Chapter 6
Neural Processing of Verbal Event Structure: Temporal and Functional Dissociation Between Telic and Atelic Verbs

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Anything that happens in the world—a storm in the afternoon, a baby starting to crawl, a vase falling on the floor and breaking—is parsed by humans into individual events. This ability—termed *event segmentation*—helps humans analyze, memorize, and compare events that occur around them in order to survive. Individuated events can also be communicated to others in predicative units: sentences. Each well-formed sentence in human languages is constructed around a predicate, typically expressed by a verb. Verbs across languages parse and formulate observable events in a logically restricted fashion (e.g., Son and Cole 2008; Borer 1994; Ritter and Rosen 1998; Davis and Demidarche 2000; Hale and Keyser 1993; Van Valin 2007). Linguists have known for a long time that semantic features of verbs can influence the grammar of the sentence, like the number of arguments, or the typically used tense. The facets

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of verb meaning which have an effect on the structure of sentences in which they appear are called grammatically relevant semantic features (Pinker 1989).

This decompositional view of verbal meaning, which includes both event and argument structure, has been gaining currency in recent theoretical linguistic and neuroscience research (Kemmerer and Gonzalez-Castillo 2008). The present work describes an effort to extrapolate linguistic theory of event structure into the realm of language processing, in order to understand the neurological mechanisms underlying the difference between different types of verbal events.

6.1 Telicity and Event Structure in Linguistic Theory

Linguistic theory classifies verbs according to whether the event denoted by the verb is seen as having an inherent (telic) end-point (*fall, drop*), or whether the event is considered homogenous, or atelic (*read, worship*). Telicity, while an overtly semantic feature, is a component of verbal-event structure, relating verbal meaning to syntactic frames. Event structure of the verb is closely tied to its argument structure: for example, presence of a resultant state in telic verbs increases the number of obligatory arguments (Ramchand 2008). Interactions between event structure, especially telicity, and grammatical phenomena have been described in many typologically distinct languages, including English, Dutch, Russian, Bengali, Icelandic and Scottish Gaelic, and ASL (for a survey, see Folli and Harley 2006). In theoretical work, Ramchand (2008) has made an attempt to model these interactions in a regular manner, by unifying the predicate's event and argument properties into a cohesive framework (see Fig. 6.1) for representation of event-argument cohesion as related to event types. In Ramchand's model, events can be represented as having three phases: the Initiation phase (InitP), the Process phase (ProcP), and the Result phase (ResP). The participants involved in each phase of the event assume the roles of, respectively, the Initiator, the Undergoer, and the Resultee (note that one argument can be linked to one, two, or all three of these roles).

This system captures the fact that verbal morphology of individual languages can represent individuated elements of event structure, which allows the use of a single verbal root—though tied to different event structures—to yield telic or atelic meanings. The explanatory power of this system on the level of theoretical coverage of existing linguistic data is compelling. However, complete analysis of all known human languages with respect to their linguistic structure is, at the moment, unfeasible. An alternative ground for testing a linguistic theory is empirical evidence from an orthogonal field of language processing.

Behavioral studies have provided early evidence for telicity affecting sentence processing. A word maze[1] study by O'Bryan et al. (2003) has demonstrated that telicity and transitivity independently affect response times to a word maze task in

[1] In a word maze task, the first word of the sentence is followed by a choice of two words, only one of which can be a grammatically correct continuation of the sentence. Once the participants

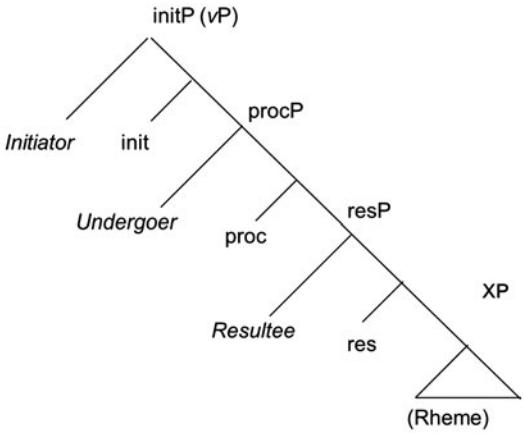

Fig. 6.1 Event structure tree model of syntax–semantics interface, after Ramchand (2008)

Object reduced relative clauses (such as "The actress awakened by the writer left in a hurry"). The experiment demonstrated an advantage to processing of sentences with telic verbs, which was evident in response time to the word "by," and an independent advantage for integration of the second argument in sentences with transitive verbs.

Another behavioral study (Friedmann et al. 2008) used a cross-modal priming technique to compare processing of sentences with intransitive atelic (unergative) and intransitive telic (unaccusative[2]) English verbs. This study has demonstrated an argument priming effect for intransitive telic verbs (non-alternating unaccusatives), but not for intransitive atelics (unergatives). From the processing standpoint, this means that the arguments of telic verbs had to be implicitly understood (or base-generated), before the verbal phrase could be processed.

While behavioral psycholinguistic research points to systematic relationships between the complexity of verbal event structure and expenditure of neural resources required for its processing, neurological correlates of verbal event structure processing—temporal and neuroanatomical—are still under investigation. The time-course of interaction between the semantics of the verb and the sentence structure in online language processing, and the mechanisms responsible for processing of event structure in the cortex are the topics of the empirical studies discussed here. We first consider the fine-grained processing timeline of verbal event structure, as evident from electroencephalography (EEG) studies, and the implications of resource use that this timeline entails; we then turn to the anatomical substrate of event processing in spoken and sign languages, and the evidence it provides for the basic mechanism of event segmentation as implemented in language.

choose the word that can correctly continue the sentence, the choice of two words for the next one is presented, and so on, until the sentence is completed. This task helps measure the typical expectancy of the word given prior context.

[2] Not all unaccusative verbs are obviously telic, however: gradient verbs such as *melt, cool, warm* can denote incomplete events—e.g., "melt somewhat, but not completely."

6.2 The Timeline of Telicity Processing in English Reduced Relative Clauses

The EEG studies that examined the influence of distinctions between the telic and atelic verbs in online sentence processing of English indicate that the difference in resource allocation for processing the two distinct verb types is both early and subtle (Malaia et al. 2008, 2012b, 2013). The design of these studies capitalized on the well-known "garden path" effect, as event-related brain potentials (ERPs) were recorded from native English speakers as they read sentences with reduced relative clauses, in which the main verb was either telic or atelic, e.g., "The actress awakened/worshipped by the writer left in a hurry." The linear (word-by-word) presentation of the sentence results in a drastic processing difference between telic and atelic stimuli at the word "by": in the telic ("awakened") version, "the actress" is processed (or base-generated) as the Patient of the verb, regardless of the fact that the noun is the Subject of the matrix clause. In the atelic version of the sentence ("worshipped"), the alternation of thematic role assignment ("actress" as the Patient, rather than the Agent of worshipping), required for recovery from garden-pathing is more complex, consuming resources of the working memory.

The ERPs in the two conditions—sentences with reduced relative clauses (RRCs) headed by telic and atelic verbs—were compared to each other, and to unreduced relative clause processing (URCs). As earlier behavioral studies of event structure processing (O'Bryan et al. 2003; Friedmann et al. 2008; etc.) reported that telic verbs facilitate interpretation of frame structure alternations in sentences with garden-paths in terms of reaction times, the ERPs to the atelic verbs were interpreted as indexing additional processing demands, previously reported as early negativities in ERP literature[3]. Overall, participants showed significant telicity effects, but the timing of the exact effects differed based on the individual processing resources. ERPs from the group with normal syntactic proficiency first diverged at the second argument, with the atelic condition eliciting larger negativity at the N100, and continuing to the P200 interval. In contrast, ERPs from the high-proficiency group diverged earlier in the sentence, on the preposition "by." This group's ERPs in atelic condition were also characterized by increased negativity relative to the telic condition, which became significant at the P200 interval (200–320 ms), and continued into the later 320–500 ms interval over fronto-central electrode sites.

The difference between the telic and atelic ERP waveforms in the normal proficiency group over the 100–200 ms interval (N100) was similar to that reported for grammatical and ungrammatical sentences requiring phrase structure re-analysis (Yamada and Neville 2007). The frontal and right distribution of this, and the following 200–320 ms component, was similar to the distribution reported by Yamada and Neville (2007), who attributed it to the ongoing processes of syntax-semantics integration. Both investigations converge on the conclusion that previously encountered

[3] All stimuli sentences were completely grammatical, so re-analysis effects typically seen for ungrammatical or semantically incorrect sentences, such as P600 or N400, could not be expected.

semantic information (verbal telicity, for example) may affect the way in which the following syntactic processing is carried out.

The fact that ERPs for telic and atelic conditions in the high-proficiency group differed earlier than in the normal proficiency group is consistent with data in Weber-Fox and Neville (2001) showing that high-proficiency subjects have greater reliance on closed-class words. Another explanation for differential processing found between the groups might lie in likely variations in verbal working memory capacity, which leads to different processing strategies (see also, Newman et al. 2013). Readers with large working memory capacity manage to keep more than one parsing possibility active, and subsequently choose the appropriate interpretation as later sentence information becomes available. ERP studies on verbal working memory reported similar ERP components in verb gapping sentences in English (Kaan et al. 2004) and anaphor resolution in German (Streb et al. 2004).

In general, EEG data provide further evidence that thematic roles defined by the verb can influence parsing decisions (cf. Frazier and Rayner 1982; MacDonald et al. 1994). The timing of this influence may in turn depend on the parsing strategy used by the comprehender; the latter might be the function of his or her linguistic proficiency, and depend on non-linguistic cognitive processes, such as the use of verbal working memory.

6.3 What Does Differential Processing of Grammatically Relevant Semantic Features Suggest for Language Processing and Linguistic Theory?

From the linguistic standpoint, the data on telicity processing are best explained by a combination of event structure and parallel processing theories. According to Ramchand's event structure model, telic verbs alternate between non-causal (intransitive) and causal (transitive) interpretation with the Subject of intransitive verb, or Object of transitive verb occupying the same Undergoer–Resultee thematic roles[4]. An additional argument, when it is introduced in the "by" construction, is added to the existing verbal phrase frame as an external Agent (or causer), but does not necessitate re-assignment of thematic roles to the already-processed argument.

Atelic verbs, on the other hand, initially assign the Agent and Undergoer roles to the first argument. When a new argument is encountered (and the verbal frame

[4] There is still a bit of a controversy regarding whether telicity of the predicate, or affectedness (or quantization) of the object argument is the relevant feature of the predicate that contributes to telicity computation. Ramchand's (2008) model encompasses both affectedness of the object and telicity in a cohesive structure, without suggesting that they are the same thing. In fact, as Ramchand (2008) notes, it is possible to have an affected quantized object in an atelic sentence (he pushed the cart around for hours), and non-quantized object in a telic predicate (they found gold in only 3 years). Importantly, telicity and object quantization tend to correlate in Germanic languages (cf. Ritter & Rosen 1998), but not in Slavic ones (cf. Malaia 2004).

changes from intransitive to transitive), thematic role re-assignment becomes necessary. It is this re-assignment of Agent and Undergoer roles between the subject and the object of the reduced relative clause with an atelic verb which elicits more negative ERPs as compared to simple addition of an extra argument in a vacant thematic role in RRCs with telic verbs.

The linguistic interpretation of the ERP data is consistent with lexically-driven parsing models of sentence processing, which suggest that basic syntactic information available with the verb controls the initial stages of comprehension, but can be quickly modified by the information coming later in the sentence. It is, however, evident that information about a predicate's event structure (and thus telicity) is available for processing at the syntax–semantics interface as soon as argument integration is to take place.

Linguistic ubiquity and processing applicability of event-structural information at the sentence level lead to two important questions related to the role of telicity construct in language development.

Second, how would a mechanism like telicity come to be realized (albeit by different means) in such a vast survey of languages (see Folli and Harley 2006, for review)? One possible explanation suggests that perceptual qualities of events, such as rapid motion in transition scenes, can be a cue to event segmentation (Zacks and Swallow 2007). Perceptual features denoting events could, in time, come to "fossilize" in the language and be coded at the syntax–semantics interface. While demonstrating this on modern spoken language material would be difficult, the study of sign languages is a fruitful testing ground for such hypothesis. Since sign languages are tied to visual modality in both production and perception, they provide the missing link to event-structure building properties of perceived events, by replicating salient perceptual cues to event segmentation during verb sign production. For this reason, sign languages are a great ground to test the hypothesis of telicity representation at the syntax–semantic interface.

6.4 Neural Link Between Processing Event Boundaries and Verb Meaning

The idea that semantic telicity plays a recognizable role in American Sign Language grammar is well-established. Studies have shown that delayed completive aspect only applies to telic stems (Brentari 1998), durative and continuative aspects cannot apply to telic predicates (Wilbur 2003, 2008, 2009); and certain mouth non-manuals are distributed according to predicate telicity type in both Austrian Sign Language and American Sign Language (Schalber 2004). Additionally, motion capture studies (Wilbur and Malaia 2008, Malaia and Wilbur 2012a, b, c; Malaia et al. 2013) demonstrated a kinematic production difference reflecting the semantic distinction between telic and atelic predicates in two unrelated sign languages: the signs representing telic events decelerate to a stop with a 50 % steeper slope than those representing atelic events. The signers, thus, appear to provide perceptual cues to the recipient as

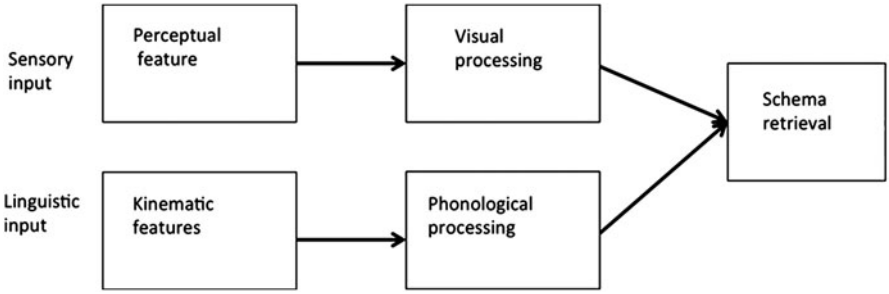

Fig. 6.2 Sensory and sign language processing parallels in event segmentation

to the event structure of the predicate. But are these cues actually received by the comprehender and processed as part of the syntax–semantics interface?

Perceptual research indicates that the manner in which reality is segmented into events affects memory encoding and updating processes (Swallow et al. 2009), and propagates the use of the perceptual features (e.g., object velocity) that relate to the retrieved event schema for future event processing (Kurby and Zacks 2008). Event segmentation theory (EST; Zacks and Swallow 2007) suggests that the information flow from visual cortex is taken apart into significant features identifying event boundaries (with velocity being processed in area MT+, for example). Those features are then used for event schema retrieval from long-term memory, possibly gated by posterior cingulate/precuneus, which is typically activated in contrasts involving event boundary (Zacks et al. 2001).

A similar mechanism appears to be in place for visual processing of event boundary, which is identified by greater deceleration in American Sign Language. The only difference is that the visual features of the linguistic signal are also processed as linguistic features (in case of ASL, phonological). A neuroimaging study (Malaia et al. 2012a) indicated that the contrast between neural activations elicited by telic and atelic ASL verb signs demonstrated activations related to event schema retrieval (posterior cingulate [MNI 18 −54 10]), and syllable weight processing (right STG and cerebellum). These data suggest that the visually expressed boundaries of events in ASL are then mapped to linguistic features of overt hand articulator motion for event schema retrieval from long-term memory (see Fig. 6.2) for the model comparison on sensory and linguistic processing of visual event boundaries.

6.5 Discussion: The Role of Telicity at the Syntax–Semantics Interface in Spoken and Signed Languages

The combined results of neuroimaging and ERP experiments point to early interaction of syntax and semantics in human languages, and suggest that grammatically relevant semantic features of the predicate's event structure, such as telicity, are used for

strategic allocation of neural resources during language processing. What follows from empirical evidence in sign and spoken languages is that not only semantics, but also syntax of human languages cross-modally are grounded in what can be construed as biological perception. In other words, the complexity of the interaction between semantics and syntax is not limited to consistent occurrence of certain structures in a specific language, as claimed by constructionist approaches, but rather operates through the complexity of linguistic structures. We suggest that events in the real world are perceived, conceptualized and verbalized in a way which takes advantage of the syntax–semantics interface with the built-in account of real-world events (Malaia and Wilbur 2014; Malaia 2014).

The evidence that the predicates which differ in visual telicity features in ASL differentially engage resources during linguistic processing highlights the theoretical relevance of event structure modeling for language processing. Finally, the combined results of the ERP experiments on English, and neuroimaging experiments in ASL suggest a direction for further research into the biological bases of human languages by identifying the links between language universals and perceptual-level features affecting event segmentation and language processing.

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