that the SIC is met. The structural participant is expressed in (3a) and (3b) so that both sentences satisfy the ARC. In addition, the constant participant, *the floor*, can be recovered with a prototypical understanding; thus, both (3a) and (3b) are acceptable. In this way, the predicate decomposition approach successfully predicts the argument structures in (3a) and (3b) through the aspectual representation of *sweep*.

In contrast, *break* is an accomplishment verb, and is represented as (8) under the aspectual approach.

(8) break: [[x ACT$_{<MANNER>}$] CAUSE [BECOME [y $<$*BROKEN*$>$]]]

This event structure has two subevents: a causative activity and a change of state. Each subevent further contains one structural participant: the *breaker* (marked as ‘x’) and the *broken* (marked as ‘y’), which are licensed by the constant and the event structure. The verb *break* identifies both subevents ensuring that the SIC is met. According to the ARC, the structural participants need to be obligatorily expressed. Thus, only (4b) is acceptable, not (4a). In this way, the predicate decomposition approach successfully predicts the argument structure in (4b) and rejects the argument structure in (4a) through the aspectual representation of *break*.

In sum, for predicate decomposition theory, argument realizations of verbs can be predicted by the aspectual event structures in the lexical semantic representations of verbs. Verbs with different aspectual representations, such as *sweep* and *break,* are supposed to project differently to argument structures.

1.2 Semantic complexity under the predicate decomposition approach

Under the aspectual predicate decomposition approach, an event is argued to be complex when the temporal relation between its subevents is not necessarily aligned (Levin & Rappaport Hovav 1999; 2005).[1] For example, *John thawed the meat*. It contains two subevents: *John caused* and *the meat thawed*. This is a complex event in the sense that these subevents do not have to continue for the same temporal duration. John could simply take the meat out of the fridge and do something else while it thaws.

[1] There have been other hypotheses about event complexity in predicate decomposition theory. For example, Pustejovsky (1991; 1995) and van Hout (1996; 2000a; 2000b) argue that an event is complex when it is aspectually telic. Levin and Rappaport Hovav’s hypothesis is adopted here because it is syntactically more meaningful in argument realization. See the discussion below.

By this criterion of event complexity, it is hypothesized that accomplishment verbs such as *break* are conceptually more complex than activity verbs such as *sweep* (Levin & Rappaport Hovav 1999). Note that these accomplishment verbs do not include incremental theme verbs (Dowty 1991), such as verbs of consumption (e.g., *eat, drink),* and verbs of creation (e.g., *write, build*).[2] Incremental theme verbs are analyzed as accomplishments in the sense that they involve an event with a duration and endpoint. However, these activities inherently coexist with the change of state. That is, the two subevents in these event structures are necessarily aligned. Therefore, they are predicted to have a simple, rather than a complex event (Levin & Rappaport Hovav 2004).

This hypothesis of event complexity is syntactically meaningful in, for example, explaining the sharp discrepancies between English resultatives as (9) and (10).

(9) a. The river froze solid.
b. *The river froze itself solid.

(10) a. *The professor talked hoarse.
b. The professor talked herself hoarse.

It is argued that sentences in (9) denote a simple event because the subevent of freezing and the subevent of becoming solid necessarily coexist with each other, while the sentences in (10) denote a complex event because the subevent of talking and the subevent of becoming hoarse do not necessarily coexist with each other. Therefore, according to the ARC, a "fake" reflexive is required in (10b) to qualify the sentence as grammatical but not in (9b) (Rappaport Hovav & Levin 2001).

The hypothesis of verbs as event-structure-taking functions has received supportive evidence in language processing studies. Gennari and Poeppel (2003) conducted a lexical decision task, a self-paced reading task, and found that eventive verbs (i.e., activities, achievements and accomplishments) take longer to respond to than stative verbs. McKoon and Macfarland (2000; 2002) performed two timed acceptability judgement tasks, two timed reading comprehension tasks and a lexical decision task. They reported that externally caused change-of-state verbs (accomplishments) take a longer time to respond to than internally caused change-of-state verbs (achievements). Moreover, McKoon and Love (2011) carried out a lexical decision task, a timed acceptability task and a stop making sense task. They concluded that externally caused change-of-state verbs (accomplishments) take longer to respond to than activity verbs, which directly supports the semantic complexity hypothesis discussed above.

[2] Verbs of consumption and creation are considered as the accomplishment use of activity verbs; thus, they are classified as active accomplishments in Van Valin and LaPolla (1997) and Van Valin (2005).

1.3 The constructional approach to verb semantics

Construction grammar is a family of theories that take constructions as the fundamental building blocks in languages. There are various instantiations of construction grammar that share a similar assumption about the constructional nature of language knowledge but emphasize slightly different aspects in their goals. For example, Cognitive Construction Grammar (Goldberg 1995) looks into argument realization and its psycholinguistic implications; Radical Construction Grammar (Croft 2001) describes language with a strong typological orientation; Sign-Based Construction Grammar (Sag & Boas & Kay 2012) is centrally concerned with the precise formalization of languages; and Embodied Construction Grammar (Bergen & Chang 2013) and Fluid Construction Grammar (Steels 2017) aim at the computational formalism of constructions.

Instead of looking into the internal structure of verb meaning as in the predicate decomposition approach, construction grammar assumes that each sense of a verb is conventionally associated with the frame semantic meaning that specifies certain participant roles (Goldberg 1995: 43; 2002: 342; 2006: 39). Participant roles are frame-specific event participants. They differ from traditional semantic roles mainly in two aspects: first, participant roles are concrete concepts that are closely related to the scenes described by verbs rather than abstract generalizations across different verbs; second, participant roles, therefore, are open-ended, which are defined by individual verbs rather than a predetermined fixed set of roles. A subset of participant roles, namely the lexically profiled roles, are obligatorily expressed (Goldberg 1995: 45) or, if unexpressed, must receive a definite interpretation (Goldberg 2002: 342; 2005b: 225). For example, the participant roles of *hand* in the sense of cause-receive are the *hander,* the *handee* and the *handed* (11) in which all three roles are profiled (marked in bold).

(11) hand: <**hander handee handed**>

Moreover, the most unique feature of construction grammar is that it takes construction as the primitive language unit. Constructions are generally defined as conventionalized pairings between form and meaning (or function) in a language (Goldberg 1995; 2006; 2013; 2019). Argument structure constructions are associated with argument roles, which roughly correspond to traditional semantic roles or thematic roles, such as agent, patient, instrument, theme, or location (Goldberg 1995: 43; 2002: 342; 2005b: 225; 2005a: 23; 2006: 39). Argument roles that are linked to a direct grammatical relation (SUBJ, OBJ, or OBJ2) are considered constructionally profiled (Goldberg 1995: 48; 2002: 343; 2005b: 225). The psychological reality of constructions has been supported by an increasing amount of evidence from language acquisition (Goldberg & Casenhiser & Sethuraman 2004; Casenhiser & Goldberg 2005; Goldberg & Casenhiser & White 2007; Boyd & Gottschalk & Goldberg 2009; Suttle & Goldberg 2011; Boyd & Goldberg 2012; Goldberg 2016; Perek 2016; Perek & Goldberg 2017; Robenalt & Goldberg 2015) and language processing (Ahrens 1995; Bencini & Goldberg 2000; Kaschak & Glenberg 2000; Goldberg &

Casenhiser & Sethuraman 2005; Kako 2006; Goldwater & Markman 2009; Allen et al. 2012; Johnson & Goldberg 2013; Johnson & Turk-Browne & Goldberg 2015).

The representation of verb participant roles has a great impact on argument realization under construction grammar. Take the same set of example sentences discussed in Section 1.1, for instance (repeated below):

(12) a. John swept.
b. John swept the floor.

(13) a. *John broke.
b. John broke the dishes.

Sweep is a three-participant-role verb, and it is represented as (14) under the constructional approach. The participant roles are the *sweeper*, the *swept* and the *sweep.tool*, in which the first two are lexically profiled.

(14) sweep: <**sweeper swept** sweep.tool>

Fusion is the interaction between verbs and argument structure constructions. It captures the simultaneous constraints on participant roles and argument roles in argument realization. In sentences (12a) and (12b), the verb *sweep* fuses with an intransitive construction and a transitive construction, respectively. The fusion is restricted by the Semantic Coherence Principle (15) and the Correspondence Principle (16).

(15) Semantic Coherence Principle (SCP): Only roles which are semantically compatible can be fused.

(16) Correspondence Principle (CoP): Each participant role that is lexically profiled and expressed must be fused with a profiled argument role of the construction (Goldberg 1995: 50; 2002: 342; 2005a: 225–226; 2005b: 25; 2006: 39–40).

The SCP ensures that participant roles and argument roles are semantically compatible, and the CoP ensures that participant roles and argument roles are pragmatically compatible. Likewise, the Lexical Constructional Model (Ruiz de Mendoza Ibáñez & Mairal Usón 2008; Butler 2009; Mairal Usón & Ruiz de Mendoza 2009; Ruiz de Mendoza Ibáñez & Mairal usón 2011; Ruiz de Mendoza Ibáñez 2013; Butler & Gonzálvez-García 2014: 118–125) has developed a more refined set of constraints, both internal and external to the fusion process. The internal constraints take the form of licensing or blocking factors that depend on lexical class ascription, lexical-constructional compatibility, and either predicate or internal variable conditioning of external variables. The external constraints result from the possibility or impossibility of performing high-level metaphoric and metonymic operations on the lexical items involved in the subsumption (fusion) process.

In sentence (12b), the sweeper, *John,* fuses with the agent argument, and the swept, *the floor*, fuses with the patient argument so that the SCP is met. The lexically profiled roles, namely, *John* and *the floor*, realize as the constructionally profiled argument roles so that the CoP is satisfied. Therefore, sentence (12b) is acceptable. In sentence (12a), although the swept, *the floor,* is a profiled role, it can receive a definite interpretation in the context, and as long as it is not the focus of the sentence, then it is omissible. Therefore, sentence (12a) is also acceptable. In this way, the constructional approach successfully predicts the argument structures in (12a) and (12b) through the participant-role representation of *sweep*.

In contrast, *break* is a two-participant-role verb,[3] and it is represented as (17) under the constructional approach. The two participant roles are the *breaker* and the *broken,* and both are lexically profiled.

(17) break: <**breaker broken**>

In sentences (13a) and (13b), the verb *break* fuses with an intransitive construction and a transitive construction, respectively. In sentence (13b), the breaker, *John,* fuses with the agent argument, and the broken, *the dishes,* fuses with the patient argument so that the SCP is met. The lexically profiled roles, namely, *John* and *the dishes*, realize as the constructionally profiled argument roles so that the CoP is satisfied. Therefore, sentence (13b) is acceptable. In (13a), the lexically profiled role of the verb *break*, the *broken*, is not realized. The intransitive construction lacks an argument role for the verb *break* to realize its lexically profiled roles, which violates the CoP. Sentence (13a) is therefore unacceptable. In this way, the constructional approach successfully predicts the argument structure in (12a) and rejects the argument structure in (12b) through the participant-role representation of *break*.

In sum, for the constructional approach, the argument realizations of verbs are predicted by the fusion between the participant roles of verbs and the argument roles of argument structure constructions. Verbs with different numbers and profiling statuses of participant roles, such as *sweep* and *break,* are supposed to fuse differently with argument structure constructions.

1.4 Semantic complexity under the constructional approach

Under the constructional approach, a verb is hypothesized to be complex when it has more participant roles than others. That is, three-participant-role verbs such as *sweep* are conceptually more complex than two-participant-role verbs such as *break*. This hypothesis of event complexity is syntactically meaningful in argument realization because the number of participant roles is an important determinant of fusion. Take the case of the English resultatives again, for example.

(18) a. The waiter wiped the table clean. (wipe: <**wiper wiped** wipe.tool>)
b. The professor talked herself hoarse. (talk: <**talker**>)

[3] Although the verb *break* can take an instrument component in a sentence, e.g., *Kim broke the window with a baseball bat*, unlike the case of *sweep*, the tool here is contributed by the argument structure. It is not a participant role, in the sense that a tool is not felicitously involved in a *break* event. For more information, please refer to the discussion of “Mismatches of roles” in Goldberg (1995: 52–56).

Sentences in (18) are instances of the resultative construction with a three-participant-role verb *wipe*, and a one-participant-role verb *talk*. In (18a), the verb *wipe* inherently contributes a semantically compatible participant role, the *wiped,* to fuse with the patient object of the resultative construction. In contrast, in (18b), the verb *talk* lacks such a participant role; thus, according to the CoP and SCP, a "fake" reflexive *herself* is augmented to fill in the patient object position in the construction (Goldberg & Jackendoff 2004). This expression is motivated by external constraints that result from high-level metaphorical and metonymic operations (Ruiz de Mendoza Ibáñez & Mairal Usón 2008; Peña-Cervel 2016). The metaphor involved here is A VERBAL PROCESS/A VERBAL PROCESS AS A FORM OF BEHAVIOUR IS A MATERIAL CONTACT PROCESS. This implies that the verb *talk* is metaphorically construed as a material contact process in which the talker becomes the actor and the verbal process of talking corresponds to a material contact process such as *wipe.* Furthermore, the metaphor provides a goal, *herself*, and a result, *hoarseness*. In addition, the metonymy involved here is MANNER FOR VERBAL PROCESS/ VERBAL PROCESS AS FORM OF BEHAVIOUR. This implies that the manner, which is conflated into the meaning of *talk*, stands for the whole matrix domain of the verbal process of talking.

The hypothesis of verb as participant-role-taking functions has received supportive evidence in language processing studies as well. Ahrens and Swinney (1995) conducted a cross-modal lexical decision showing a significant reaction time difference between verbs with different numbers of participant roles. Following this study, Ahrens (2003) performed a sentence-continuation lexical decision task indicating that verbs with more participant roles take a longer time to integrate into sentences. These findings have consistently supported the hypothesis that verbs with more participant roles are more complex in sentence processing.

In summary, the predicate decomposition approach and the constructional approach are two competing theories of verb semantic representation. Both approaches are syntactically meaningful in predicting argument structures and supported by language processing evidence. However, the two approaches make distinct hypotheses of verb semantic complexity. The predicate decomposition approach hypothesizes that accomplishment verbs (e.g., *break*) are more complex than activity verbs (e.g., *sweep*). On the contrary, the constructional approach hypothesizes that three-participant-role verbs (e.g., *sweep*) are more complex than two-participant-role verbs (e.g., *break*). The experiments reported below thus test these hypotheses in lexical access (Experiment 1) and sentence processing (Experiment 2) using reaction time as an indicator of semantic complexity. It is assumed that the representation of verbs is derived from the experience of real-world situations and language use. The semantic representation of verbs is a generalization of the events and scenarios associated with the verb. Thus, understanding a verb online recruits the representation of the corresponding events and scenarios. Following previous work on the semantic representation of verbs (McRae & Ferretti & Amyote 1997; McRae et al. 1997; McKoon & Macfarland 2000; 2002; e.g., Ferretti & McRae & Hatherell 2001; Gennari & Poeppel 2003;

McKoon & Ratcliff 2008), it is hypothesized here that the more complex the events and scenarios, the greater the amount of information to be accessed in working memory, and thus the longer the processing time of the verb is likely to be.

2 Experiment 1: Verb semantic complexity in lexical access

Experiment 1 is designed to examine verb semantic complexity in lexical access. Existing research has suggested that semantic representations are readily activated during lexical decision judgements (McKoon & Macfarland 2000; 2002; McKoon & Love 2011; Manouilidou & de Almeida 2013). Therefore, Experiment 1 adopts a lexical decision task, and the lexical decision time is an indicator of verb semantic complexity. The predicate decomposition approach predicts that accomplishment verbs (e.g., *break*) take a longer reaction time than activity verbs (e.g., *sweep*), whereas the constructional approach predicts that three-participant-role verbs (e.g., *sweep,* hereafter referred to as three-role verbs) take a longer reaction time than two-participant-role verbs (e.g., *break*, hereafter referred to as two-role verbs).

2.1 Methods

Lexical decision is a task in which participants are asked to judge whether strings of letters form real words as rapidly and accurately as possible. In this experiment, verb stimuli were developed into four groups, each containing eight verbs. The four groups were two-role activity verbs, two-role accomplishment verbs, three-role activity verbs, and three-role accomplishment verbs (**Table 1**). These verbs were selected based on three conditions: the aspectual type, the number of participant roles, and whether they are used more frequently as verbs than other parts of speech. The following section describes how the verb stimuli were selected.

Two-role activity verbs	Two-role accomplishment verbs	Three-role activity verbs	Three-role accomplishment verbs
bite	bend	hit	bake
caress	break	pour	deliver
kiss	cook	scrub	lend
lick	crumple	shave	purge
rub	rip	skim	rent
tap	smash	sweep	rinse
touch	snap	thump	sell
wring	split	wipe	wash

Table 1: Verbs used in Experiment 1.

Activity and accomplishment verbs were selected with reference to Levin's (1993) classifications of English verbs and identified through Dowty's (1979: 60) diagnostic tests for verb aspectual categories. For example, activity verbs can be modified by "*for* + time period" phrases but not "*in* + time period", while accomplishment verbs can be modified by both phrases; activity verbs can be found as complements to *stop* but not to *finish*, while accomplishment verbs can be found as complements to both verbs. In addition, accomplishment verbs that have no incremental themes were selected according to the aspectual hypothesis of verb semantic complexity.

The number of participant roles was primarily identified through the diagnostic test "no v-ing occurred" (Goldberg 1995). The participant roles implicitly understood in the interpretation of this expression correspond to the participant roles of the verb. For example, for the statement *no kicking occurred* to be valid, then there should be no kicker and no kicked object. That is, the statement requires a two-participant interpretation indicating that *kick* has two participant roles.

Difficulties of the test arise when the verb in question is involved with an implicit event participant, such as the default instruments in *sweep* and *shave*. To solve this problem, the statement "no v-ing occurred" was interpreted with further reference to the Semantic Obligatoriness Criterion (19a) and the Semantic Specificity Criterion (19b) proposed by Koenig et al. (2003).

(19) a. Semantic Obligatoriness Criterion (SOC): If r is an argument participant role of predicate P, then any situation that P felicitously describes includes the referent of the filler of r.

b. Semantic Specificity Criterion (SSC): If r is an argument participant role of predicate P denoted by verb V, then r is specific to V and a restricted class of verbs/events.

These two criteria were originally proposed to differentiate arguments from adjuncts. Following the same idea, in the identification of participant roles, the SOC suggests that a participant role must constitute an entity that obligatorily appears in all events that a verb describes. The SSC, on the other hand, indicates that a participant role must be highly characteristic of the event that a verb describes and individuates the verb meaning from the rest. An event participant is a participant role if and only if it satisfies *both* the SOC and the SSC. A default instrument is often semantically obligatory to the event, but it is not necessarily semantically specific. Thus, according to the SOC and SSC, implicit participants are participant roles only when they serve to differentiate verb meaning from its near-synonyms. To diagnose the number of participant roles, the statement of "no v-ing occurred" was interpreted with reference to SOC and SSC. In addition, the number of participant roles was also assessed by asking participants how many puppets and props they would need to perform and explain the meaning of the verb to a non-English speaker (Ahrens & Swinney 1995). Participants were also asked to explain the role of each puppet and prop in the event associated with the verb. The puppets and props that are critical to describing the central meaning of the verb were calculated as participant roles.

A simple norming study about the verb classifications was conducted. Five linguistic major native English speakers[4] were asked to categorize verbs based on the above diagnostic tests. A verb was selected as experimental material only when all five raters sorted it into the same category.

Apart from aspectual types and participant roles, the lexical decision targets should be primarily understood as verbs rather than other parts of speech, so that they are more likely to trigger the verb meaning representation and show the potential difference of verb semantic complexity. That is, these targets should be used in their verb senses more frequently than in the other senses. Take the verbs used in McKoon and Love (2011) for example. Six out of the 32 experimental verbs are less frequently used as verbs compared with their total occurrences in the Corpus of Contemporary American English (COCA), which are *batter, pat, wrinkle, crack, hush,* and *tear*. In these cases, it is not certain whether verb representations were activated or not during the lexical decision of these targets, which makes the reaction time unreliable in interpreting verb semantic complexity. Given this consideration, in the current experiment, words were selected as lexical decision targets only when they were used as verbs at least 50% of their total occurrences in the COCA. The average percentage of verb use of these experimental words was 80.49%.

In addition, factors that have been well acknowledged to affect lexical decision time were measured. These factors included word frequency (HAL frequency and logarithmic HAL frequency[5]), word length (in terms of numbers of characters, phonemes, syllables, and morphemes), orthographic neighborhood size (as defined by the number of words that can be obtained by changing one letter in the target word, i.e., Coltheart's N (Coltheart et al. 1977)), phonological neighborhood size (as defined by the number of words that can be obtained by changing one phoneme in the target word), and the number of senses (as defined in WordNet (Princeton University 2010)). Note that although there were studies claiming that the number of argument structures affects verb semantic complexity (Shapiro & Zurif & Grimshaw 1987; 1989), this factor was not considered in the current experiment. First, the rationale of this factor lies in the hypothesis that verb semantics can be represented by subcategorization frames (Chomsky 1965), but this hypothesis is not theoretically compatible with either the predicate decomposition approach or the constructional approach discussed here. In addition, empirical studies have offered evidence that contradicts this factor (Schmauder 1991; Schmauder & Kennison & Clifton 1991; Ahrens & Swinney 1995). Thus, the number of argument structures was not included here. All the other factors of the experimental verbs are summarized in **Table 2** and **Table 3**.

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[4] The number of participants was small due to practical limitations. Ideally, the norming study should be larger in scale.

[5] HAL refers to the Hyperspace Analogue to Language (HAL) frequency norms based on the HAL corpus (Lund & Burgess 1996).

	Activity verbs		Accomplishment verbs	
	mean	**SD**	**mean**	**SD**
HAL frequency	10291.50	16188.94	14127.00	19743.63
Log HAL frequency	8.27	1.44	8.73	1.47
Length (character)	4.31	0.85	4.63	1.05
Length (phoneme)	3.44	0.70	3.94	0.97
Length (syllable)	1.06	0.24	1.19	0.53
Length (morpheme)	1.00	0.00	1.00	0.00
Orthographic neighborhood	9.25	6.51	9.00	6.81
Phonological neighborhood	22.13	14.28	17.19	12.58
Senses	9.88	7.31	15.69	16.58

Table 2: Features of the experimental activity and accomplishment verbs.

	Two-role verbs		Three-role verbs	
	mean	**SD**	**mean**	**SD**
HAL frequency	11669.69	12695.26	12748.81	22304.62
Log HAL frequency	8.58	1.59	8.42	1.34
Length (character)	4.44	1.06	4.50	0.87
Length (phoneme)	3.69	0.92	3.69	0.85
Length (syllable)	1.13	0.33	1.13	0.48
Length (morpheme)	1.00	0.00	1.00	0.00
Orthographic neighborhood	9.19	6.89	9.06	6.43
Phonological neighborhood	19.56	13.86	19.75	13.50
Senses	15.69	17.04	9.88	6.16

Table 3: Features of the experimental two-role verbs and three-role verbs.

The lexical decision times of the experimental verbs were extracted from the English Lexicon Project (Balota et al. 2007). The English Lexicon Project is an online database containing the lexical decision time of 40,481 words and 40,481 nonwords from 816 native English speakers. The average age of the speakers is 22.86 (SD = 6.85), and their average years of education is 14.76 (SD = 1.72). Each participant gave lexical decisions to either 3,374 or 3,372 targets in two different sessions that were held on different days. In each session, there was an equal number of real words and nonwords. The real words included verbs, nouns, adjectives, and prepositions. The nonwords were pronounceable and generated by changing one or two letters in a corresponding real word. During each trial, the target was presented for a maximum of 4,000 ms. After each response, participants immediately received feedback about the accuracy of their lexical decision. At the end of each trial, there was a 1,000 ms interval before the next trial. For more details about the design and procedure of the lexical decision task, please refer to Balota et al. (2007). This experiment extracted the lexical decision times of the 32 verbs from the English Lexicon Project. There were 33 to 38 observations for each verb, for a total of 1098 data points. The number of observations varies for each verb due to data loss. These data were contributed by 592 participants in the corpus, with each participant only seeing a subset of the 32 verbs.

2.2 Results

Reaction times shorter than 200 ms and longer than 3,000 ms were first excluded from the data analysis. For the rest of the data, any reaction time shorter than the mean (of the same participant and the same lexical decision target) minus three times its standard deviation or longer than the same mean plus three times its standard deviation was excluded. This has led to 2.64% loss of the original data and resulted in 1,069 observations. Participants responded faster and more accurately to accomplishment verbs (Mean Reaction Time = 631.38 ms; Standard Error = 9.56; Mean Accuracy = 0.96) than to activity verbs (Mean Reaction Time = 637.06 ms; Standard Error = 9.65; Mean Accuracy = 0.93). In addition, participants responded faster to two-role verbs (Mean Reaction Time = 626.64 ms; Standard Error = 9.81) than to three-role verbs (Mean Reaction Time = 641.99 ms; Standard Error = 9.37), but the accuracies for the two types of verbs were almost identical (Mean Accuracy = 0.95). The mean reaction times for the four types of verbs are shown in **Figure 1**.

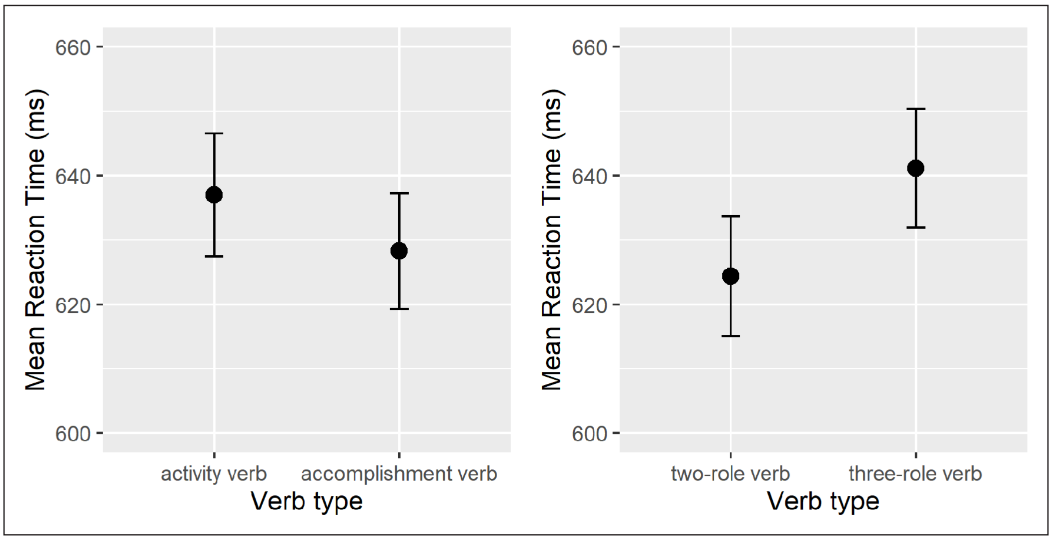

Figure 1: Reaction time by verb types in Experiment 1 (Error bars indicate mean ± SE).

The reaction times and accuracies were further analyzed using linear mixed effects models (Baayen 2012) with the lmerTest package (Kuznetsova & Brockhoff & Christensen 2017) in R (R Core Team 2013). First, because the distribution of the reaction time was right skewed, the original data were log-transformed to improve the accuracy of statistical modeling. Second, the collinearity of the numerical factors summarized in **Table 2** and **Table 3** was checked. Factors measuring the same dimension (e.g., frequency and logarithmic frequency) were minimized to one to keep the correlation between predictors as small as possible. This left five predictors, which were logarithmic frequency, word length in terms of the number of syllables, phonological neighborhood size, orthographic neighborhood size and the number of senses ($\kappa = 22.94$).

A mixed effects model was fitted to predict the log-transformed reaction time. The fixed effects were the verb aspectual type, the number of participant roles, their interaction as well as the selected covariates and their binary interactions. These factors were coded as sum contrasts (1 vs –1 for accomplishment verbs and activity verbs, and for three-role verbs and two-role verbs). The random intercepts were the participant and the item. Then the model was minimized by the Akaike information criterion (AIC) using the likelihood ratio test. The results are summarized in **Table 4**.

Predictor	**coefficient**	**SE**	**df**	**t value**	**p**	
(Intercept)	6.382	0.227	32.73	28.167	<0.000	***
Participant role	0.035	0.013	30.929	2.720	0.011	*
Aspectual type	0.009	0.011	31.534	0.775	0.444	
Senses	0.015	0.009	33.523	1.699	0.099	
Log frequency	–0.016	0.018	32.657	–0.897	0.376	
Length (syllable)	0.169	0.093	33.422	1.820	0.078	
Orthographic neighborhood	–0.058	0.017	31.319	–3.473	0.002	**
Phonological neighborhood	0.029	0.008	31.135	3.482	0.002	**
Senses: Length (syllable)	–0.015	0.009	33.592	–1.667	0.105	
Log frequency: Orthographic neighborhood	0.006	0.002	31.47	3.076	0.004	**
Log frequency: Phonological neighborhood	–0.003	0.001	31.357	–3.290	0.002	**

Table 4: Log-transformed reaction time (* $p < .05$, ** $p < .01$, *** $p < .001$).

It is shown that three-role verbs significantly increase ($t(30.929) = 2.720$, $p = 0.011$) the log-transformed reaction time by 0.035 ± 0.013 compared to two-role verbs. In contrast, the reaction time difference between activity verbs and accomplishment verbs is not statistically significant ($t(31.534) = 0.775$, $p = 0.444$). Additionally, the model indicates two pairs of significant interactions. The effects of orthographic neighborhood size ($t(31.470) = 3.076$, $p = 0.004$) and phonological neighborhood size ($t(31.357) = -3.290$, $p = 0.002$) on reaction time changed significantly based on the logarithmic word frequency.

Another mixed effects model was fitted to predict the accuracy. The fixed effect was the verb aspectual type. The factor was again coded as sum contrasts as in the models for reaction times. The random intercepts were the participant and the item. It is shown that there is no significant difference in accuracy between activity verbs and accomplishment verbs ($t(32.098) = 0.948$, $p = 0.350$).

2.3 A replication of McKoon and Love (2011)

The results from Experiment 1 do not support significantly longer lexical decision time of accomplishment verbs over activity verbs, which turns out to be inconsistent with the findings in McKoon and Love (2011). To better understand the discrepant results and to further examine the lexical decision time of accomplishment verbs and activity verbs, the lexical decision task in McKoon and Love (2011) was replicated here.

This replication was carried out with the same set of verbs as the original study. Lexical decision times of the 32 verbs used by McKoon and Love (**Table 5**) were again extracted from

Activity verbs	Accomplishment verbs
bang	heal
batter	wrinkle
bite	split
caress	crumple
hit	break
kick	crack
kiss	fade
knock	freeze
lick	thaw
nudge	hush
pat	tilt
pinch	rip
slap	fold
swipe	scorch
tap	smash
touch	tear

Table 5: Verbs used in McKoon and Love (2011).

the English Lexicon Project. There were 34 to 40 observations for each verb, for a total of 1188 data points. The number of observations varies for each verb due to data loss. These data were contributed by 436 participants in the corpus, with each participant only seeing a subset of the 32 verbs.

Reaction times shorter than 200 ms and longer than 3,000 ms were first excluded from the data analysis. For the rest of the data, any reaction time longer than the mean (of the same participant and the same word target) plus three times the standard deviation or shorter than the same mean minus three times the standard deviation was excluded. This has led to 2.86% loss of the original data and resulted in 1,154 observations. Participants responded faster to activity verbs (Mean Reaction Time = 610.68 ms; Standard Error = 7.33) than accomplishment verbs (Mean Reaction Time = 641.39 ms; Standard Error = 9.51), but the accuracy was identical for both types of verbs (Mean Accuracy = 0.97). The mean reaction times for the two types of verbs are shown in **Figure 2**.

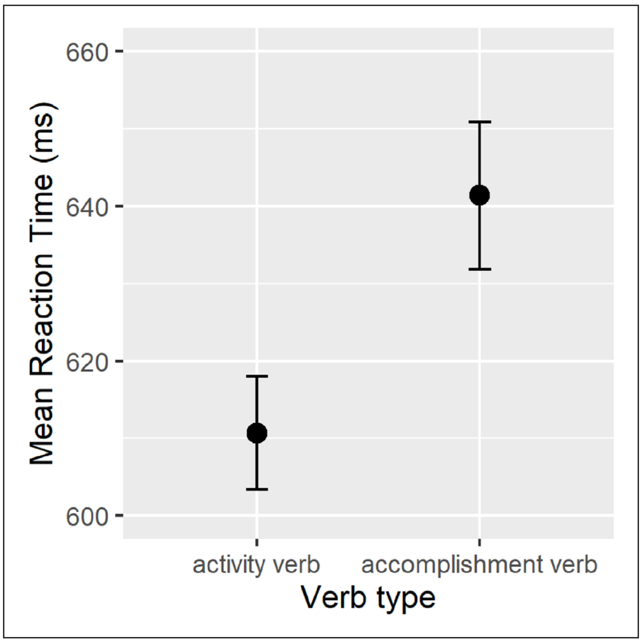

Figure 2: Mean reaction time by verb types in the replication of McKoon and Love (2011) (Error bars indicate mean ± SE).

The reaction time was first analyzed using an ANOVA test as in McKoon and Love (2011). The results show that accomplishment verbs take significantly longer reaction times ($F(1, 1152) = 6.542$, $p = 0.011$) than activity verbs, as concluded in McKoon and Love (2011).

An alternative way to analyze the data here is to use linear mixed effects models as in Section 2.2. Here, two mixed effects models were fitted. The outcome was the log-transformed reaction time. In the first model, the fixed effect was simply the verb aspectual type, and the factor was coded as sum contrasts (1 vs –1 for accomplishment verbs and activity verbs). The random intercepts were the participant and the item. This model indicates that the reaction time difference between activity verbs and accomplishment verbs is not significant ($t(31.572) = 1.167$, $p = 0.252$). The second model built on the first model by adding other covariates that are known to influence lexical decision times and adopted a similar structure as the mixed effects model in Section 2.2, except that it did not include the number of participant roles. This model was minimized by AIC using the likelihood ratio test. The result again indicates that the reaction time difference between activity verbs and accomplishment verbs is not significant ($t(29.273) = 0.243$, $p = 0.810$).

The two methods of data analysis have produced very different results. This can be attributed to the experimental design of McKoon and Love (2011), as well as the different assumptions between the two statistical methods. In the McKoon and Love's study, the data contains multiple responses from the same participant and multiple responses to the same verb. In this case, the responses are not independent of each other, which in fact violates one of the most important assumptions of the ANOVA, the independence of observations (e.g., Howell 2014: 400). Violating independence may greatly increases the likelihood of obtaining spurious results and lead to meaningless p-values (Winter 2013). However, this problem can be addressed by adding random effects to the subjects and items and using mixed models. Mixed models can account for by-subject and by-item variation in a single model, solving the problem of non-independence.

The incongruence between the results of the ANOVA and the mixed effects models suggests that the significant reaction time difference reported by McKoon and Love (2011) may be better explained by the individual difference among participants and/or experimental verbs rather than verb aspectual types per se. This is probably why the current study failed to replicate their results and found a null effect of verb aspectual type on lexical decision time.

2.4 Conclusion

The results of Experiment 1 and the replication of McKoon and Love (2011) jointly show that verbs with more participant roles, but not more complex aspectual event structures, cause longer lexical decision time. This has supported the verb semantic complexity hypothesis under the constructional approach but not the predicate decomposition approach. In other words, according to the word processing data reported above, the number of participant roles is a better indicator of verb semantic complexity than the aspectual event structure.

3 Experiment 2: Verb semantic complexity in sentence processing

Experiment 1 suggests that participant role information is more likely to be accessed in word processing and, thus, to affect verb processing load. However, it is not certain whether this information is accessed during sentence processing. Therefore, Experiment 2 is designed to investigate whether the constructional approach also better predicts verb processing load during sentence processing than the predicate decomposition approach. Previous research has shown that self-paced reading tasks are sensitive to verb semantics (Balota & Ferraro & Connor 1991; Balota 1994; Gennari & Poeppel 2003). Therefore, Experiment 2 adopted a self-paced reading task, and the reading time is an indicator of verb semantic complexity. The predicate decomposition approach predicts that accomplishment verbs (e.g., *break*) yield longer reading time than activity verbs (e.g., *sweep*), whereas the constructional approach predicts that three-role verbs (e.g., *sweep*) yield longer reading time than two-role verbs (e.g., *break*).

3.1 Methods

The experiment used a self-paced reading moving window paradigm (Just & Carpenter & Woolley 1982). The self-paced reading task measures the reading time as readers control the presentation duration of a given word or phrase on the screen by pressing buttons. The moving window paradigm is a kind of self-paced reading task. In this paradigm, each time participants press the button to proceed to the next word/phrase in the sentence, the previous one will become masked, which makes the visible part in the sentence between each button pressing looks like a "moving window". Studies have shown that this moving window paradigm closely resembles natural reading and often replicates the results of eye-tracking data (Binder & Rayner 1998).

In this experiment, experimental sentences were developed with the same set of verbs used in Experiment 1 (**Table 1**). Each experimental verb was matched with four subject NPs, resulting in four experimental sentences for the same verb, as demonstrated in (20). Each subject NP was associated with four experimental verbs from each group, resulting in four experimental sentences for the same subject, as demonstrated in (21). These sentences were divided into four Latin-square lists, with each list containing 32 experimental sentences so that no participant would read the same verb or the same subject NP twice (the full lists of the experimental sentences can be found in the Supplementary files). In addition, 64 distractor sentences were created in a similar length but with more diverse sentence structures compared with the experimental sentences.

(20) a. The restless toddler hit the window and shattered it.
b. The mischievous child hit the window and shattered it.
c. The chubby kid hit the window and shattered it.
d. The naughty boy hit the window and shattered it.

(21) a. Two-role activity verb: The defeated Olympian tapped the competitor on his shoulder.
b. Two-role accomplishment verb: The defeated Olympian smashed the trophy against the wall.
c. Three-role activity verb: The defeated Olympian thumped the judges' desk angrily.
d. Three-role accomplishment verb: The defeated Olympian delivered the bad news to his parents.

Two pretests were conducted to better control the relationship between the subject NPs and the critical verbs. The tasks were implemented on Amazon Mechanical Turk (https://www.mturk.com/) with participants restricted to English native speakers holding at least a bachelor's degree. First, the predictability from the subject NPs to the critical verbs needs to be controlled. Subject NPs that do not get the critical verbs easily predicted are preferred because they would highlight the processing load of the verbs themselves. For this purpose, a sentence completion task with all the subject NPs was conducted. In this task, twenty participants were asked to complete the sentence segments with the subject NPs in a meaningful way. According to the responses, no participants completed any sentences with the critical verbs designed here, indicating the low predictability of the subject NPs.

Second, the plausibility for the combinations of subject NPs and critical verbs needs to be controlled. A plausibility rating task was conducted, asking participants to rate how plausible it is to see a given subject NP perform the corresponding action denoted by the verb in the same experimental sentence on a scale of 1 to 7, with 7 meaning the most plausible. Twenty participants who had not participated in the sentence completion task took part in this task. To avoid participants seeing the same subject NP and verb repeatedly, the combinations of a subject NP and a critical verb were divided into four Latin-square lists, and each participant rated only one of the lists. The mean scores for all combinations were calculated for later consideration in data analysis.

Thirty-three native English speakers from a university in Hong Kong within the age range of 18–30 ($M = 20.1$) participated in the experiment. They do not have any uncorrected visual or auditory impairments. All participants volunteered for the experiment with a compensation of $40 HKD.

The experiment was conducted in E-prime 3.0 with a Chronos Response Device. Participants were instructed to read sentences by pressing the button box at a normal speed. Participants were first instructed through a practice of 16 sentences and then were asked to complete a real task of 96 sentences. Within a trial of every four sentences, there was one sentence at random sequence followed by a true-or-false comprehension question to make sure participants processed the content of the sentences rather than simply pressed buttons.

3.2 Results

The data were cleaned based on the accuracy of comprehension questions and the reading times of the words. First, any participants with a mean accuracy of comprehension questions lower than the mean accuracy of all participants minus three times the standard deviation were excluded from further analysis. This has led to the loss of one participant's data. The rest of the data has reached a mean accuracy of 97.08%. Second, any reading time data that were shorter than 100 ms or longer than 3,000 ms were excluded. Third, any reading time data that were shorter than the mean of the word minus three times the standard deviation or longer than the mean reading time plus three times the standard deviation were excluded. This has led to a 4.89% loss of the original data. The remaining reading time data were all used in the analysis. This was done even if the corresponding comprehension question was not answered correctly.

Figure 3 and **Figure 4** show the reading time of the region of interest: the critical verb, the noun before it and the determiner after it. Participants read activity verbs (Mean Reading Time = 413.04 ms; Standard Error = 8.45) faster than accomplishment verbs (Mean Reading Time = 428.11 ms; Standard Error = 8.65), and participants read two-role verbs (Mean Reading Time = 405.96 ms; Standard Error = 7.93) faster than three-role verbs (Mean Reading Time = 435.15 ms; Standard Error = 9.10).

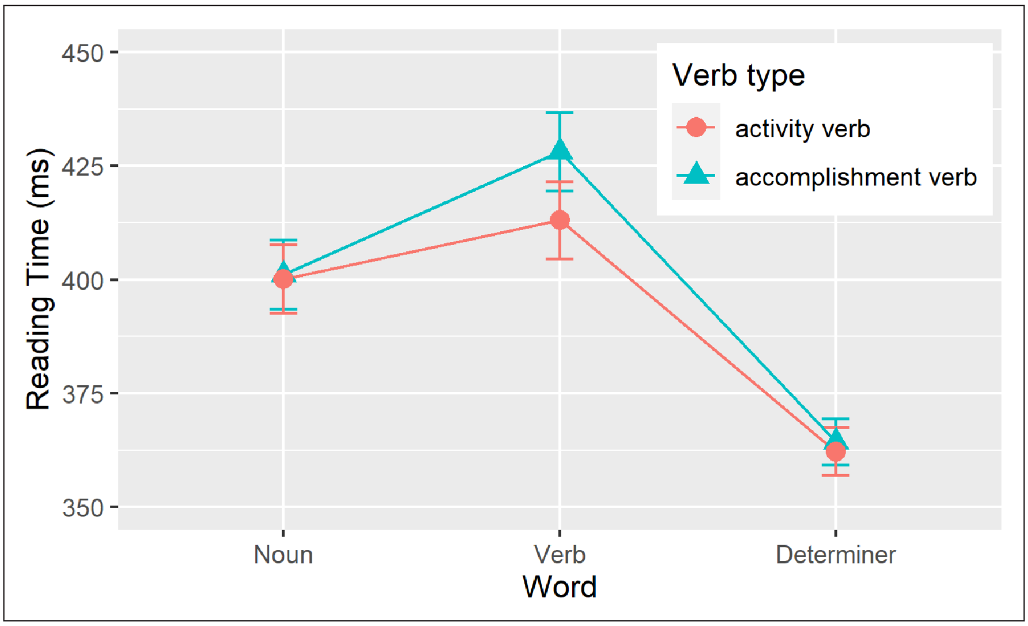

Figure 3: Reading time of region of interest by aspectual verb types (Error bars indicate mean ± SE).

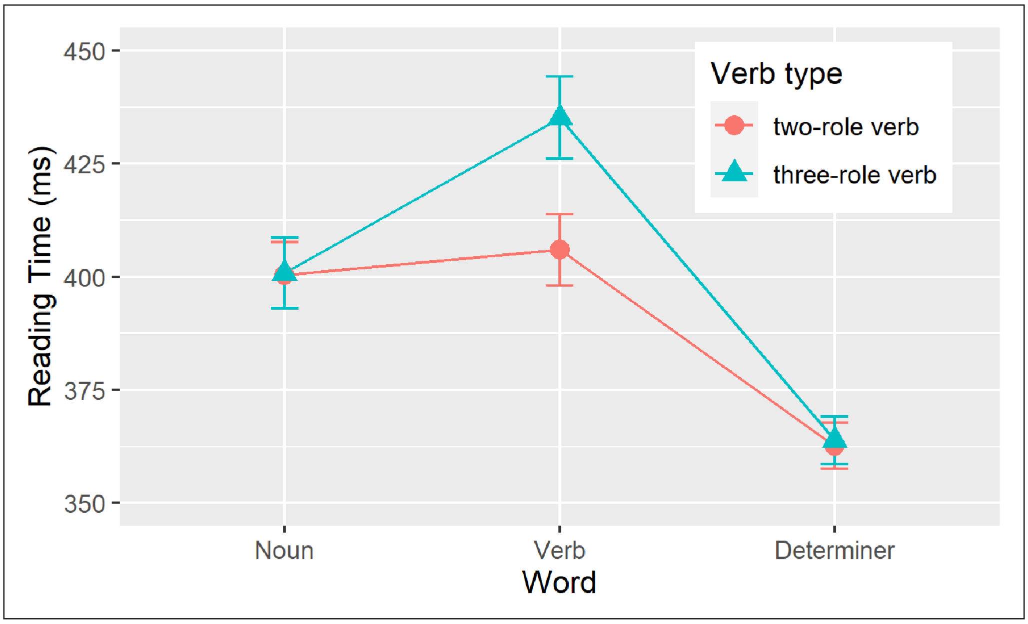

Figure 4: Reading time of region of interest by number of participant roles (Error bars indicate mean ± SE).

The reading times were further analyzed using linear mixed effects models. First, the distribution of the reading time was right skewed; thus, the raw data were log-transformed as the new outcome. Second, in addition to the verb semantic categories of interest here, a similar set of covariates as Experiment 1 were taken into consideration. They were word frequency, word length (in terms of numbers of characters, phonemes, syllables, and morphemes), orthographic neighborhood size, phonological neighborhood size, the number of senses, and the plausibility score from the second pretest. The number of argument structures was not considered here for the same reasons stated in Experiment 1. In addition, the previous-word reading time was not included, because this factor has been balanced by the Latin-square design.

The collinearity of the numerical factors was checked. Factors measuring the same dimension were minimized to one to keep the correlation between predictors as small as possible. This left five predictors, which were logarithmic frequency, word length in terms of the number of syllables, orthographic neighborhood size, the number of senses, and the plausibility score (κ = 15.32).

A mixed effects model was fitted. The fixed effects were the verb aspectual type, the number of participant roles and their interaction as well as the selected covariates and all their binary interactions. These factors were coded as sum contrasts (1 vs –1 for accomplishment verbs and activity verbs, and for three-role verbs and two-role verbs). The random intercepts were the participant and the item. This model was then minimized by AIC using the likelihood ratio test. The results are summarized in **Table 6**.

Predictor	coefficient	SE	df	t value	p	
(Intercept)	5.978	0.080	53.423	74.827	< 0.000	***
Participant role	0.026	0.012	30.716	2.115	0.043	*
Aspectual type	0.014	0.012	30.558	1.097	0.281	
Plausibility	0.178	0.073	404.677	2.429	0.016	*
Log frequency	–0.011	0.007	30.473	–1.523	0.138	
Length (syllable)	0.060	0.028	29.591	2.147	0.040	*
Plausibility: Log frequency	–0.023	0.009	356.541	–2.534	0.012	*

Table 6: Log-transformed reading time (* $p < .05$, ** $p < .01$, *** $p < .001$).

It is shown that three-role verbs significantly increase ($t(30.716) = 2.115$, $p = 0.043$) the log-transformed reading time by 0.026 ± 0.012 compared to two-role verbs. In contrast, the reading time difference between accomplishment verbs and activity verbs is not statistically significant ($t(30.558) = 1.097$, $p = 0.281$). In addition, there is a significant interaction between the plausibility score and word frequency. The effect plausibility significantly varies based on logarithmic word frequency ($t(365.541) = –2.534$, $p = 0.012$).

3.3 Conclusion

The results of Experiment 2 show that verbs with more participant roles but not more complex aspectual event structures, cause a longer reading time. This has again supported the verb semantic complexity hypothesis under the constructional approach. In other words, according to the sentence processing data reported above, the number of participant roles is a better indicator of verb semantic complexity than the aspectual event structure, which is consistent with Experiment 1.

4 Discussion

The predicate decomposition approach represents verb meaning with event structures and the aspectual approach assumes that accomplishment verbs are conceptually more complex than activity verbs. In contrast, the constructional approach represents verb meaning with frames and participant roles and assumes that verbs with more participant roles are conceptually more complex. In this article, two experiments were conducted to examine these predictions by reaction times in lexical access and sentence processing. Both results have consistently supported the prediction of the constructional approach rather than the predicate decomposition approach. This suggests that participant role information better captures the psychological reality of verb semantic complexity and thus is more likely to be encoded in verb semantic representation, indicating a higher psychological plausibility of the constructional approach to argument realization.

Note that the predicate decomposition approach does not reject the representation of event participants in verb meaning. The key difference between the two approaches to verb semantics lies in whether there is a structured relation between participants and whether this relation reflects semantic complexity. The aspectual predicate decomposition approach assumes that event participants are structured by the temporal properties between subevents, and it is such properties that determine event complexity. In contrast, the constructional approach assumes that event participants are unstructured, and it is the number of participant roles that determines event complexity. In this sense, the experiments reported here imply that the unstructured participant role information is more likely to be stored in verb semantic representation and hence affects verb processing load in language processing. Conversely, the aspectual approach is more likely to be an analytical imposition for argument realization with limited psychological plausibility in language processing compared to the constructional approach.

If temporal structures are not encoded in verb meaning, then how can we account for the fact that some grammatical constraints are sensitive to verb aspectual class? For example, it has been observed that "*in* + time period" phrases can modify accomplishment verbs as in (22) but not activity verbs as in (23), and this has often been used as a diagnostic test of these verb categories in the literature.

(22) a. Mary ate a sandwich in ten minutes.
b. Mary painted a picture in ten minutes.

(23) a. *Mary pushed a cart in ten minutes.
b. *Mary hammered the metal in ten minutes.

However, note that when a goal argument or a result argument is added to the activity verb sentences above, the predicates would force an accomplishment reading as (24). This phenomenon is called aspectual shift.

(24) a. Mary pushed the cart to the store in ten minutes.
b. Mary hammered the metal flat in ten minutes.

The evidence of aspectual shifts has raised an essential question about the verb aspectual class: what exactly is being classified in the aspectual category? Is it a distinction about verbs per se, or is it a property gained at the level of the VP, the sentence, or even the event? The current experiments have failed to find any evidence suggesting that aspectual distinction is encoded at the verb level of representation. Alternatively, aspectual properties should probably be at least attributed to the VP (Verkuyl 1972; 1996), or even higher levels, to account for the grammatically relevant facets of verb meaning in argument realization. This is compatible with the Lexical Construction Model in which argument structure constructions are represented by the universal semantic metalanguage in association with aspectual characterization. For example, the caused-motion construction can be represented as the following, where the asterisk marks the optional status of an element (Ruiz de Mendoza Ibáñez & Mairal Usón 2008):

(25) [**do'** (x, y)] CAUSE [BECOME *NOT LOC (y, z)]

The aspectual properties of constructions can act as filters for certain lexical-constructional fusion/subsumption. If this is the case, then any verbs that may show aspectual shifts will be aspectually ambiguous at the verb position during sentence comprehension, and such ambiguity will be resolved after the complement of the sentence is recognized. This hypothesis should be further explored in the future.

Interestingly, the idea that aspectual distinction is encoded at a high level of representation happens to coincide with the proposal of argument structure constructions in construction grammar. Under construction grammar, argument structure constructions are hypothesized to encode the grammatical constraints in argument realization, and they are represented independently from verbs. In this sense, the experiments reported above also provide a basis for the existence of argument structure constructions. The psychological reality of argument structure constructions has been supported by a sizeable number of studies. It is suggested that argument structure constructions are mentally represented (Chang & Bock & Goldberg 2003; Allen et al. 2012) and automatically accessed (Johnson & Goldberg 2013) in language processing. Argument structure constructions facilitate the understanding of sentences (Bencini & Goldberg 2000; Goldberg et al. 2005; Johnson et al. 2015) and the interpretation of individual words in sentences (Ahrens 1995; Kaschak & Glenberg 2000; Kako 2006; Goldwater & Markman 2009).

Furthermore, if unstructured participant roles are represented in verb meaning, then what is their role in sentence processing? In almost every English sentence, the main verb is made available before the whole argument structure construction is recognized. In this case, when readers get to the verb position during sentence processing and activate the corresponding participant roles associated with the verb, such information may help people anticipate the argument structure construction of the target sentence and thus the whole sentence. Participant roles would activate the argument structure constructions that contain compatible argument roles and inhibit the argument structure constructions that do not contain compatible argument roles. The compatibility between participant roles and argument roles is evaluated by the semantic coherence and profiling status as suggested by the semantic coherence principle, the correspondence principle, and the internal and external constraints proposed by the Lexical

Construction Model. This hypothesis is motivated by the linguistic reality of verb semantics in argument realization and the psychological reality in verb processing. The hypothesis can be further extended depending on the word order of different languages. For verb-initial languages (VSO or VOS), the participant role information of the verb should be very predictive of the argument structure and thus the whole sentence. For verb-middle languages (SVO or OVS), as discussed in this paper for English, the participant role information of the verb is also predictive of the argument structure and the whole sentence. In contrast, for verb-final languages (SOV or OSV), the participant role information of the verb should have a limited predictive effect on the argument structure and the whole sentence. This is to say that languages with typologically different word orders will differ in their processing strategies. This hypothesis has important implications for understanding both sentence processing and language acquisition, which should be explored in future research.

Data Availability

The experimental materials, data and analysis scripts of both experiments can be found through https://osf.io/nqzsf/

Ethics and consent

This study was approved by the University of Hong Kong, Human Research Ethics Committee, Reference Number EA1612022. Informed consent was obtained from each adult participant, and all research data has been anonymized.

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Competing interests

The author has no competing interests to declare.

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