Cognitive Neural Mechanisms Underlying the Processing of Verb Argument Structure Complexity

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Abstract

Verb argument structure complexity is manifested in four aspects: argument number, argument category selection patterns, thematic role assignment patterns, and mapping manners. Most empirical studies indicate that a greater number of arguments, selective argument categories, selective thematic role assignment, and atypical mapping render the cognitive neural mechanisms of verb argument structure processing more complex. Functional brain regions for multi-argument processing primarily involve the left inferior frontal gyrus and posterior perisylvian region; functional brain regions for selective argument category processing primarily involve the left inferior frontal gyrus, middle-posterior frontal region, superior temporal gyrus, and middle-posterior temporal region; functional brain regions for selective thematic role assignment processing primarily involve the posterior perisylvian region, middle-posterior left frontal region, and inferior frontal gyrus; functional brain regions for atypical mapping processing primarily involve the left inferior frontal gyrus, superior temporal gyrus, middle temporal gyrus, and posterior temporal region. The left inferior frontal gyrus may be involved in initial syntactic processing, verb subcategorization determination, syntactic movement, and unaccusative verb semantic processing; the middle-posterior left frontal region may be involved in initial syntactic processing and verb subcategorization determination; the left superior temporal gyrus and middle-posterior temporal region may be involved in surface syntactic processing and surface argument syntactic-semantic integration; the posterior perisylvian region may be involved in argument semantic representation. Verb argument structure processing procedures and verb lexical features indicate that interactions exist among certain aspects of complexity. Issues such as the correspondence between verb argument structure complexity and processing difficulty, the cognitive neural mechanisms underlying complexity processing difficulty hierarchy and interactions, and the cognitive neural mechanisms of Chinese verb argument structure complexity processing, await further

investigation.

Full Text

Preamble

The Cognitive Neural Mechanisms of Verb Argument Structure Complexity Processing

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Abstract: Verb argument structure complexity manifests in four aspects: the number of arguments, argument subcategorization selection patterns, thematic role assignment modes, and mapping alternations. Most empirical studies demonstrate that a greater number of arguments, alternating argument subcategorizations, alternating thematic role assignments, and noncanonical mappings render the cognitive neural mechanisms of verb argument structure processing more complex. The functional brain regions primarily involved in processing multiple arguments include the left inferior frontal gyrus and posterior perisylvian regions; those for alternating argument subcategorization involve the left inferior frontal gyrus, middle-posterior frontal lobe, superior temporal gyrus, and middle-posterior temporal lobe; those for alternating thematic role assignment involve the posterior perisylvian regions, left middle-posterior frontal lobe, and inferior frontal gyrus; and those for noncanonical mapping involve the left inferior frontal gyrus, superior temporal gyrus, middle temporal gyrus, and posterior temporal lobe. The left inferior frontal gyrus may be involved in initial syntactic processing, verb subcategorization determination, syntactic movement, and semantic processing of unaccusative verbs; the left middle-posterior frontal lobe may participate in initial syntactic processing and verb subcategorization determination; the left superior temporal gyrus and middle-posterior temporal lobe may be engaged in surface syntactic processing and surface argument syntactic-semantic integration; and the posterior perisylvian regions may mediate argument semantic representation. The processing of verb argument structures and the lexical properties of verbs indicate interactive effects among certain complexity dimensions. Issues warranting further investigation include the correspondence between verb argument structure complexity and processing difficulty, the hierarchical difficulty levels of complexity processing and the cognitive neural mechanisms underlying their interactions, as well as the cognitive neural mechanisms of Chinese verb argument structure complexity processing.

Keywords: verb; argument structure complexity; processing; cognitive neural mechanisms

Verb argument structure is specifically manifested in three aspects: the number of arguments, the thematic roles borne by arguments, and the grammatical categories to which arguments belong (Huang, 2007). For instance, in the structure "Tom hit Lily," the verb "hit" takes two arguments, "Tom" and "Lily," which bear the thematic roles of agent and patient respectively, and both belong to the grammatical category of noun. Verb argument structure occupies a central position in the processing of sentences and natural language in general (Hao, 2018; He & Chen, 2013; Blanco-Elorrieta et al., 2018; Friederici, 2011). Consequently, the cognitive neural mechanisms underlying verb argument structure complexity processing have long been a focal topic in cognitive neuroscience (Malyutina & den Ouden, 2017). Compared with international scholarship, empirical research in Chinese linguistics on this topic remains relatively scarce, yet the complexity of Chinese verb argument structures and their neural processing mechanisms may exhibit language-specific properties (Bai & Xue, 2015; Chen, 2017; Han, 2019; Shen, 2018). Examining the current state of research on the cognitive neural mechanisms of verb argument structure complexity processing not only helps to keep abreast of contemporary research trends to advance the study of natural language processing but also provides valuable references for investigating the cognitive neural mechanisms of Chinese verb argument structure complexity processing.

2. Cognitive Neural Mechanisms of Processing the Four Aspects of Verb Argument Structure Complexity

Empirical studies investigating the cognitive neural mechanisms of verb argument structure complexity encompass four dimensions: processing mechanisms under different argument quantities, different argument subcategorization selection patterns, different thematic role assignment modes, and different mapping alternations.

2.1 Cognitive Neural Mechanisms of Verb Argument Structure Processing Under Different Argument Quantities

Syntactic analysis posits that different verbs possess varying numbers of arguments, constituting distinct argument structures. Examples (1a), (1b), and (1c) illustrate that intransitive, transitive, and ditransitive verbs form single-argument, double-argument, and triple-argument syntactic structures, respectively. Moreover, an argument structure with *n* arguments entails the representation of *n* semantic meanings bearing specific thematic roles. Consequently, the greater the number of arguments, the more complex the syntactic structure and argument semantic representation become (Thompson et al., 2013). Grounded in this theoretical framework, research on the cognitive neural mechanisms of verb argument structure processing under different argument quantities primarily compares the processing mechanisms of intransitive, transitive, and ditransitive verbs.

(1a) Tom cried. / 汤姆哭了。(NP1(agent)+V)
(1b) Tom hit Lily. / 汤姆打了莉莉。(NP1(agent)+V+NP2(patient))

(1c) Tom gave Lily a present. / 汤姆送莉莉礼物。(NP1(agent)+V+NP2(recipient)+NP3(patient))

Numerous empirical studies indicate that a greater number of arguments consumes more cognitive neural resources during argument structure processing. Ren and Liang (2014) investigated the production of argument structures with intransitive, transitive, and ditransitive verbs in Chinese-speaking children with intellectual disabilities through a single-picture description task. Results revealed that these children exhibited significantly more subject argument omissions when producing transitive and ditransitive argument structures compared to intransitive structures. Barbieri et al. (2019) employed a similar experimental design with healthy Italian participants and found that production reaction times were longest for ditransitive verb argument structures, intermediate for transitive structures, and shortest for intransitive structures. The lexicalist syntactic view holds that verb lexical information contains corresponding argument structure information; thus, processing of individual verbs can reflect argument structure processing (Bachrach et al., 2014; Thompson et al., 2013). Numerous studies using lexical naming tasks have demonstrated that both healthy participants and individuals with aphasia experience the greatest difficulty producing ditransitive verbs, moderate difficulty with transitive verbs, and the least difficulty with intransitive verbs (Barbieri et al., 2019; Caley et al., 2017; Malyutina et al., 2016; Thompson et al., 2013; Wang & Thompson, 2016). Furthermore, Thompson et al. (2013) suggested that differential performance in processing varying argument quantities among aphasic patients likely relates to lesion location. Studies by Caplan et al. (2000) and Dronkers et al. (2004) indicate that aphasic patients' lesions are often located near the left inferior frontal gyrus (IFG) and perisylvian regions. Therefore, the left inferior frontal gyrus and perisylvian regions may be associated with the cognitive neural processing of multiple arguments (Thompson et al., 2013), a conclusion supported by fMRI evidence.

To exclude confounding factors such as sentence length, fMRI studies investigating the cognitive neural mechanisms of argument quantity processing have examined individual verb processing based on the lexicalist syntactic view (den Ouden et al., 2009; Meltzer-Asscher et al., 2015; Tompson et al., 2007; Thompson et al., 2010). Lexical decision fMRI tasks have examined brain activation patterns when participants processed English intransitive verbs (die/fade/sit/sneeze), transitive verbs (achieve/adopt/hold/explore), and ditransitive verbs (borrow/bring/buy/teach) (Meltzer-Asscher et al., 2015; Tompson et al., 2007). Results showed that compared to intransitive verbs, transitive verb processing elicited significant activation in the left posterior perisylvian region. Processing of both transitive and ditransitive verbs activated bilateral posterior perisylvian regions. Using a similar design to their 2007 study, Tompson et al. (2010) examined brain activation during processing of English intransitive, transitive, and ditransitive verbs (using the same stimuli as Tompson et al., 2007) in both aphasic patients (nine with lesions in left frontotemporal regions, three with unspecified lesion locations) and healthy controls. Consistent with their 2007 findings, healthy participants showed significant posterior perisylvian activation when processing verbs with more arguments. Among aphasic patients, four exhibited unilateral activation in posterior perisylvian regions (one left hemisphere, three right hemisphere), possibly due to damage in the corresponding contralateral brain areas. The three patients with right perisylvian activation had left temporoparietal lesions, while the one with left perisylvian activation had right frontotemporal damage. Additionally, den Ouden et al. (2009) employed a picture-word matching task to examine brain activation during processing of English transitive (kiss/stir/cut/put) and intransitive (cry/sleep/laugh/jump) verbs in zero context. Results revealed that transitive verb processing, compared to intransitive verbs, significantly activated the posterior perisylvian regions and left inferior frontal gyrus.

Lexical items in the mental lexicon undergo derivation to form initial syntax (deep syntax), which then transforms into surface syntax through specific mapping rules. Friederici (2011) and Friederici and Kotz (2003) found that the left inferior frontal gyrus is involved in initial syntactic processing. As previously noted, different argument quantities yield different initial syntactic structures. Therefore, activation of the left inferior frontal gyrus during multi-argument processing suggests its involvement in initial syntactic structure processing during verb argument structure processing (den Ouden et al., 2009). Moreover, meta-analyses reveal that posterior perisylvian regions are closely associated with semantic representation of core nouns in event structures (Binder et al., 2009). As syntactic analysis demonstrates, different argument quantities entail different argument semantic representations. Thus, activation of posterior perisylvian regions during processing of argument structures with more arguments indicates their potential involvement in argument semantic representation during verb argument structure processing (den Ouden et al., 2009; Meltzer-Asscher et al., 2015; Tompson et al., 2010).

Recent research also suggests that the left inferior frontal gyrus is involved in complex semantic processing (Wang & Huang, 2019). The aforementioned fMRI tasks were conducted in zero context, making it difficult to exclude semantic influences. This might suggest that the left inferior frontal gyrus activation observed in these studies could be related to verb semantic processing. However, this possibility appears unlikely because, from a semantic perspective, both transitive verbs and unergative intransitive verbs denote actions with high semantic concreteness and should exhibit similar processing difficulty. Transitive verbs should be even easier to process than unaccusative intransitive verbs, which denote states. Yet all experimental results indicate that transitive verbs are more difficult to process than intransitive verbs.

Furthermore, Meltzer-Asscher et al. (2015) noted that although Tompson et al. (2007) selected stimuli differing primarily in argument quantity, some verbs (e.g., transitive verbs and alternating unaccusative verbs) also varied in thematic role assignment complexity. Consequently, Meltzer-Asscher et al. (2015) selected only simple unaccusative verbs, as these share a single thematic role assignment pattern with general transitive verbs. However, some transitive verbs in their study (e.g., "accept") differed from intransitive verbs not only in argument quantity but also in argument subcategorization selection patterns. Although these verbs constituted a small proportion, they could still potentially influence experimental results.

2.2 Cognitive Neural Mechanisms of Verb Argument Structure Processing Under Different Argument Subcategorization Selection Patterns

Syntactic analysis suggests that verbs differ in their argument subcategorization selection patterns regarding the exclusivity versus selectivity of grammatical unit properties. Example (2a) shows that for verbs with exclusive subcategorization, argument categories can only be nouns (phrases) or clauses. Example (2b) demonstrates that for verbs with alternating subcategorization, argument structures may select either nouns/nominal phrases or clauses. This distinction determines differences in both surface and initial syntactic structures: the former yields unique surface and initial syntactic structures, while the latter exhibits selectivity, rendering its argument structure syntactically more complex (Bachrach et al., 2014). Based on this theoretical foundation, research on cognitive neural mechanisms under different argument subcategorization selection patterns primarily compares processing mechanisms between verbs with exclusive versus alternating subcategorization patterns.

(2a) Tom hit Lily. (NP+V+NP)
Tom thought Lily is beautiful. / 汤姆认为莉莉漂亮。(NP1+V+clause)

(2b) Tom hated Lily. / 汤姆讨厌莉莉。(NP+V+NP)
Tom hated that his parents lied. / 汤姆讨厌他父母撒谎。(NP+V+clause)

Empirical research demonstrates that more complex argument subcategorization selection patterns consume greater cognitive neural resources during argument structure processing. Malyutina et al. (2016) analyzed large samples of narrative discourse materials and found that compared to verbs with exclusive subcategorization, aphasic patients produced fewer argument structures with alternating subcategorization and exhibited lower accuracy rates, indicating that verbs with more subcategorization options involve more complex cognitive neural processing. Early behavioral experiments (Chodorow, 1979) and fMRI studies (Malyutina et al., 2017; Shetreet et al., 2010b) also show that processing alternating subcategorization verb argument structures requires greater cognitive neural resource expenditure. Furthermore, fMRI research indicates that functional brain regions involved in alternating subcategorization processing primarily include the left inferior frontal gyrus, left middle-posterior frontal lobe, left superior temporal gyrus (STG), and left middle-posterior temporal lobe.

Early fMRI research using auditory stimulation tasks required participants to judge whether sentence content occurred at home, examining processing of Hebrew sentences with exclusive subcategorization verbs (Dan hidlik [esh] [ba-kirayim]/Dan lit [fire]theme [in-the-stove]adjunct) and alternating subcategorization verbs (Gal [the-book]theme ha-sefer] [in-the-midnight]adjunct/Sara nista [et ha-kova] [b-a-xanut]/Sara tried [the-hat]theme [in-the-shop]adjunct) (Shetreet et al., 2010b; Shetreet et al., 2007). Results revealed that compared to the former, processing the latter significantly activated the left superior temporal gyrus and left inferior frontal gyrus. A recent study using sentence plausibility judgment tasks examined processing of English sentences with exclusive subcategorization verbs (The user completed the survey) and alternating subcategorization verbs (The swimmer hated the referee) (Malyutina et al., 2017). Findings showed that compared to the former, processing the latter activated the left middle-posterior frontal lobe, left middle-posterior temporal lobe, and temporo-parietal areas.

As previously mentioned, the left inferior frontal gyrus is closely associated with initial syntactic processing (Friederici & Kotz, 2003), while studies on ambiguous syntactic structures have found that the left middle-posterior frontal lobe is primarily involved in initial syntactic processing of alternating syntax (Mason et al., 2003). Syntactic analysis indicates that different argument subcategorization selection patterns entail varying complexity in initial syntactic structures. Therefore, activation of the left inferior frontal gyrus and left middle-posterior frontal lobe during alternating subcategorization processing suggests their involvement in initial syntactic processing during verb argument structure processing (Shetreet et al., 2007; Thompson & Meltzer-Asscher, 2014). Rodd et al. (2010) found that the left temporal lobe is associated with surface structure processing of alternating syntax. As syntactic analysis demonstrates, argument subcategorization selection patterns affect surface syntactic complexity. Thus, activation of the left superior temporal gyrus and middle-posterior temporal lobe during alternating subcategorization processing indicates their involvement in surface syntactic processing during verb argument structure processing (Shetreet et al., 2010b, 2007; Malyutina et al., 2017).

2.3 Cognitive Neural Mechanisms of Verb Argument Structure Processing Under Different Thematic Role Assignment Modes

Thematic roles refer to semantic roles assigned by verbs to arguments, such as agent, patient, and theme. Syntactic analysis suggests that verbs differ in their thematic role assignment patterns regarding exclusivity versus selectivity. Example (3a) shows that simple verbs assign thematic roles in only one way, exhibiting an exclusive pattern. Example (3b) demonstrates that alternating verbs possess two subcategorization subclasses (transitive and intransitive) and assign thematic roles in two ways, exhibiting a selective pattern (Cuervo, 2014; Fadlon, 2016; Rappaport-Hovav & Levin, 2011). Consequently, compared to simple verbs, alternating verbs exhibit more complex argument semantic representations and syntactic structures. Based on this theoretical foundation, research on cognitive neural mechanisms under different thematic role assignment modes primarily compares processing mechanisms between simple and alternating verbs.

(3a) [Tom] [hit Lily]. ([agent] [V theme])
(3b) [The worker] [opened the door.] / 工人打开了那扇门。([agent] [V theme])
[The door] [opened.] / 那扇门打开了。([theme] [V])

Most empirical studies indicate that alternating thematic role assignment requires more cognitive neural resources than exclusive assignment. Wang and Thompson (2016) examined aphasic patients' processing of simple versus alternating verbs through a lexical naming task based on the lexicalist syntactic view. Results showed that aphasic patients experienced greater difficulty processing alternating verbs. Another study with healthy participants using a similar design found longer reaction times for producing alternating verbs compared to simple verbs (Barbieri et al., 2019). Additionally, fMRI research reveals that alternating thematic role assignment activates additional functional brain regions, further indicating that processing more thematic role assignment options consumes greater cognitive neural resources.

Based on the lexicalist syntactic view, Meltzer-Asscher et al. (2013) used a lexical decision task to compare brain activation patterns during processing of English alternating verbs (break/roll/tear/sink) and simple verbs (laugh/cry/wink/sniff). Results showed that alternating verb processing, compared to simple verb processing, activated bilateral posterior perisylvian regions and the left middle-posterior frontal lobe. Malyutina et al. (2017) employed sentence plausibility judgment tasks to examine brain activation during processing of English alternating verb sentences (The scientist collected the samples) and simple verb sentences (The maid cleaned the room). Findings revealed that alternating verb sentence processing significantly activated the left inferior frontal gyrus and left middle-posterior frontal lobe compared to simple verb sentences.

As previously analyzed, the left inferior frontal gyrus is primarily associated with initial syntactic processing (Friederici & Kotz, 2011). fMRI studies on processing of category-ambiguous words have found that the left inferior frontal gyrus and left middle-posterior frontal lobe are involved in verb subcategorization determination (Mason & Just, 2007). Thompson and Meltzer-Asscher (2014) also suggested that the left middle-posterior frontal lobe may be involved in initial syntactic processing. Syntactic analysis indicates that different thematic role assignment patterns entail varying complexity in initial syntactic structures and different numbers of verb subcategorization options. Therefore, activation of the left inferior frontal gyrus and left middle-posterior frontal lobe during alternating thematic role assignment processing suggests their involvement in initial syntactic processing and verb subcategorization determination during verb argument structure processing (Malyutina et al., 2017). Additionally, previous analyses have shown that posterior perisylvian regions are involved in semantic representation of core nouns in event structures (Binder et al., 2009). Syntactic analysis demonstrates that different thematic role assignment patterns yield different argument semantic representations. Thus, activation of posterior perisylvian regions during alternating thematic role assignment processing indicates their involvement in argument semantic representation during verb argument structure processing (Meltzer-Asscher et al., 2013).

Moreover, Malyutina et al. (2017) noted that although Meltzer-Asscher et al. (2013) focused on processing differences across thematic role assignment modes, their study included some simple unergative verbs and some alternating unaccusative verbs, which differ in mapping patterns. Consequently, the additionally activated brain regions might reflect not only processing differences in thematic role assignment modes but also differences in mapping patterns. However, this possibility appears unlikely because Meltzer-Asscher et al. (2013) examined verbs in zero context without arguments present, whereas the realization of unaccusative verb mapping patterns is closely tied to arguments.

2.4 Cognitive Neural Mechanisms of Verb Argument Structure Processing Under Different Mapping Patterns

Syntactic analysis posits that arguments bearing specific thematic roles in deep structure map to particular syntactic positions in surface structure: agent arguments typically map to surface subject positions, while theme arguments map to surface object positions. Mapping that follows conventional correspondences between thematic roles and surface syntactic positions constitutes canonical mapping, whereas mapping that violates these correspondences constitutes noncanonical mapping (Wang & Yang, 2018). Compared to unergative and transitive verbs, the argument structures of both unaccusative and passive verbs represent noncanonical mapping patterns (Momma et al., 2018; Perlmutter, 1978; Vernice & Guasti, 2015). Example (4a) shows that unaccusative verb arguments are assigned the thematic role of theme and occupy internal argument positions in deep structure, whereas unergative verb arguments are assigned the agent role and occupy external argument positions. Although both unaccusative and unergative argument structures surface as "NP+V," the former' s surface subject derives from syntactic movement of the deep internal argument and bears the theme role, constituting a noncanonical mapping pattern. In contrast, the latter' s surface subject maps directly from the deep external argument and bears the agent role, representing canonical mapping. Additionally, transitive verbs become passive when marked with passive morphology (e.g., "was hit"), and passive verbs share unaccusative properties (Chomsky, 1981). Example (4b) shows that the patient argument in passive verb argument structures undergoes syntactic movement from internal argument to surface subject position, bearing the patient role. Therefore, passive verb argument structure mapping also represents noncanonical mapping. Since surface arguments in noncanonical mapping structures occupy syntactic positions (surface subject) that are asymmetrically related to their thematic roles (patient or theme), the mapping process and surface argument syntactic-semantic integration are more complex than in canonical mapping structures (Momma, 2018; Vernice & Guasti, 2015). Based on this theoretical foundation, research on cognitive neural mechanisms under different mapping patterns primarily compares processing mechanisms between unaccusative and unergative verb argument structures, as well as between passive and active sentences.

(4a) [(Subject/agent)Tom] [cried.] (Deep argument structure of unergative verb)
[(Subject/agent)Tom] [cried.] (Surface argument structure of unergative verb)
[e] [died(Object/theme)Tom.] (Deep argument structure of unaccusative verb)
[(Subject/theme)Tomi] [died(Object/theme)ti] / 汤姆死了。(Surface argument structure of unaccusative verb)

(4b) [(Subject/agent)Tom] [hit(Object/patient)Lily.] (Deep argument structure of transitive verb)
[(Subject/agent)Tom] [hit(Object/patient)Lily.] (Surface argument structure of transitive verb)
[e] [was hit(Object/patient)Lily.] (Deep argument structure of passive verb)
[(Subject/patient)Lilyi] [was hit(Object/theme)ti] (Surface argument structure of passive verb)

2.4.1 Cognitive Neural Mechanisms of Unaccusative and Unergative Verb Argument Structure Processing Current empirical research indicates that functional brain regions involved in unaccusative verb argument structure processing primarily include the left frontal and temporal lobes. First, aphasia studies using lexical naming tasks (Sung, 2016; Thompson, 2003) and picture-sentence matching tasks (McAllister et al., 2009; Sullivan et al., 2017) have consistently shown that compared to healthy controls, aphasic patients produce fewer unaccusative verb argument structures, with lower accuracy and longer reaction times. Additionally, Lee and Thompson (2011) used eye-tracking technology to examine production of unaccusative sentences (The black tube is floating) and unergative sentences (The black dog is barking) in healthy participants and aphasic patients. Results revealed longer eye fixation times and significant delays when aphasic patients produced unaccusative verbs compared to healthy controls. Thompson and Meltzer-Asscher (2014) suggested that difficulties in processing unaccusative verb argument structures among aphasic patients likely relate to lesion location. Aphasia typically results from damage to Broca' s area (primarily left frontal lobe) and Wernicke' s area (primarily left temporal lobe). Therefore, Thompson and Meltzer-Asscher (2014) further proposed that impaired ability to process unaccusative verb argument structures in aphasic patients indicates that the left frontal and temporal lobes are involved in the cognitive neural processing of unaccusative verbs, a conclusion supported by fMRI evidence.

Early fMRI studies using auditory stimulation tasks required participants to judge whether Hebrew unaccusative verb sentences (ha-yeled nafal [me-ha-mita ha-xadasha]/The boy fell [from the new bed]adjunct), unergative verb sentences (ha-yalda hit atsha [al ha-shatiax ha-adom]/The girl sneezed [on the red carpet]adjunct), and transitive verb sentences (ha-yeled nish an [al ha-ec ha-gavoah]/The boy leaned [on the tall tree]complement) described events occurring at home. Results showed that compared to unergative and transitive sentences, unaccusative sentence processing significantly activated the left inferior frontal gyrus and left middle temporal gyrus (MTG), while no significant differences in activation were observed between unergative and transitive sentences (Shetreet et al., 2010a). Subsequently, using a similar design to their 2010 study, Shetreet and Friedmann (2012) examined brain activation during processing of Hebrew unaccusative sentences (Dana hitmoteta [ba-rexov ha-rashi]/Dana collapsed [in the main street]adjunct+modifier), unergative sentences (Dana hit' amla [ba-rexov ha-rashi]/Dana exercised [in the main street]adjunct+modifier), and reflexive verb sentences (Dana hitgarda [ba-rexov ha-rashi]/Dana scratched herself [in the main street]adjunct+modifier). Findings revealed that compared to unergative and reflexive sentences (canonical mapping), unaccusative sentence processing significantly activated the left inferior frontal gyrus and middle temporal gyrus. A recent study employing a design similar to Shetreet et al. (2010) examined brain activation during processing of unaccusative and unergative sentences with identical surface syntactic structures "NP+V+Det+N+PP" (Agnew et al., 2014). Results showed that compared to unergative sentences, unaccusative sentence processing significantly activated the superior temporal gyrus. Another recent study based on the lexicalist syntactic view used a lexical decision task to compare brain activation during processing of simple English unaccusative verbs (appear/arrive/come/died), unergative verbs (sneeze/kneel/blink/rest), and transitive verbs (accept/adopt/build/collect) in zero context (Meltzer-Asscher et al., 2015). Findings revealed that compared to unergative and transitive verbs, unaccusative verb processing activated the left inferior frontal gyrus. Integrating these results with Shetreet and Friedmann (2012), Meltzer-Asscher et al. (2015) suggested that these findings indicate that unaccusative verb argument structures employ noncanonical mapping and that verb lexical information contains syntactic information about argument movement. However, this interpretation appears questionable because noncanonical mapping in argument structures is realized through syntactic movement of theme arguments, yet Meltzer-Asscher et al. (2015) examined individual unaccusative verbs without containing theme arguments.

In fact, unaccusative and unergative verbs also differ substantially in semantics: the former expresses non-volitional states while the latter expresses volitional actions. The former has lower semantic concreteness and more complex processing. As previously noted, the left inferior frontal gyrus is also related to complex semantic processing (Wang & Huang, 2019). Therefore, the left inferior frontal gyrus activation in Meltzer-Asscher et al. (2015) may reflect semantic processing of unaccusative verbs.

Furthermore, except for Meltzer-Asscher et al. (2015), other fMRI studies selected unaccusative verbs that included alternating verbs, making it possible that complexity differences in experimental stimuli reflected not only noncanonical mapping but also thematic role assignment patterns.

2.4.2 Cognitive Neural Mechanisms of Passive and Active Sentence Argument Structure Processing Empirical research demonstrates that passive sentence argument structure processing is more complex than active sentence processing. An early aphasia study using picture-sentence matching tasks found higher error rates in aphasic patients' production of passive sentences compared to active sentences (Friederici & Graetz, 1987). Cho-Reyes and Tompson (2012) employed sentence priming experiments and found that aphasic patients produced passive sentences with significantly higher error rates than active sentences. Similar results have been reported in other studies (Faroqi-Shah & Thompson, 2003; Grodzinsky, 2000). Recent research using eye-tracking technology examined comprehension of active and passive sentences in healthy participants and aphasic patients (Mack et al., 2016). Results showed longer eye fixation times when aphasic patients processed passive sentences compared to active sentences, indicating greater cognitive neural resource consumption during passive verb argument structure processing. Liu and Yang (2016) used ERP technology with sentence plausibility judgment tasks to examine processing of Chinese pivotal passive sentences (客户被老板指使员工赶走了/The client was instructed by the boss to have the employee driven away) and active pivotal sentences (经理和老板同意员工出国了/The manager and boss agreed that the employee could go abroad). Results revealed that compared to canonically mapped active pivotal sentences, noncanonically mapped passive pivotal sentences elicited larger anterior negativities and relatively smaller P600 components at VP2 (e.g., "赶走/driven away"), and only anterior negativity effects at VP1 (e.g., "指使/instructed"). Analyses suggest that anterior negativity effects reflect retrieval of moved constituents from working memory, while P600 effects reflect syntactic integration after establishing syntactic dependencies between moved constituents and their traces. Therefore, passive sentence argument structure processing consumes more cognitive neural resources. Using a similar design, another ERP study examining the cognitive neural mechanisms of empty category processing in Chinese compared brain responses to general passive sentences (窗户被母亲擦了两遍/The window was wiped twice by mother) and general active sentences (昨天母亲擦了桌子/Yesterday mother wiped the table). Results showed that compared to active sentences, passive sentences elicited significant P600-like effects at sentence-final positions (e.g., "两遍/twice"). Analyses suggest that P600-like effects reflect cognitive neural processing during noncanonical mapping, including retrieval of moved constituents from working memory, establishment of syntactic dependencies with their traces, and integration into verb argument structures (Liu & Jiang, 2016). Additionally, since aphasia typically results from left frontal and temporal lobe damage, Mack et al. (2016) proposed that impaired passive structure processing ability in aphasic patients indicates that functional brain regions for passive verb argument structure processing involve the left frontal and temporal lobes, a view also supported by fMRI research.

Mack et al. (2013) used auditory stimulation tasks in which participants heard

English active sentences (The boy is hugging the girl) and passive sentences (The girl was hugged by the boy) and performed picture-sentence matching tasks with button responses. Results showed that compared to active sentences, passive sentence processing elicited significant activation in the left inferior frontal gyrus and left temporo-occipital cortex. A recent study using a similar design examined brain activation during processing of Chinese active sentences (小狗把骨头叼走了/The puppy carried away the bone), passive sentences (骨头被小狗叼走了/The bone was carried away by the puppy), and general declarative sentences (小狗叼走了骨头/The puppy carried away the bone) (Feng et al., 2015). Results revealed that compared to general declarative sentences, passive sentence processing produced significant activation in left frontal and temporal regions. Compared to active sentences, passive sentence processing elicited significant activation in the left inferior frontal gyrus and left posterior superior temporal gyrus.

Research investigating syntactic movement processing mechanisms has found that the left inferior frontal gyrus is closely associated with syntactic movement operations (Constable et al., 2004; Friedmann & Shapiro, 2003). As previously analyzed, noncanonical mapping involves syntactic movement. Therefore, activation of the left inferior frontal gyrus during noncanonical mapping argument structure processing suggests its involvement in syntactic movement operations during argument structure processing (Feng et al., 2015; Mack et al., 2013; Meltzer-Asscher et al., 2015; Shetreet et al., 2010a). Studies examining surface syntactic-semantic integration mechanisms have found that the left temporal lobe is involved in syntactic-semantic integration of subjects and objects in surface syntactic structures (Caplan, 2010; Hirotani et al., 2011). As syntactic analysis demonstrates, surface argument syntactic-semantic integration is more complex in noncanonical mapping argument structures. Therefore, activation of the left superior temporal gyrus, left middle temporal gyrus, and left posterior temporal lobe during noncanonical mapping argument structure processing suggests their involvement in surface argument syntactic-semantic integration during argument structure processing (Agnew et al., 2014; Feng et al., 2015; Mack et al., 2013; Meltzer-Asscher et al., 2015; Shetreet et al., 2010a).

2.5.1 Summary

Syntactic analysis suggests that the number of arguments, argument subcategorization selection patterns, thematic role assignment modes, and mapping patterns collectively reflect verb argument structure complexity. The empirical studies reviewed above demonstrate that more complex argument structures involve more complex cognitive neural processing mechanisms. Current fMRI and some aphasia research findings regarding functional brain regions involved in various aspects of argument structure complexity and their potential cognitive processing roles are summarized in Table 1 .

Table 1 Correspondence among Verb Argument Structure Complexity, Functional Brain Regions, and Cognitive Neural Processing

Verb Argument Structure Complexity	Functional Brain Regions	Cognitive Neural Processing Involved
Multiple Arguments	Posterior Perisylvian Regions	Argument Semantic Representation
	Left Inferior Frontal Gyrus	Initial Syntactic Processing
Alternating Argument Subcategorization	Left Superior Temporal Gyrus & Middle-Posterior Temporal Lobe	Surface Syntactic Processing
	Left Inferior Frontal Gyrus	Initial Syntactic Processing
Alternating Thematic Role Assignment	Left Middle-Posterior Frontal Lobe	Initial Syntactic Processing
	Posterior Perisylvian Regions	Argument Semantic Representation
Noncanonical Mapping	Left Inferior Frontal Gyrus	Initial Syntactic Processing, Verb Subcategorization Determination
	Left Middle-Posterior Frontal Lobe	Initial Syntactic Processing, Verb Subcategorization Determination
	Left Superior Temporal Gyrus, Middle Temporal Gyrus & Posterior Temporal Lobe	Surface Argument Syntactic-Semantic Integration
	Left Inferior Frontal Gyrus	Syntactic Movement, Unaccusative Verb Semantic Processing

Note: Current empirical studies examining specific aspects of argument structure complexity maintain consistency in stimuli by isolating the particular complexity dimension under investigation. Therefore, their results and conclusions should be considered referential. Moreover, most previous studies have discussed correspondences between specific functional brain regions and cognitive neural processing stages of verb argument structures by integrating findings from prior research, yielding relatively indirect conclusions.

2.5.2 Hypotheses Regarding Interactive Effects of Argument Structure Complexity

Table 1 also suggests that argument semantic representation may be related to argument number and thematic role assignment; initial syntactic processing may be related to argument number, argument subcategorization selection, and thematic role assignment; surface argument syntactic-semantic integration and mapping processes may be related to mapping patterns; and surface syntactic processing may be related to argument subcategorization selection. Thompson and Meltzer-Asscher (2014) noted that surface syntactic processing is also related to argument number. These associations demonstrate that certain aspects of verb argument structure complexity involve identical cognitive neural processing stages, indicating interactive effects. Building on Meltzer-Asscher et al. (2015) and other studies, verb argument structure processing (production and comprehension) involves argument semantic representation, initial syntactic structure processing (construction and deconstruction), mapping (reverse mapping, where mapping refers to the process from initial to surface syntax and reverse mapping refers to the process from surface to initial syntax), surface syntactic structure processing (construction and deconstruction), and surface argument syntactic-semantic integration. From the perspective of verb argument structure production, these interactive effects may manifest as follows: thematic role assignment influences argument number, which in turn affects argument semantic representation and initial syntactic construction. Argument subcategorization selection also influences initial syntactic construction and subsequently affects surface syntactic construction. Mapping patterns affect the mapping process and surface argument syntactic-semantic integration. From the perspective of verb argument structure comprehension, interactive effects may manifest as: thematic role assignment influences argument number, which affects surface syntactic deconstruction, initial syntactic deconstruction, and argument semantic representation. Argument subcategorization selection also influences surface and initial syntactic deconstruction. Mapping patterns affect surface argument syntactic-semantic integration and reverse mapping. Additionally, from a lexical perspective, the argument structure complexity of individual verbs often manifests across multiple dimensions (Bachrach et al., 2014; Malyutina et al., 2017). For example, the verb "break" exhibits complexity in thematic role assignment, mapping patterns, and argument number: when "break" assigns thematic roles as "[agent] [V theme]," its surface argument structure is realized through canonical mapping with two arguments; when assigning roles as "[theme] [V]," its surface argument structure is realized through noncanonical mapping with one argument. Therefore, from a lexical perspective, thematic role assignment influences mapping patterns and argument number. In summary, interactive effects of argument structure complexity during production and comprehension may be represented in Figure 1 [Figure 1: see original paper] and Figure 2 [Figure 2: see original paper], respectively.

Note: Black font in the figures indicates dimensions of verb argument structure *complexity, red font indicates stages of verb argument structure processing, black lines connect processing stages, and light blue arrows indicate "influences."*

Given these interactive effects among certain aspects of verb argument structure complexity, subsequent research examining the cognitive neural mechanisms of specific complexity dimensions should ideally control for other aspects of complexity. For instance, when investigating noncanonical mapping complexity, selecting "die" and "come" as a control pair is preferable to selecting "break" and "come," as the former pair differs only in mapping patterns while the latter pair differs in both mapping patterns and thematic role assignment modes.

3. Research Prospects

While research on the cognitive neural mechanisms of verb argument structure complexity processing has achieved the aforementioned results, several issues remain for further investigation.

3.1 Correspondence Between Verb Argument Structure Complexity and Processing Difficulty

Although numerous empirical studies suggest that greater verb argument structure complexity corresponds to increased processing difficulty, some research has reached contradictory conclusions. A recent fMRI study using lexical decision tasks found that compared to transitive verbs, intransitive verb processing elicited significant activation in the left frontal and temporal lobes (Hernandez et al., 2014). Rodriguez-Ferreiro et al. (2014) also found lower accuracy and longer reaction times for intransitive verb processing compared to transitive verbs using lexical decision tasks. Thus, transitive verbs with higher argument structure complexity appear easier to process than less complex intransitive verbs. Hernandez et al. (2014) and Rodriguez-Ferreiro et al. (2014) both argued that verbs with more arguments contain richer semantic information that is more easily accessed. Another recent fMRI study using lexical decision tasks examined brain activation during processing of individual English alternating versus simple verbs (Malyutina et al., 2017). Results showed that alternating verb processing, compared to simple verb processing, significantly activated the left temporal lobe. Additionally, Malyutina et al. (2017) investigated processing of English verbs with exclusive versus alternating subcategorization patterns using lexical decision tasks. Findings revealed that processing exclusive subcategorization verbs, compared to alternating subcategorization verbs, produced significant activation in bilateral frontal regions. The authors suggested that although alternating verbs and verbs with alternating subcategorization exhibit higher argument structure complexity, their richer semantic information makes lexical semantics more accessible in zero context. In summary, the correspondence between verb argument structure complexity and processing difficulty remains controversial. Resolving this controversy could provide references for refining models of lexical representation and verb argument structure processing. Therefore, this disagreement represents a potential topic for future research.

Subsequent studies might employ ERP technology to examine processing of argument structures with varying complexity, providing comparisons with fMRI and other empirical findings while expanding research methodologies.

3.2 Hierarchical Difficulty Levels and Interactive Cognitive Neural Mechanisms of Verb Argument Structure Complexity

Compared to transitive verbs, unaccusative verb argument structure processing elicits activation in additional functional brain regions (Meltzer-Asscher et al., 2015; Shetreet et al., 2010a), suggesting that noncanonical mapping is more difficult to process than multiple arguments and that different aspects of argument structure complexity may exhibit hierarchical difficulty levels. However, current empirical studies have only examined individual aspects of argument structure complexity in isolation, leaving the cognitive neural mechanisms of complexity interactions without direct empirical support. Investigating hierarchical difficulty levels and interactive cognitive neural mechanisms of complexity could deepen understanding of verb argument structure processing mechanisms. Therefore, these issues represent potential directions for future research. When examining hierarchical difficulty levels, researchers might draw inspiration from Europa et al. (2019), who investigated hierarchical difficulty in syntactic movement processing, by using fMRI and other techniques to first compare brain activation between high- and low-complexity argument structures within the same dimension, then compare results across different complexity dimensions. When investigating interactive effects, researchers could compare brain activation patterns between control groups differing in single complexity dimensions versus those differing across multiple dimensions. Furthermore, subsequent syntactic research might explore the motivations and mechanisms underlying interactive effects of verb argument structure complexity from perspectives of lexical evolution and grammaticalization, complementing empirical findings.

3.3 Cognitive Neural Mechanisms of Chinese Verb Argument Structure Complexity Processing

Current research examining the cognitive neural mechanisms of Chinese verb argument structure complexity processing remains relatively limited. Moreover, Chinese verb argument structure complexity exhibits distinct language-specific properties across multiple dimensions that warrant further empirical investigation or verification.

3.3.1 Mapping Patterns of Chinese Unaccusative Verb Argument Structures Chinese unaccusative verbs can take objects to form "overt unaccusative structures" such as "来了客人" (came guests). Chinese unergative verbs can also take objects, as in "我们宿舍睡了两个人" (our dorm slept two people). Therefore, both Chinese unaccusative and unergative argument structures might be considered canonical mapping structures (Shen, 2018). However, recent research argues that Chinese unaccusative verb argument structures represent noncanonical mapping patterns (Han, 2019). Given that the stipulations of the “unaccusative hypothesis” are relative to “covert unaccusative structures” with surface form “NP-V” (e.g., “客人来了” / guests came), subsequent research could use fMRI and ERP techniques to compare brain activation patterns during processing of Chinese covert unaccusative structures and unergative structures. If covert unaccusative structures elicit similar ERP components or activate similar functional brain regions as unergative structures, this would support their classification as canonical mapping structures. If covert unaccusative structures, compared to unergative structures, elicit P600 components reflecting syntactic movement or activate functional brain regions such as the left inferior frontal gyrus that reflect syntactic movement, this would support their classification as noncanonical mapping structures.

3.3.2 Mapping Patterns of Chinese Possessor-Possessum Sentence Argument Structures Chinese possessor-possessum sentences (e.g., “王冕死了父亲” / Wang Mian died father [Wang Mian’ s father died]) exhibit the syntactic property that core intransitive verbs have both subjects and objects (Han, 2019). Regarding this special argument structure, some researchers consider it a canonical mapping structure (Han, 2019; Ren, 2009), others argue it involves a covert light verb expressing “experiential” meaning and constitutes a light verb argument structure (Wang, 2006), while still others propose that it involves movement of the possessor noun (e.g., “王冕” in the example) and represents a noncanonical mapping structure (Tian, 2018). ERP research has found that light verb argument structure processing elicits an anterior negativity within the 500-900ms time window (Wittenberg et al., 2014), while fMRI studies have shown that light verb argument structure processing activates the left middle frontal gyrus (Feng & Yang, 2011). Future research could employ ERP or fMRI techniques to investigate the mapping patterns of Chinese possessor-possessum sentence argument structures. If possessor-possessum sentences, compared to canonical mapping structures (e.g., “王冕骗了父亲” / Wang Mian deceived father), elicit similar ERP components or activate similar functional brain regions, this would support their classification as canonical mapping structures. If they elicit anterior negativities in the 500-900ms time window reflecting light verb processing or activate functional brain regions such as the left middle frontal gyrus associated with light verb processing, this would support their classification as light verb argument structures. If they elicit P600 components reflecting syntactic movement or activate the left inferior frontal gyrus associated with syntactic movement, this would support their classification as noncanonical mapping structures.

3.3.3 Mapping Patterns of Chinese “V+Event NP” Argument Structures In Chinese “V+Event NP” argument structures such as “做报告” (do report), “加以批评” (give criticism), “得到表扬” (receive praise), and “发生争论” (occur argument), verbs like “做” (do), “加以” (give), “得到” (receive), and “发生” (occur) express varying degrees of semantic “weight.” Consequently, the formation of such argument structures is influenced by verb semantic weight, suggesting that these structures have different mapping patterns from English light verb constructions where the verb lacks semantic content (e.g., "give" in "give a kiss") (Bai & Xue, 2015). These theoretical hypotheses require empirical verification. Related research has found that semantically abstract verbs consume more cognitive neural resources than semantically concrete verbs during processing (Alyahya et al., 2018; Rodriguez-Ferreiro et al., 2014). Therefore, future research could employ fMRI and ERP techniques to examine the cognitive neural mechanisms of "V+Event NP" argument structures with varying verb semantic weights. If argument structures with lighter semantic weight activate additional brain regions or elicit significant ERP components, this would indicate hierarchical processing difficulty for Chinese "V+Event NP" argument structures and demonstrate that their mapping patterns differ from English light verb argument structures.

3.3.4 Thematic Role Assignment in Chinese Non-canonical Object Argument Structures Compared to canonical object argument structures (e.g., "吃米饭" / eat rice, "买毛笔" / buy brush), Chinese non-canonical object argument structures (e.g., "吃食堂" / eat cafeteria, "写毛笔" / write brush, "喝大碗" / drink large-bowl) appear to have objects that do not directly enter into semantic relationships with verbs and are not direct arguments of verbs (Chen, 2017), suggesting more complex thematic role assignment processes. These theoretical hypotheses require empirical verification. Future research could employ fMRI and ERP techniques to compare brain activation patterns or ERP components during processing of different object types in Chinese argument structures. If non-canonical object argument structures, compared to canonical object structures, activate functional brain regions such as the left middle frontal gyrus that reflect complex semantic integration (Wang & He, 2017) or elicit ERP components such as N400 that reflect complex semantic integration (Wang et al., 2017), this would indicate more complex thematic role assignment and suggest that nouns in object positions may not be direct arguments of verbs.

This paper has reviewed empirical research on the cognitive neural mechanisms of verb argument structure complexity to provide timely insights into current research trends and developments. Based on the current state of research and the specific characteristics of Chinese, this paper has proposed potential directions for future investigation, aiming to advance understanding of verb argument structure complexity processing mechanisms by considering both universal aspects of human language and language-specific properties of Chinese.

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English references follow the same format as in the original text, preserved exactly as provided.

Note: Figure translations are in progress. See original paper for figures.