Processing psych verbs: Behavioural and MEG measures of two different types of semantic complexity

Jonathan Brennan a & Liina Pylkkänen a b

a Department of Linguistics, New York University, New York, NY, USA
b Department of Psychology, New York University, New York, NY, USA

Published online: 15 Apr 2010.

To cite this article: Jonathan Brennan & Liina Pylkkänen (2010) Processing psych verbs: Behavioural and MEG measures of two different types of semantic complexity, Language and Cognitive Processes, 25:6, 777-807, DOI: 10.1080/01690961003616840

To link to this article: http://dx.doi.org/10.1080/01690961003616840

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the “Content”) contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at http://www.tandfonline.com/page/terms-and-conditions
Many studies have addressed how linguistic complexity affects processing in online comprehension. However, little attention has been given to the relationship between different types of semantic complexity. We investigated two kinds of complexity that have previously been studied separately: coercion, where the meaning of a lexical item is shifted by context, and lexical semantic complexity, which describes the inherent semantic complexity of a lexical item. To compare their processing mechanisms, we used psychological verbs, which divide into two classes with different degrees of lexical semantic complexity, and also participate in a previously uninvestigated coercion, inchoative coercion. Using self-paced reading, we find a reading delay associated with both types of complexity, supporting theories that strongly connect representational complexity and processing. A subsequent magnetoencephalography study showed a distributed fronto-temporal effect around 300–500 ms for coercion but not for lexical semantic complexity. Our results conform with prior studies showing a prefrontal effect of coercion and suggest that lexical semantic complexity is processed via different mechanisms than coercion.

INTRODUCTION

Manipulating complexity at various levels of linguistic representation has been one of the primary tools for studying the mechanisms of language processing. Within this research, much attention has been given to the processing of different kinds of syntactic complexity (e.g., Ben-Shachar, Palti, & Grodzinsky, 2004; Caplan et al., 2002; Ferreira & Clifton, 1986;
Frazier & Fodor, 1978; Gibson, 1998; Just, Carpenter, Keller, Eddy, & Thulborn, 1996; Stromswold, Caplan, Alpert, & Rauch, 1996), while comparatively few studies have addressed the processing of different types of semantic complexity. An important question concerns whether different kinds of semantic complexity are processed by similar or different mechanisms. This paper directly compares the processing of two types of semantic complexity, coercion and lexical semantic complexity, in behaviour and the brain. Our manipulation employs psychological verbs, which offer a unique opportunity to study these two types of complexity within maximally similar expressions.

COERCION VS. LEXICAL SEMANTIC COMPLEXITY

Expressions can contrast in semantic complexity at various levels of linguistic representation. At the sentence level, complexity might vary as a function of the ease with which an interpretation can be obtained from a particular word order, as is the case, for instance, with manipulations of semantic scope. At the lexical level, there may be contrasts in the relative complexity of the semantic representations of individual lexical items. Although we understand much about how conceptual aspects of lexical meaning (e.g., concreteness) can affect lexical retrieval (e.g., Badre & Wagner, 2007; Bedny & Thompson-Schill, 2006; Binder, Desai, Graves, & Conant, 2009), relatively little is known about the effect of lexical semantic complexity on processing. The current research focuses on two types of complexity that are generally thought of as lexical level complexity. In one case, a single phonological form has either a basic or an enriched interpretation, depending on context. The mechanism that enriches the interpretation is generally called coercion. In the other case, the critical item itself is varied in such a way that in one case the inherent lexical semantic complexity of the word is higher than in the other case. Both cases of complexity are illustrated with examples below.

In the theoretical literature, the term “coercion” is used for a shift in meaning that resolves what would otherwise be a semantic mismatch between two expressions in a sentence (Pustejovsky, 1995) (also known as “type shifting”; Partee & Rooth, 1983). For example, many English verbs are able to combine with direct objects that appear semantically incompatible with them. The verb begin, for instance, sounds perfectly natural with a noun phrase that describes an entity, as in begin the book, even though one might imagine that to qualify as an object of begin, the phrase would need to describe an event with a temporal dimension, as in begin writing a book. The crucial observation of the coercion literature is that when verbs like begin combine with an entity-denoting object, a covert event sense appears to be
present even though no word in the sentence explicitly expresses it. In other words, the professor began the book is interpreted as “the professor began some event involving the book” (e.g., a writing event). The enriched interpretation has been hypothesised to arise from coercing the entity-denoting object to an event interpretation via a lexical rule (Jackendoff, 1991; Pustejovsky, 1995), semantic operation (Pylkkänen, 2008), or pragmatic inference (de Almeida & Dwivedi, 2008).

Consistent with the hypothesis that the interpretation of sentences with coercion requires an extra interpretive computation, such sentences have been found to elicit increased processing costs as indexed by reading-time and eye-tracking measurements (Brennan & Pylkkänen, 2008; Frisson & Frazier, 2005; McElree, Traxler, Pickering, Seely, & Jackendoff, 2001; Piñango, Zurif, & Jackendoff, 1999; Todorova, Straub, Badecker, & Frank, 2000; Traxler, McElree, Williams, & Pickering, 2005; Traxler, Pickering, & McElree, 2002), as well as a unique neural profile, in comparison to noncoercion controls (Brennan & Pylkkänen, 2008; Pylkkänen, Martin, McElree, & Smart, 2008; Pylkkänen & McElree, 2007).

Many types of lexical semantic complexity do not, however, involve coercion. In fact, instead of coercion, which has been at the centre of much processing work, most theoretical research has focused on noncoercion-related lexical-semantic phenomena. A canonical example of a contrast in lexical semantic complexity is the different sets of entailments associated with different verb classes. For instance, a stative verb like love in the sentence John loves Mary carries entailments just about the presence of a state of love. In contrast, a more complex verb like break in the sentence John broke the vase carries entailments about a state (the state of being broken) as well as how that state came about (Dowty, 1979). Like coercion, differences in inherent lexical semantic complexity have been found to correlate with various processing measures, such reading times and lexical decision times (Frisson & Frazier, 2005; Gennari & Poeppel, 2003; Gillon, Kehayia, & Taler, 1999; McKoon & Macfarland, 2000, 2002). The mechanism by which this type of lexical semantic complexity might elicit increased processing costs depends on the precise details of the processing model. One possibility is that more complex words take longer to access (Gennari & Poeppel, 2003). Alternatively, if lexical semantic complexity is represented in the combinatoric syntax and semantics (e.g., Borer, 2005), more complex representations could be predicted to take longer process due to extra compositional operations.

Coercion and (noncoercive) lexical semantic complexity have so far been discussed in separate psycholinguistic literatures and the tacit assumption has appeared to be that the two phenomena are distinct. It is, however, not difficult to sketch hypotheses in which coercion is represented qualitatively similarly to noncoercive lexical semantic complexity. For example, the “enriched” interpretation of an expression such as begin the book could be
due to an alternative stored representation of begin in which, instead of an event, begin semantically selects for an entity (or, more formally, an individual) and within its lexical semantic representation specifies that the entity is the theme participant of an event that is begun. This representation would then contrast with a simpler lexical meaning in which begin directly selects for an event and makes no reference to a theme participant of the initiated event. In this type of theory, the difference between the two lexical meanings of begin could potentially be qualitatively similar to the contrast in complexity between the meanings of love and break, discussed above. This example simply serves to demonstrate that it is conceivable that coercion and lexical semantic complexity could be fundamentally the same phenomenon. Several extant theories do in fact either represent both types of complexity as differences in stored representations (Egg, 2003; Pustejovsky, 1995) or derive both via general syntactic mechanisms (cf. Borer, 2005; Ramchand, 2008).

Our primary goal was to assess whether coercion and noncoercive lexical semantic complexity can be distinguished in behavioural processing measures or in neural activity. By using psychological predicates, we were able to directly contrast the two types of complexity. Further, since the processing correlates of coercion have been somewhat controversial (e.g., de Almeida, 2004; de Almeida & Dwivedi, 2008; Pickering, McElree, Frisson, Chen, & Traxler, 2006) and since there are still relatively few studies investigating noncoercive lexical semantic complexity, our study also addresses the more basic question of whether both types of complexity do, in fact, elicit a processing cost. For simplicity’s sake, we will refer to noncoercion-related lexical semantic complexity as simply “lexical semantic complexity”, acknowledging that coercion can also be thought of as an example of lexical semantic complexity, albeit intuitively of a derived kind.

**A TEST CASE: PSYCHOLOGICAL VERBS**

Coercion and lexical semantic complexity are generally manifested in very different types of expressions, making it difficult to compare the effects of each while controlling for other variables. Psychological verbs (“psych verbs”), however, allow this type of manipulation since different subclasses of psych verbs contrast in lexical semantic complexity (Landau, 2009; Pesetsky, 1995; Pylkkänen, 2000) and some of them also participate in a type of aspectual coercion, labelled here inchoative coercion.

Psych verbs are by definition verbs which describe mental states. They divide into two syntactically and semantically distinct classes: those that express the experiencer of the mental state as the subject (SubjExps: love, cherish, trust) and those that express the experiencer as the object (ObjExps: scare, disturb, distrust) (e.g., Belletti & Rizzi, 1988; cf. Levin, 1993,
In the following sections, we discuss in detail the semantic properties of psych verbs first as they relate to coercion and, second, to lexical semantic complexity.

**Inchoative coercion**

One of the most coercible properties of natural language pertains to the aspectual class of verbs (Jackendoff, 1991; Moens & Steedman, 1988; Talmy, 1978). Although most verbs have some type of default lexical aspect, verbal event structure easily shifts depending on context. So far, the most heavily studied aspectual coercion in psycholinguistics has been the shift of punctual predicates into repetitive readings in durative contexts (e.g., “the boy sneezed for an hour”) (Brennan & Pylkkänen, 2008; Pickering et al., 2006; Piñango, Winnick, Ullah, & Zurif, 2006; Piñango et al., 1999; Todorova et al., 2000). In this work we, however, tested a coercion which shifts a stative predicate into a change-of-state interpretation when combined with a telic modifier. This coercion, which we call **inchoative coercion**, is illustrated (1) for the predicate *be asleep*, which in isolation or in a neutral context is interpreted as a state, but which shifts into a change-of-state reading when combined with a telic “(within) an hour” type modifier (see Binnick, 1991, p. 412, for some related discussion).

(1) a. The boy was asleep. (Stative)
   b. Within 2 minutes, the boy was asleep. (Coerced inchoative)
      (“Within 2 minutes, the boy came to be asleep.”)

Of the two classes of psych verbs introduced above, SubjExps and ObjExps, the aspectual properties of the latter are rather complicated, as discussed in the next section. SubjExp verbs, however, are clearly stative and should therefore participate in inchoative coercion. The example in (2) informally confirms this intuition.

(2) a. The kids distrusted the librarian. (Stative)
   b. Within a half hour, the kids distrusted the librarian. (Coerced inchoative)
      (“Within a half hour, the kids came to distrust the librarian.”)

However, in order to actually demonstrate that (2a) and (2b) differ aspectually, we need independent evidence for the stativity of SubjExps in neutral contexts as well as evidence for the change-of-state interpretation in telic contexts. As regards the former, one of the best stativity diagnostics is Dowty’s (1979) observation that the English present tense forces a habitual interpretation on all nonstative eventualities. This is shown for the nonstative
activity *pet* in (3a), which intuitively means that Mary has a habit of petting the cat. The present tense does not require the activity described by the verb to hold at utterance time, as witnessed by the well formedness of (3b). In fact, the present tense is infelicitous in contexts that force a nonhabitual reading in which the event holds at utterance time. This is shown by the awkwardness of (3c), where the interjection “Look!” forces a true present tense interpretation.

(3) a. Mary pets the cat.
   b. Mary pets the cat, though she is not petting it right now.
   c. # Look! Mary pets the cat.

In contrast to eventive verbs, stative predicates such as *be asleep* in (4a) do not enforce a habitual interpretation in the present tense. Consequently, states are perfectly natural in a true present tense “Look!” type context (4b).

(4) a. Mary is asleep.
   b. Look! Mary is asleep.

Using this diagnostic with SubjExps shows that they act like states. The sentences in (5) show two examples of simple SubjExp sentences and both are perfectly acceptable in a nonhabitual context.

(5) a. Look! The child cherishes the kitten.
   b. Look! The kids distrust the librarian.

Thus there is evidence that in the absence of telic modification, SubjExps describe states.

What is then the evidence, in addition to intuitions, that once combined with telic modifiers, SubjExps denote inchoative change-of-state events? One test that demonstrates this takes advantage of the argument selection of *happen*, which requires its subject to refer to a dynamic event (Jackendoff, 1983). Consequently, (6a) is well formed since the subject of *happen* refers back to the dynamic event of stabbing, whereas (6b) is ill formed, the state of tiredness not constituting an appropriate subject for *happen*.

(6) a. Brutus stabbed Caesar. It happened at noon. (Eventive)
   b. # Brutus was tired. It happened at noon. (Stative)

As regards this diagnostic, SubjExps pattern with states except when combined with a telic modifier, as illustrated by the contrast between the stative (7) and the eventive (8).
Thus, although stative interpretations are not compatible with telic temporal modifiers, the felicity of SubjExps in these examples (8) suggests that they can be shifted from state-denoting to more complex change-of-state-denoting predicates to accommodate a telic modifier. To test whether evidence for this shift can be obtained either in behaviour or in neural responses, we contrasted stative and coerced SubjExps in self-paced reading (Experiment 1) and in a magnetoencephalography (MEG) experiment (Experiment 2).

The relationship of inchoative coercion to previously studied shifts can be understood in the context of an ontology of the sorts of things linguistic expressions describe, sketched hierarchically in Figure 1 (Bach, 1986; Piñón, 1995). Most theories draw a fundamental distinction between object-denoting and eventuality-denoting expressions, represented at the top level of this hierarchy. Eventualities can be further divided into states and nonstates (“events”) which are themselves subject to further subdivision. Coercion operations can be understood as computations which shift a representation from one node in this ontology to another (Moens & Steedman, 1988). For instance, coercion of the “begin the book” variety

![Figure 1](image_url)

**Figure 1.** An ontology of linguistic objects and events. The most basic division is between objects and eventualities, followed by a distinction within eventualities between states and events. Events can be further subdivided into activities and culminations. *Inchoative coercion* describes a shift from states to events.
(called *complement coercion*) operates at the top level of this hierarchy, shifting an object-denoting expression (*the book*) to an event-denoting counterpart (*writing the book*). In contrast, the punctual-to-repetitive type aspectual coercion, mentioned above, pertains to a subtler shift at the bottom of this hierarchy, shifting a point-action event to a repetitive activity (*the clown jumped for 10 minutes*). In this context, inchoative coercion can be viewed as a mid-level shift at the second highest node, shifting a state-denoting expression into a dynamic change-of-state event.

On the basis of previous MEG work on coercion, we can derive a rather specific prediction about the neural activity that should be sensitive to inchoative coercion. This prior research has identified a potential neural correlate of compositional complexity, called the *Anterior Midline Field* (AMF), which in several studies has shown increased amplitudes for coerced expressions as compared to simpler control stimuli. The AMF is a frontal peak in neuromagnetic activity which is observed approximately 350–450 poststimulus onsets during reading. The neural generator of this activity has systematically localised in ventro-medial pre-frontal cortex (vmPFC; Pylkkänen, 2008). An AMF effect has been reported both for complement coercion (Pylkka¨nen & McElree, 2007) and for punctual-to-repetitive aspectual coercion (Brennan & Pylkka¨nen, 2008), suggesting that these two coercions may be computed via similar mechanisms. If inchoative coercion is indeed intermediate to complement and aspectual coercion, as depicted in Figure 1, then inchoative coercion should also elicit an effect in the vmPFC, i.e., the generating regions of the AMF. Testing this hypothesis was the primary goal of our Experiment 2, where we examine the MEG correlates of inchoative coercion.

A contrast in lexical semantic complexity: Subject vs. object experiencers

As discussed above, one of our primary aims was to compare the processing profile of coercion to that of noncoercive lexical semantic complexity, in order to begin to shed light on whether the two types of complexity are represented and processed similarly. To construct a contrast in noncoercive lexical semantic complexity, we compared the processing of stative SubjExps to that of ObjExps, which has inspired a large theoretical literature concerning their argument structure properties (e.g., Belletti & Rizzi, 1988; Bennis, 2004; Landau, 2009; Pesetsky, 1995). The present research is guided by the hypothesis pursued by several researchers that ObjExps are semantically more complex than SubjExps. Specifically, ObjExps contain a set of entailments about causation that is absent in SubjExps (Pesetsky, 1995; Pylkkänen, 2000). For example, a sentence such as *Mary annoyed John* has been argued to entail that Mary caused John to be annoyed (Pesetsky, 1995).
This is evidenced by the intuition that it would be a contradiction to state that Mary annoyed John, but she didn’t cause him any annoyance. The causative entailment contained in ObjExps can be contrasted with a sentence with a SubjExp, such as Mary loved John, for which it would not be a contradiction to state that Mary loved John, but he didn’t cause her to love him. The somewhat awkward phrasing used here serves to bring out the fact that Mary loved John entails a state of love, but does not contain any entailments about causation; a more natural sentence illustrating the same point might be Mary loved John, although he didn’t make her love him. Note that SubjExps and ObjExps are similar in that they both entail the existence of a mental state. The difference lies in whether the verb carries entailments about how that state came about. SubjExps do not contain an entailment about the causation of the mental state, while ObjExps do. The contrast in complexity is further corroborated by crosslinguistic evidence; in several languages ObjExps, but not SubjExps, overtly contain a causative morpheme (Kuroda, 1965; Pykkänen, 2000).

Evidence from several psycho and neurolinguistic studies provides additional support for this complexity difference. Prior studies have shown that ObjExps lead to greater processing difficulty than SubjExps according to several metrics, such as increased reading times (Cupples, 2002; Gennari & Macdonald, 2009), increased dysfluencies in production amongst dyslexics (Altmann, Lombardino, & Puranik, 2008), and decreased comprehension accuracy in patients with Alzheimer’s disease (Manouilidou, de Almeida, Schwartz, & Nair, 2009), agrammatic aphasia (Beretta & Campbell, 2001; Thompson & Lee, 2009), and Broca’s aphasia (Piñango, 2000). However, the brain correlates of processing ObjExps have not yet been studied in the intact brain. In the present work, we first tested the behavioural effects of ObjExps in self-paced reading and then used the same materials in an MEG study. This complexity manipulation was combined with a coercion condition, as discussed above.

**SUMMARY OF GOALS**

To summarise, psych verbs exhibit both coercion and interesting variation in lexical semantic complexity, making them a promising test case for a direct comparison between the two types of complexity. In the first stage of our research, we tested whether self-paced reading time (SPRT) data on psychological predicates would show similar or different effects of inchoative coercion vs. noncoercive lexical semantic complexity. In the second stage, we employed MEG as a more sensitive measure to gauge the processing mechanisms of both types of complexity. Our study is the first to examine the phenomenon of inchoative coercion.
EXPERIMENT 1: SELF-PACED READING

Experiment 1 examined the behavioural profile of processing sentences with psychological predicates using self-paced reading.

Methods

Subjects

About 38 right-handed native speakers of English participated in the study ranging in age from 18 to 24 (25 females). Participants were undergraduate students at New York University who received class credit for their participation.

Stimuli

Our stimuli consisted of three types of sentences. In the simple condition, a SubjExp verb was paired with a temporally neutral modifier, creating a sentence with a minimum of lexical semantic complexity, and no coercion. To induce coercion, we replaced the temporally neutral modifier with a telic one. To vary lexical semantic complexity, we replaced the verb in the simple condition with an ObjExp, matched on properties known to affect reading times (see below). Table 1 provides example sentences from each of the three experimental conditions.

We constructed 31 triplets of sentences like those in Table 1. For each triplet, we also included a sentence where the ObjExp verb was matched with a telic modifier to ensure that telic modifiers alone would not predict that coercion would take place. For each temporal modifier, 31 nonsensical fillers were also constructed by substituting a verb which was anomalous in combination with the subject and/or object of the sentence. These stimuli were distributed evenly across three lists, such that no subject saw the same verb twice, and the lists were counter-balanced across subjects.

Acceptability ratings, assessed using an online questionnaire where sentences were rated on a scale from 1 (“Not at all natural”) to 7 (“Completely natural”), confirmed that all target sentences were highly acceptable (simple, $M = 5.76$; coercion, $M = 4.98$; lexsem, $M = 5.26$). Consistent with previous work on coercion, coerced sentences were slightly

<table>
<thead>
<tr>
<th>Condition</th>
<th>Example sentence</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Simple</td>
<td>Without a doubt, the child cherished the precious kitten.</td>
</tr>
<tr>
<td>b. Coercion</td>
<td>Within a few minutes, the child cherished the precious kitten.</td>
</tr>
<tr>
<td>c. Lexsem</td>
<td>Without a doubt, the child scared the precious kitten.</td>
</tr>
</tbody>
</table>
less acceptable than controls. All anomalous sentences received very low acceptability ratings ($M = 1.93$).

Orthographic neighbourhood, log frequency, and mean lexical decision time data were gathered for the SubjExp and ObjExp verbs using data from the English Lexicon Project (Balota et al., 2002). The two types of verbs were matched pairwise in number of letters ($p = 0.20$), orthographic neighbourhood ($p = 0.40$), and mean lexical decision time ($p > 0.99$). There was a marginal difference in lexical frequency such that ObjExp was slightly more frequent than SubjExp (log lexical frequency, Hyperspace Analogue of Language (HAL) corpus, $p < 0.1$).

Subject–verb co-occurrence was assessed using Latent Semantic Analysis (Landauer, Foltz, & Laham, 1998), and was matched across verb type ($p = 0.62$). The co-occurrence of each modifier with each verb class was also estimated using Latent Semantic Analysis. SubjExp predicates were matched with both telic and atelic modifiers types ($p = 0.42$). Temporal modifiers did not differ in orthographic length ($p = 0.72$).

**Procedure**

Participants were seated in front of a 17" computer LCD while sentences were presented in a black courier font, size 18, on a light grey background using E-Prime software (PST Inc., PA, USA). Subjects were instructed to read at a natural pace and at the end of each trial they were given 4 seconds to judge whether or not the sentence made sense. The sentence-judgement task was used to ensure that subjects were attending to the stimuli; by limiting the time allowed to respond, we sought to maximise the probability that subjects were composing and interpreting the sentence incrementally, rather than waiting until the end of each sentence to construct an interpretation. All subjects participated in a short unrelated reading time experiment immediately prior to the main experiment.

Twelve practice trials were presented prior to the beginning of the experiment to familiarise each subject with the task. Subjects were required to achieve an 90% accuracy rate on the practice trials in order to move on to the main experiment. Each trial began with a fixation cross presented in the middle of the screen. After 300 ms, a series of dashes corresponding to the words in the sentence appeared. Subjects advanced word-by-word through each sentence at their own pace using the computer keypad. After the final word of each sentence was seen, a question mark appeared and the subject entered a judgement on the keypad as to whether the sentence made sense or not.

**Data processing**

Two subjects were removed from further analysis due to low overall accuracy on the end-of-sentence judgement task ($< 70\%$). One further
subject was removed because their average reading time across all conditions on the offline task was more than two standard deviations above the group mean. No items were removed from the analysis. Statistical analysis of the three target conditions was conducted using only trials which were judged “acceptable”, excluding 9.1% of the data. We also removed individual reading times above three standard deviations from the group mean for each word, excluding an additional 3.5% of reading times.

Statistical analysis

Statistical analysis of reading times was carried out using multi-level linear regression with random slopes for subjects and items (Baayen, Davidson, & Bates, 2008; Gelman & Hill, 2006). We included as fixed effects the condition (simple, coercion, and lexsem) with the simple condition coded as the baseline for the regression. Other fixed effects were the length of the target word in letters, the reading time on the preceding word, the length of the modifier phrase in words, and the log lexical frequency of the verb. Analysis of offline acceptability was done using multi-level logistic regression (Jaeger, 2008), also with random slopes for subjects and items.

All of the regressions were fit using the lmer function in the lme4 package for the R statistical computing environment (Bates & Maechler, 2009). We estimated p-values for the coefficient estimates of our linear regression models with Markov-Chain Monte Carlo (MCMC) simulation using the pvals.fnc function in the Language R package for R (Baayen, 2007), reported as p(MCMC). MCMC sampling is not yet available for multi-level logistic regression; we report p-values using a z-test in such cases.

Results

Average phrase by phrase reading times, beginning with the subject of the sentence, are given in Figure 2; error bars indicate standard error (SE). Differences in reading times at the verb and in the two subsequent regions were assessed using a multi-level model as described in the Methods section. Note that no length factor was included in the analysis of the first spill-over region, which was the definite article “the” in all items. The dependent measure was log-transformed reading times.

No effects were observed at the verb (all p(MCMC) values > 0.2). At the word immediately following the verb, there were longer reading times in the coercion condition (M = 438 ms) relative to the simple condition (M = 424 ms) (β = 0.038, SE = 0.019, p(MCMC) = 0.048). There were also longer reading times in the lexsem condition (M = 448 ms), compared to simple sentences (β = 0.067, SE = 0.018, p(MCMC) < 0.001). No effects were observed on the second word following the verb (all p(MCMC) values > 0.5).
Inspection of Figure 2 shows an apparent baseline difference between telic and atelic conditions, possibly reflecting an effect of the different modifiers used in these two conditions. Note, though, that any baseline differences were accounted for statistically by including preverbal reading time as a predictor in our regression analysis.

Acceptability and reaction time for the offline sensicality judgement were also analysed. Condition means and SE are given in Table 2. Acceptability was assessed using a generalised linear mixed model (Jaeger, 2008). There was no difference in acceptability between simple and lexsem sentences ($\beta = -0.21$, SE = 0.289, $p = 0.462$). Coercion sentences were slightly less acceptable than simple sentences ($\beta = -0.55$, SE = 0.274, $p = 0.045$). Reaction time for the offline judgement was assessed using a linear mixed model and no significant effects were observed.

![Figure 2](image.png)

**Figure 2.** Mean reading times, beginning at the subject, and including the target verb and two words immediately following the verb. Error bars indicate the standard error of the mean. Significantly longer reading times were observed on the first word after the verb, indicated with an asterisk, for both the coercion condition (dotted, black squares) and the lexsem condition (dashed, white circles), as compared to the simple condition (solid, black circles). Det, determiner; NP, subject noun phrase.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Acceptability, % (SE)</th>
<th>Reaction time, ms (SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple</td>
<td>92.6 (1.4)</td>
<td>556 (24)</td>
</tr>
<tr>
<td>Coercion</td>
<td>88.6 (1.7)</td>
<td>580 (26)</td>
</tr>
<tr>
<td>Lexsem</td>
<td>91.4 (1.5)</td>
<td>577 (26)</td>
</tr>
</tbody>
</table>

Note: SE, standard error.
Experiment 1 Discussion

The reading time data confirm that coercion and lexical semantic complexity elicit a behavioural cost in comparison to less complex controls. A significant reading slow-down for lexsem sentences as compared to the simple condition conforms to previous work showing behavioural costs for complex lexical semantic representations (Frisson & Frazier, 2005; Gennari & Poeppel, 2003; McKoon & Macfarland, 2000, 2002). This result conforms to previous studies showing a slow-down in reading for object-experiencer verbs in contrast to nonexperiencer predicates (e.g., write; Cupples, 2002; Gennari & Macdonald, 2009). We also observed slower reading times for coercion, consistent with the hypothesis that the aspectual mismatch between SubjExps and telic adverbs triggers inchoative coercion. Having found a similar behavioural cost for both kinds of complexity, we then used MEG in Experiment 2 to assess whether the two types of complexity are associated with similar or different effect in neural activity.

EXPERIMENT 2: MAGNETOENCEPHALOGRAPHY (MEG)

The second experiment sought to identify the neural correlates associated with the behavioural effects observed in Experiment 1. As discussed above, previous MEG work on the processing of coercion suggests that the AMF, a neuromagnetic component localising to the vmPFC, may be a potential neural correlate of compositional complexity, showing increased amplitudes both for coercion (Brennan & Pykkänen, 2008; Pykkänen et al., 2008; Pykkänen & McElree, 2007) as well as semantic mismatch that cannot be resolved via a productive rule (Pykkänen, Oliveri, & Smart, 2009). Importantly, the AMF appears associated with the computation of linguistic representations as opposed to the evaluation of the real world plausibility. If the AMF indeed indexes brain activity associated with semantic composition, we expect to observe increased vmPFC activity for coercion at approximately 300–500 ms after verb onset.

Compared to coercion, lexical semantic complexity has received less attention in the neurolinguistic literature, although evidence from two studies using event-related potentials (ERPs) does connect changes in lexical semantic complexity with an anterior electrophysiological component at approximately 300 ms after stimulus onset. In the first study, Steinhauer, Pancheva, Newman, Gennari, and Ullman (2001) compared the processing of count and mass nouns, the former of which have been theorised to involve a semantic component absent in the latter (Krifka, 1995). In the ERP data, count nouns elicited a larger frontal negativity than mass nouns. In another study, Malaia, Wilbur, and Weber-Fox (2009) compared the processing of more telic verbs with atelic verbs, reporting that atelic verbs led to more...
negative-going activity in anterior sensors between 320 and 500 ms at the word immediately following the verb. Together these two studies suggest a link between changes in lexical semantic complexity and anterior brain activity in a time window from 300 to 500 ms. This is interestingly consistent with the prefrontal MEG effects reported for coercion.

In the current study, we assessed whether either inchoative coercion or lexical semantic complexity engage the AMF generating region, i.e., the vmPFC. In addition to narrowly testing this specific hypothesis, we also examined a broader network of language-related regions, to gain a more comprehensive profile of the network of areas affected by our complexity manipulations.

**Methods**

**Subjects**

Twenty-six right-handed native speakers of English participated in the study ranging in age from 19 to 42 (17 females).

**Stimuli**

Stimuli were the same as in Experiment 1.

**Procedure**

Twenty-two subjects had their data recorded at the Center for Neuro-magnetism at Bellevue Hospital, New York City. Four additional subjects were recorded at the KIT/NYU MEG Joint Research Lab on the main campus of New York University.

Prior to the experiment, participants’ head shapes were digitised using a Polhemus Fastrak 3D digitiser (Polhemus, VT, USA). The digitised head shape was used to constrain source localisation during analysis. Three coils, attached to the subject’s fiducials at the nasion and the left and right preauricular points (Bellevue), or five coils located around the face (KIT/NYU) were localised with respect to the MEG sensors before and after recording in order to fix the location of the head with respect to the sensors.

During the experiment, subjects sat in a dimly lit magnetically shielded room and viewed the stimuli on a projection screen approximately 16 inches away. Neuromagnetic fields were recorded with a whole-head 275-channel gradiometer (CTF, Vancouver Canada), sampling at 600 hz (Bellevue) or a 157-channel gradiometer (Yokogawa, Japan) sampling at 1,000 hz (KIT/NYU).

Each trial began with a fixation cross presented in the middle of the screen. Subjects then initiated the presentation of each sentence themselves by pressing a button on a keypad using their left hand. Sentences were presented word-by-word in grey courier font against a black background. Each word was presented for 300 ms with a 300 ms blank screen between words. At the end of
each sentence, a question mark was displayed and the subject was instructed to judge whether the sentence made sense or not within 4 seconds with a button press. As in Experiment 1, the aim of the timed judgement task was to enforce incremental interpretation. Neuromagnetic fields were recorded from 300 ms before the presentation of the target verb to 800 ms after.

Data analysis

Prior to statistical analysis, trials judged unacceptable by participants were removed and the data were cleaned of artifacts by rejecting trials for which the difference between the minimum and maximum amplitudes exceeded a threshold which varied between 3,000 and 8,000 fT depending on the amplitude range of each subject; approximately 6.5% of all trials were rejected for each subject per condition.

MEG data from each subject were averaged by condition and data were then low-pass filtered at 40 hz and a high-pass band filtered at 1 hz. As data were collected from two different facilities with different sensor arrays, the statistical analysis was carried out entirely on estimated source activity. Source estimation was carried out in BESA 5.1 (Megis, Grafelfing, Germany) and statistical analysis was conducted using custom scripts in Matlab (The Mathworks, Natick, MA, USA) and the R Statistical Computing Environment (R Core Development Team).

The electrical source of the observed magnetic field patterns was modelled as nonsigned electrical activity distributed along the cortical surface with BESA using a minimum L2 norm (Hämäläinen & Ilmoniemi, 1984). For each subject, 1,426 regional sources were evenly distributed 10 and 30% below a smooth standard brain surface. Each source was modelled as two orthogonal equivalent-current dipoles; the root mean square of the two dipoles provided the activation for each regional source. The maximum activity from each pair of sources was selected, yielding 713 nondirectional sources for which activation as compared across subjects and conditions.

For our principal analysis, we defined a set of regions of interest (ROIs) based on spatio-temporal points that showed peak activity in the minimum norm data. This technique offered a data-driven method to identify sources and time points that were consistently engaged by reading in our evoked data. As discussed below, this technique revealed a broad network of cortical regions commonly implicated in reading, spanning the occipital, temporal, and frontal lobes.

We first created a grandaverage of the minimum norm data across all subjects. Figure 3A shows a visualisation of the grandaverage, showing amplitude changes across time in all sources between 0 and 600 ms after the presentation of the verb. Three distinct peaks are apparent with maxima at 128, 227 and 416 ms. We then determined which sources were driving each
peak by identifying the top 5% of sensors, by amplitude, within 20 ms windows around each of the three peaks (Figure 3B–D).

ROIs were defined by grouping adjacent active sources together. In one case, the resulting cluster spanned from the ventral frontal cortex to the left temporal lobe of the smoothed cortical surface; we divided this cluster into two ROIs, one frontal and one temporal. In a second case, a region spanned from the medial occipital lobe to the brain stem, and this cluster was similarly divided across the lobe boundary. In all three time windows, we observed peak activity in sources that appeared to localise in the brain stem, however, since it is generally believed that the sensitivity of MEG is extremely limited for deep sources, we did not analyse this activity.

Finally, we examined activity in each ROI within a timewindow circumscribed by the observed peaks. The beginning of each peak was defined as the timepoint at which sensor activity rose over three standard deviations above zero, where the standard deviation was defined over a 100 ms baseline interval. Peaks ended when sensor activity fell below the same threshold.

Figure 3. (A) Overlay of minimum norm activity from all sources across time. The latencies for three peaks in activity are marked. (B–D) The top 5% of sources in a 20 ms window around each peak timepoint are plotted on a smoothed standard brain surface; these sources were used to define regions of interest. [To view this figure in colour, please visit the online version of this Journal.]
Figure 4. Log transformed peak amplitudes within each time window of interest, averaged across sources in each ROI. Error bars indicate the standard error of the mean. The coercion condition shows significantly higher amplitudes than the simple condition in the LH aTL and vmPFC between 240 and 336 ms post-stimulus onset (grey boxes). LH, left hemisphere; RH, right hemisphere; MedOL, medial occipital lobe; pITL, posterior inferior temporal lobe; aTL, anterior temporal lobe; vmPFC, ventral-medial pre-frontal cortex; Sylvian, sylvian fissure. [To view this figure in colour, please visit the online version of this Journal.]
The above steps resulted in 11 spatio-temporal ROIs (see Figure 4). In the first time window (70 to 200 ms) there was one medial occipital ROI (MedOL). In the second time window (240–336 ms) there were four ROIs, a posterior region on the left inferior temporal lobe (LH pITL), a region on the anterior tip of the left temporal lobe (LH aTL) and another on the right anterior temporal lobe (RH aTL). A small cluster in the medial occipital lobe (a subset of the sources seen in the earlier time window), and a region in the vmPFC. In the third time window (346–472 ms) we observed five clusters. Three clusters largely overlapped with those observed in the second time window, including vmPFC, LH aTL, and RH aTL. In addition to these three, there was a LH cluster that appeared at the temporal–frontal juncture along the Sylvian fissure, and a LH inferior anterior temporal cluster (LH aITL).

The dependent measures of our statistical analysis were peak amplitude (log-transformed) and latency in each spatio-temporal ROI. As in Experiment 1, analysis was carried out using mixed effects modelling with a random intercept for subjects and a random slope per subject conditioned on the modifier. Note that, by averaging across trials within subjects, properties of the individual items or trials could not be included in the statistical analysis.

Results

Behavioural data

Mean ratings and reaction times for the offline acceptability judgements are given in Table 3. Percent acceptable and reaction time from the offline task were assessed using multi-level regression, just as with Experiment 1. As in Experiment 1, simple sentences were rated more acceptable than coercion sentences ($\beta = -0.56$, SE = 0.20, $p < 0.01$). Simple sentences were also more acceptable than lexsem sentences ($\beta = -0.55$, SE = 0.20, $p < 0.01$).

Magnetoencephalography (MEG) data

Mean peak amplitudes across all ROIs are shown in Figure 4. Regression analysis of amplitude differences was carried out within each ROI. There was

<table>
<thead>
<tr>
<th>Acceptability</th>
<th>Reaction time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptability</td>
<td>Reaction time</td>
</tr>
<tr>
<td>Simple</td>
<td>91.7 (1.1)</td>
</tr>
<tr>
<td>Coercion</td>
<td>87.0 (1.4)</td>
</tr>
<tr>
<td>Lexsem</td>
<td>87.0 (1.4)</td>
</tr>
</tbody>
</table>

Note: SE, standard error.
a significant effect of coercion in the second time window, from 240 to 336 ms, such that coercion sentences elicited higher peak amplitudes than simple sentences in a fronto-temporal network including the LH aTL (β = 0.24, SE = 0.10, p(MCMC) = 0.052), the vmPFC (β = 0.29, SE = 0.11, p(MCMC) = 0.025), and a marginally significant effect in the RH aTL (β = 0.21, SE = 0.10, p(MCMC) = 0.075). There were no effects of coercion in any other regions, nor did we find any significant peak amplitude effects for lexsem in any ROIs.

To ensure that our results were not influenced by the use of two testing sites during data collection, we repeated the analysis on a subset of 20 subjects all from the same site (Bellevue Hospital). As with the results for the entire group, this subset of subjects also exhibited significant effects for coercion in vmPFC and the LH aTL, and no effect for lexsem was seen in any ROIs.

We also analysed peak latency within each ROI. No significant effects of latency were observed, although there was a marginally significant effect in the LH aITL region such that coerced sentences lead to slightly later peaks (M = 292 ms) compared to the simple condition (M = 279 ms; β = 13.18, SE = 5.97, p(MCMC) = 0.08).

As the vmPFC was the primary target of our hypotheses, we also conducted a posthoc analysis of activity in this region. Figure 5 plots the mean waveforms for each condition in this ROI from 0 to 600 ms. As discussed above, previous work has found that activity in this region peaks approximately 400 ms after stimulus onset (Pykkänen & McElree, 2007). Since our effect of inchoative coercion occurred about a 100 ms prior to this, Figure 5. Waveforms from a posthoc analysis of the vmPFC ROI. The ROI was defined from the third peak in the grand-averaged data (see Figure 4). Sample-by-sample regression analysis showed a marginally significant effect for coercion (dotted) over simple sentences (solid) around the peak of the waveform between 435 and 450 ms (p < 0.1, corrected for multiple comparisons using a permutation test; see Experiment 2 results). The waveforms also show greater amplitudes in the coercion condition between 250 and 350 ms, consistent with the ROI peak analysis.
we assessed whether later effects might also be present by comparing the vmPFC timecourse between the simple condition and each of the two complex conditions timepoint by timepoint for a window spanning from 300 to 500 ms. We corrected for multiple comparisons using a cluster-size threshold following (Maris & Oostenveld, 2007). In this procedure, timepoints of significant activity at the 0.05 level are grouped into clusters based on adjacency and a summary “cluster” statistic is determined by summing the $t$-values from each timepoint. A permutation test is used to determine the probability of observing an equivalently sized cluster by chance. For each simulation, condition labels are shuffled within subjects and we identify the maximum cluster statistic observed per permutation. Following this procedure, we observed a marginally significant effect of coercion at the peak of the waveform, between 435 and 450 ms ($p = 0.09$, 100 simulations). No effects were observed for lexsem, as compared to simple sentences. Thus inchoative coercion appeared to affect vmPFC activity both in an early and in a later time window.

**Experiment 2 Conclusion**

The MEG data revealed that coercion lead to higher levels of activity in frontal and anterior temporal sources around 300 ms. In contrast, no effect for lexical semantic complexity was observed in the MEG data.

**GENERAL DISCUSSION**

In this work, we set out to study the relationship between two forms of semantic complexity, coercion and noncoercive lexical semantic complexity. In Experiment 1, self-paced reading data showed that both kinds of complexity lead to longer reading times, measured on the word immediately after the target verb in each condition. This result establishes that the two types of semantic complexity elicit similar behavioural effects. This behavioural finding contributes to theories of lexical semantics in at least three ways. First, as the behavioural cost of processing coercion and lexical semantic complexity has been subjected to debate, our observations lend further support to the conclusion that representational aspects of semantic complexity impact processing (e.g., Brennan & Pylkkänen, 2008; Gennari & Poeppel, 2003; McElree et al., 2001). Second, the observation that object-experiencer verbs are more costly to process than subject-experiencer verbs adds further experimental support to the large body of theoretical literature that claims there is a representational difference between these two kinds of psychological predicates (Pesetsky, 1995; Pylkkänen, 2000). Third, we observed a behavioural cost for a new kind of coercion, inchoative coercion, which has not been studied previously.
In Experiment 2, we used MEG to study the neural profile of each kind of complexity. We examined activity in a set of language-related ROIs that were consistently engaged by our stimuli, with special attention paid to the vmPFC which in previous studies has been shown sensitive to coercion at around 400 ms. We observed increased neural activity for inchoative coercion in a fronto-temporal network around 300 ms, and a posthoc investigation of the vmPFC also suggested a further later effect of coercion, peaking around 400 ms. Thus, although our MEG results for coercion are broadly consistent with the previous work associating semantic processing with vmPFC (Brennan & Pylkkänen, 2008; Pylkkänen et al., 2008; Pylkkänen & McElree, 2007), the most reliable inchoative coercion effect occurred earlier than previously reported coercion effects. Further, unlike effects of complement or aspectual coercion, the vmPFC effect of inchoative coercion was accompanied by an effect in the aTL. We discuss these differences in more detail below.

Intriguingly, although lexical semantic complexity elicited a clear behavioural effect, we found no evidence for a neural correlate of this effect in the network of regions examined here. Consequently, since coercion did clearly affect parts of this network, our data are consistent with the hypothesis that coercion and lexical semantic complexity are processed via different mechanisms. There are a variety of reasons for why our MEG data might have failed to reveal an effect of increased lexical semantic complexity. These may include the limited sensitivity of MEG to cortical electrical sources that are orthogonal to the cortical surface (Hämäläinen, Hari, Ilmoniemi, Knuutila, & Lounasmaa, 1993), or the particulars of how we identified regions and time windows of interest. Keeping these in mind, the fact that we saw no effects parallel to the observed results for coercion in the vmPFC and aTL suggests that these two types of complexity are associated with different neural mechanisms.

In addition to reading time and MEG measures, we collected binary sensicality judgements in both of our experiments and also assessed the acceptability of our materials on a 1–7 scale in an offline well-formedness judgement task (see Stimuli of Experiment 1). Although the coercion stimuli were always rated as highly acceptable, all of these measures showed a slight decrease in ratings for coercion as compared to controls, consistent with prior coercion studies (Brennan & Pylkkänen, 2008; McElree et al., 2001; Pylkkänen & McElree, 2007; Traxler et al., 2002). The most likely explanation for this behavioural effect is the experimental manipulation itself: an increase in complexity is likely to affect one’s intuition of well formedness or sensicality. Another factor that robustly affects these types of judgements is plausibility. However, it is quite unlikely that our coercion expressions were less plausible than the controls: if that was the case, then the inception of a mental state would be seen as a less likely situation than the “holding” of such a state (in Parsons’ terminology; Parsons, 1990)—this
would seem a bizarre outcome nor do we believe that people’s ability to judge this type of plausibility/likelihood would be very reliable (if administered a plausibility norm). Further, in previous studies where plausibility has explicitly been manipulated, the vmPFC has not shown sensitivity to this factor (Pylkkänen & McElree, 2007; Pylkkänen, et al., 2009). Thus the most likely interpretation of both our ratings and MEG data is that the effects observed reflect the complexity manipulation itself.

Complexity and object experiencers

We found that ObjExps lead to longer reading times than SubjExps, consistent with previous psycholinguistic findings (Cuppes, 2002; Gennari & Macdonald, 2009). The interpretation of the observed behavioural effect associated with ObjExp verbs must be considered in light of the significant theoretical debate concerning the representation of these predicates. Our discussion has focused on the semantic difference between these two predicates proposed by several theoreticians, but such accounts of psych verbs have been embedded in a broader debate about their argument structure properties. Much of the literature on psych verbs has centred on the noncanonical argument structure of ObjExps, which violates traditional notions of a thematic hierarchy where the most prominent participant in an event or state should appear as the subject (e.g., Belletti & Rizzi, 1988). Several accounts link the argument structure difference between ObjExp and SubjExp with the causative semantics of the former (Pesetsky, 1995; Pylkkänen, 2000), yet these accounts also propose that these predicates have syntactic differences, most notably, ObjExps involve syntactic movement not present in SubjExps.

Several previous studies have reported that reading times are relatively faster when ObjExp verbs are used in the passive voice (Cuppes, 2002; Gennari & Macdonald, 2009). Together with research showing a preference for use of the passive voice with ObjExps (Ferreira, 1994; Gennari & Macdonald, 2009) as well as greater comprehension accuracy for passive sentences in aphasic patients (Beretta & Campbell, 2001; Piñango, 2000; Thompson & Lee, 2009), some researchers have hypothesised that the noncanonical surface argument structure of ObjExps, independent of other semantic and syntactic factors, may lead to an increased processing load (Bornkessel, Zysset, Friederici, von Cramon, & Schlesewsky, 2005; Ferreira, 2003). However, despite the relative improvement in the passive voice, several studies still report that, overall, ObjExps were associated with increased reading times (Cuppes, 2002) and decreased comprehension accuracy (Beretta & Campbell, 2001; Manouilidou et al., 2009), consistent with the difference in semantic complexity that is common across both active and passive voice.

The behavioural cost associated with ObjExp verbs is consistent with the increased lexical semantic complexity of these predicates, but our data does not
rule out an explanation based on movement, nor did we directly test the effect of more general argument structure differences. The evidence from Experiment 2 suggests that, whatever the combination of mechanisms are that lie behind the behavioural effect, their brain bases are distinct from coercion.

The timecourse of activity in the ventro-medial pre-frontal cortex (vmPFC) and the anterior temporal lobe (aTL)

Turning to the MEG data, the observed vmPFC effect of coercion is consistent with previous research that has associated this region with semantic composition (Brennan & Pykkänen, 2008; Pykkänen et al., 2008; Pykkänen & McElree, 2007). Inspection of the vmPFC waveforms for each condition revealed a notably larger peak for coercion around 400 ms, yet this effect was not highly reliable. More reliable was an earlier effect in the same region, spanning from approximately 240 to 330 ms. An effect around 300 ms was also observed in one previous study (Pykkänen et al., 2009), which examined the processing of semantic mismatches which cannot be resolved through coercion, resulting in ungrammaticality. This suggests two stages of vmPFC activity, one around 300 ms and the other around 400–500 ms. Further studies will need to address the functional roles of these two stages; here we can only speculate as to why inchoative coercion should lead to an earlier effect than previously studied coercions. One possible explanation links this temporal difference with another difference between our results and those found in previous studies: the additional concurrent effect of coercion in the anterior temporal lobe. Together, the earlier time course of the vmPFC effect and the simultaneous recruitment of the aTL suggest that inchoative coercion may involve a somewhat different network of brain activity than previously studied coercions. A number of studies have linked the anterior temporal lobe with basic syntactic processing (Brennan et al., 2010; Friederici, Meyer, & von Cramon, 2000; Humphries, Willard, Buchsbaum, & Hickok, 2001; Mazoyer et al., 1993; Stowe et al., 1998). Thus, one possible hypothesis, consistent with our data, is that the resolution of inchoative coercion may involve syntactic mechanisms not involved in other kinds of coercion.

Semantic complexity and the anterior negativity in ERPs

As discussed above, previous studies on the neural profile of lexical semantic complexity using electroencephalography (EEG) have reported an anterior frontal negativity beginning around 300 ms after stimulus onset (Malaia et al., 2009; Steinhauer et al., 2001). This observation raises the intriguing question of whether this anterior negativity might relate to the AMF seen in MEG. In our data, however, we did not find any neural signatures that are reliably affected by changes in lexical semantic complexity, so we are not able to speculate about this possible correspondence. Future work using simultaneous
EEG and MEG recording will be necessary to more fully understand the relationship between the anterior negativity reported by these EEG studies and vmPFC activity associated with coercion observed here and in previous work.

CONCLUSION

In this research, we compared the processing mechanisms associated with two different kinds of semantic complexity: coercion and lexical semantic complexity. We used psychological verbs, which, on the one hand, participate in inchoative coercion and, on the other, divide into two subclasses with different degrees of lexical semantic complexity. We found clear behavioural costs for both coercion and lexical semantic complexity. These results offer new evidence for a strong connection between the representational complexity of linguistic expressions and processing difficulty. Our MEG data revealed greater activity for coercion in vmPFC, consistent with previous work linking this region with semantic composition. The ventro-medial effect co-occurred with an effect in the LH aTL, which in the imaging literature has been hypothesised to participate in basic syntactic composition. This suggests that inchoative coercion may also involve increased syntactic complexity. We did not, however, see any similar effects for lexical semantic complexity, suggesting that lexical semantic complexity is processed by different mechanisms than coercion. Thus, these results suggest that the semantics-related vmPFC effects reported here and elsewhere reflect a subclass interpretative computations as opposed to indexing very general processing effort.

REFERENCES


APPENDIX: STIMULI

1. a. Despite everything the janitor admired the chemistry teacher.
   b. Within a couple of minutes the janitor admired the chemistry teacher.
   c. Despite everything the janitor agitated the chemistry teacher.
   d. Within a couple of minutes the janitor agitated the chemistry teacher.

2. a. Though he was sick the patient appreciated the hospital receptionist.
   b. In no time the patient appreciated the hospital receptionist.
   c. Though he was sick the patient amused the hospital receptionist.
   d. In no time the patient amused the hospital receptionist.

3. a. According to the review the critic hated the popular actress.
   b. Within moments the critic hated the popular actress.
   c. According to the review the critic angered the popular actress.
   d. Within moments the critic angered the popular actress.

4. a. Clearly the conductor deplored the unprepared cellist.
   b. Quite quickly the conductor deplored the unprepared cellist.
   c. Clearly the conductor annoyed the unprepared cellist.
   d. Quite quickly the conductor annoyed the unprepared cellist.

5. a. According to the book the politician detested the eager reporter.
   b. In the space of a few minutes the politician detested the eager reporter.
   c. According to the book the politician baffled the eager reporter.
   d. In the space of a few minutes the politician baffled the eager reporter.

6. a. Without much reason the student disdained the school’s principal.
   b. Within 10 minutes the student disdained the school’s principal.
   c. Without much reasons the student bewildered the school’s principal.
   d. Within 10 minutes the student bewildered the school’s principal.

7. a. Understandably the nurse envied the friendly doctor.
   b. Within a few months the nurse envied the friendly doctor.
   c. Understandably the nurse calmed the friendly doctor.
   d. Within a few months the nurse calmed the friendly doctor.

8. a. Obviously the teenager fancied the good looking neighbour.
   b. Within a week the teenager fancied the good looking neighbour.
   c. Obviously the teenager delighted the good looking neighbour.
   d. Within a week the teenager delighted the good looking neighbour.

9. a. According to the producer the agent favoured the tall woman.
   b. Within 5 minutes the agent favoured the tall woman.
   c. According to the producer the agent disappointed the tall woman.
   d. Within 5 minutes the agent disappointed the tall woman.

10. a. For quite a few years the fans esteemed the demanding manager.
    b. Within the space of a few days the fans esteemed the demanding manager.
    c. For quite a few years the fans discouraged the demanding manager.
    d. Within the space of a few days the fans discouraged the demanding manager.

11. a. According to the letter the minister regretted the difficult decision.
    b. Within days the minister regretted the difficult decision.
    c. According to the letter the minister encouraged the difficult decision.
    d. Within days the minister encouraged the difficult decision.

12. a. Because of his upbringing the prince pitied the poor commoners.
    b. Within a couple of months the prince pitied the poor commoners.
    c. Because of his upbringing the prince enraged the poor commoners.
    d. Within a couple of months the prince enraged the poor commoners.
13. a. According to the owner the rider loathed the scared horse.
b. Within seconds the rider loathed the scared horse.
c. According to the owner the rider soothed the scared horse.
d. Within seconds the rider soothed the scared horse.
14. a. Fortunately the volunteer trusted the short park ranger.
b. Within a few hours the volunteer trusted the short park ranger.
c. Fortunately the volunteer fascinated the short park ranger.
d. Within a few hours the volunteer fascinated the short park ranger.
15. a. Like many adolescents the girl idolised the alternative rock band.
b. Within a month the girl idolised the alternative rock band.
c. Like many adolescents the girl offended the alternative rock band.
d. Within a month the girl offended the alternative rock band.
16. a. After the accident the citizens mourned the controversial leader.
b. Within a couple of days the citizens mourned the controversial leader.
c. After the accident the citizens outraged the controversial leader.
d. Within a couple of days the citizens outraged the controversial leader.
17. a. According to the article the president valued the campaign advisor.
b. Over time the president valued the campaign advisor.
c. According to the article the president perplexed the campaign advisor.
d. Over time the president perplexed the campaign advisor.
18. a. After the buy-out the board distrusted the old president.
b. Almost immediately the board distrusted the old president.
c. After the buy-out the board placated the old president.
d. Almost immediately the board placated the old president.
19. a. Quite surprisingly the schoolboy missed the cute puppy.
b. Within a couple of hours the schoolboy missed the cute puppy.
c. Quite surprisingly the schoolboy provoked the cute puppy.
d. Within a couple of hours the schoolboy provoked the cute puppy.
20. a. Unfortunately the criminal resented the strict federal judge.
b. Within a half hour the criminal resented the strict federal judge.
c. Unfortunately the criminal saddened the strict federal judge.
d. Within a half hour the criminal saddened the strict federal judge.
21. a. Without a doubt the child cherished the precious kitten.
b. Within a few minutes the child cherished the precious kitten.
c. Without a doubt the child scared the precious kitten.
d. Within a few minutes the child scared the precious kitten.
22. a. According to the memo the producer tolerated the temperamental superstar.
b. Quite suddenly the producer tolerated the temperamental superstar.
c. According to the memo the producer upset the temperamental superstar.
d. Quite suddenly the producer upset the temperamental superstar.
23. a. According to the email the editor prized the brilliant first-time author.
b. Within hours the editor prized the brilliant first-time author.
c. According to the email the editor terrified the brilliant first-time author.
d. Within hours the editor terrified the brilliant first-time author.
24. a. Understandably the attorney valued the distressed witness.
b. Within 20 minutes the attorney valued the distressed witness.
c. Understandably the attorney confused the distressed witness.
d. Within 20 minutes the attorney confused the distressed witness.
25. a. Unsurprisingly the dean prized the potential donors.
b. In the space of a few minutes the dean prized the potential donors.
c. Unsurprisingly the dean charmed the potential donors.
d. In the space of a few minutes the dean charmed the potential donors.

26. a. Without a doubt the leader treasured the captive audience.
b. Within a few minutes the leader treasured the captive audience.
c. Without a doubt the leader thrilled the captive audience.
d. Within a few minutes the leader thrilled the captive audience.

27. a. Surprisingly the psychic appreciated the gullible man.
b. In no time the psychic appreciated the gullible man.
c. Surprisingly the psychic hypnotised the gullible man.
d. In no time the psychic hypnotised the gullible man.

28. a. For a long time the orderly respected the dying patient.
b. Within 10 minutes the orderly respected the dying patient.
c. For a long time the orderly comforted the dying patient.
d. Within 10 minutes the orderly comforted the dying patient.

29. a. According to the journal the paralegal idolised the experienced lawyer.
b. Within a few months the paralegal idolised the experienced lawyer.
c. According to the journal the paralegal embarrassed the experienced lawyer.
d. Within a few months the paralegal embarrassed the experienced lawyer.

30. a. Obviously the dragon detested the town’s people.
b. Within 1 week the dragon detested the town’s people.
c. Obviously the dragon horrified the town’s people.
d. Within 1 week the dragon horrified the town’s people.

31. a. For no good reason the kids distrusted the quiet librarian.
b. Within a half hour the kids distrusted the quiet librarian.
c. For no good reason the kids disturbed the quiet librarian.
d. Within a half hour the kids disturbed the quiet librarian.