

Short Communication

The Anterior Midline Field: Coercion or decision making?

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ABSTRACT

To study the neural bases of semantic composition in language processing without confounds from syntactic composition, recent magnetoencephalography (MEG) studies have investigated the processing of constructions that exhibit some type of syntax-semantics mismatch. The most studied case of such a mismatch is *complement coercion*; expressions such as *the author began the book*, where an entity-denoting noun phrase is coerced into an eventive meaning in order to match the semantic properties of the event-selecting verb (e.g., ‘the author began reading/writing the book’). These expressions have been found to elicit increased activity in the Anterior Midline Field (AMF), an MEG component elicited at frontomedial sensors at ~400 ms after the onset of the coercing noun [Pyllkkänen, L., & McElree, B. (2007). An MEG study of silent meaning. *Journal of Cognitive Neuroscience*, 19, 11]. Thus, the AMF constitutes a potential neural correlate of coercion. However, the AMF was generated in ventromedial prefrontal regions, which are heavily associated with decision-making. This raises the possibility that, instead of semantic processing, the AMF effect may have been related to the experimental task, which was a sensicality judgment. We tested this hypothesis by assessing the effect of coercion when subjects were simply reading for comprehension, without a decision-task. Additionally, we investigated coercion in an adjectival rather than a verbal environment to further generalize the findings. Our results show that an AMF effect of coercion is elicited without a decision-task and that the effect also extends to this novel syntactic environment. We conclude that in addition to its role in non-linguistic higher cognition, ventromedial prefrontal regions contribute to the resolution of syntax-semantics mismatches in language processing.

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1. Introduction

Theories of the relationship between the syntactic and semantic representations of language have traditionally been based on intuitions about wellformedness and truth conditions. In recent years, however, a new line of research has emerged aimed at developing psycho- and neurolinguistic tools for investigating the syntax-semantics interface (for reviews, see Pyllkkänen & McElree, 2006; Pyllkkänen, 2008). This research has focused on expressions exhibiting some type of syntax-semantics mismatch—expressions whose meanings do not straightforwardly map onto their syntax. A much studied example of such a mismatch is expressions such as *the author began the book*, where *the author* is interpreted as having initiated some activity involving the book (such as reading or writing) even though the sentence does not contain any word that transparently encodes that activity meaning.

Where does meaning come from when it does not come from the syntax? The traditional answer in most semantic theories is

that it is generated by purely semantic rules that accept as input one type of meaning and output a different type of meaning. For example, the interpretation of expressions such as *the author began the book* has been proposed to involve a rule called complement coercion, which shifts (or “coerces”) the meaning of an entity-denoting direct object into an event-meaning when the semantics of the verb demands an event-denoting complement (e.g., Pustejovsky, 1995). A verb like *begin* inherently describes the beginnings of events and therefore cannot combine with an entity-denoting noun phrase directly. In terms of semantic theory, the combination of *begin* and *the book* involves a so-called “type-mismatch,” because *the book* is of the wrong semantic type to directly combine with *begin*.

Thus, perhaps surprisingly, natural language has ways to fit together meanings that appear to be incompatible. What psychological mechanisms are at play in type-mismatch resolution? Behavioral studies on several constructions have shown that type-mismatch has measurable consequences for real-time comprehension, which provides a useful starting point for addressing this question since it allows further study of both the properties of the behavioral effect as well as its neural bases. So far, the most extensively studied construction has been complement coercion,

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which has been shown to engender processing costs in self-paced reading (e.g., McElree, Traxler, Pickering, Seely, & Jackendoff, 2001), eye-tracking (e.g., Traxler, McElree, Williams, & Pickering (2005), and speed–accuracy tradeoff measures (McElree, Pylkkänen, Pickering, & Traxler, 2006). Importantly, several non-coercion-related explanations of the effect have been ruled out. For example, the cost does not reflect a general difficulty in combining verbs such as *begin* with NP complements (Traxler et al., 2005) nor the telicity asymmetry between complement coercion sentences and typical control sentences such as *the author wrote the book* (Pickering, McElree, & Traxler, 2005). Further, the effect is not related to the inherent ambiguity of expressions such as *begin the book*, where the nature of the implicit activity is left unspecified (Frisson & McElree, 2008; Traxler et al., 2005). In sum, the behavioral work on complement coercion suggests that the reading time delay is directly related to the operation of shifting one type of meaning to another type, i.e., an entity ('the book') to an event ('an activity involving the book'). Other cases of type-mismatch that have been reported as behaviorally costly include aspectual coercion (Brennan & Pylkkänen, 2008; Piñango, Zurif, & Jackendoff, 1999; Piñango, Winnick, Ullah, & Zurif, 2006; Todorova, Straub, Badecker, & Frank, 2000; but see Pickering, McElree, Frisson, Chin, & Traxler, 2006), concealed questions (Harris, Pylkkänen, McElree, & Frisson, 2007) and object quantifiers (Varvoutis & Hackl, 2006; Hackl, Koster-Moeller, & Varvoutis, in press).

The neural bases of type-mismatch resolution have been addressed in several recent MEG studies (Brennan & Pylkkänen, 2008; Harris et al., 2007; Pylkkänen & McElree, 2007). In an initial investigation, Pylkkänen & McElree (2007) identified a fronto-medial MEG component for complement coercion at 400–450 ms that showed larger amplitudes for expressions such as *the journalist began the article* than for controls such as *the journalist wrote the article*. The coercion sensitive component was dubbed the Anterior Midline Field (AMF), according to the midline prefrontal distribution. Importantly, this component was not modulated by anomaly, as evidenced by a lack of an AMF effect for expressions such as *the journalist disgusted the article*. Thus, this component does not appear to reflect low cloze probability, as this hypothesis predicts the largest AMF amplitudes for the anomalous stimuli.

Thus Pylkkänen & McElree (2007) provide initial evidence that type-mismatch can have measurable effects on MEG activity. The localization of the coercion effect was, however, surprising. Both discrete and distributed source models localized the effect in ventromedial prefrontal regions, an area outside the left hemisphere fronto-temporal network that has traditionally figured in most models of language processing (e.g., Friederici, 2002; Hickok & Poeppel, 2004). A survey of the literature does, however, reveal several studies where ventromedial effects of semantic processing have been identified. For example, the ventromedial prefrontal cortex (VMF) has been reported to show increased activation for referentially ambiguous expressions in fMRI (Nieuwland, Petersson, & Van Berkum, 2007). In ERPs, similar manipulations have elicited increased anterior negativities, qualitatively different from the N400 response associated with semantic anomalies (Van Berkum, Brown, Hagoort, & Zwitserlood, 2003; Van Berkum, Koornneef, Otten, & Nieuwland, 2007). Thus it is possible that these anterior negativities may be related to the MEG AMF response. Further, several fMRI studies have shown the VMF to be involved in the processing of coherent discourse (Ferstl & von Cramon, 2001, 2002; Kuperberg, Lakshmanan, Caplan, & Holcomb, 2006). The VMF has also been identified as a network node in a recent MEG study investigating long-range connectivity between brain areas involved in the comprehension of a written story (Kujala et al., 2007). In summary, despite the seeming novelty of Pylkkänen & McElree's (2007) AMF localization, there is, in fact, a sizeable body of literature offer-

ing independent evidence for the participation of the VMF in language processing.

The aim of the current study was to test to what extent the AMF effect documented in Pylkkänen & McElree (2007) generalizes to a novel task and syntactic environment. Specifically, ventromedial prefrontal cortex has been heavily implicated for non-linguistic processing such as decision-making and social cognition. This raises the question of whether the coercion effect reported in Pylkkänen & McElree (2007) might have been due to the experimental task, which was a sensicality judgment performed at the end of each sentence, four words after the target noun had occurred (e.g., after the word *break* in *the journalist began the article after his coffee break*). In other words, one might hypothesize that the activity generating the AMF reflects the difficulty of sensicality judgments, and that those judgments are performed incrementally at each word and are the hardest for coerced nouns.

Although there was no direct evidence for this task-related explanation in Pylkkänen & McElree (2007)—for example, AMF amplitude did not correlate with behavioral response time or accuracy—there is abundant evidence that the VMF is associated with decision-making (for recent reviews, see Fellows & Farah, 2007; Wallis, 2007). Patient studies have shown that ventromedial prefrontal damage leads to poor judgment in everyday decisions (Damasio, 1994; Damasio, Grabowski, Frank, Galaburda, & Damasio, 1994; Eslinger & Damasio, 1985). In the laboratory, VMF patients fail to adjust their behavior when the rewards attached to their choices are changing in tasks such as in the Iowa gambling task (Bechara, Damasio, Tranel, & Damasio, 1997, 1998; Fellows & Farah, 2005). In even simple pairwise choice tasks, where subjects are asked which of two items within a category they prefer (e.g., pink or yellow color), VMF patients elicit a reliably higher level of inconsistency than healthy controls (Fellows & Farah, 2007). Neuroimaging studies have corroborated these findings, showing ventromedial prefrontal activity for many types of decisions, including reward-based decisions (O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001; Kringelbach, 2005; Blair et al., 2007; Daw, O'Doherty, Dayan, Seymour, & Dolan, 2006), guessing (Elliott, Rees, & Dolan, 1999) and moral judgments (Heekeren, Wartenburger, Schmidt, Schwintowski, & Villringer, 2003; Moll, Eslinger, & Oliveira-Souza, 2001; Moll, de Oliveira-Souza, Bramati, & Grafman, 2002; Moll et al., 2002). Specifically, the VMF has been hypothesized to represent the current relative value of stimuli, which is then used to guide decision making (Fellows & Farah, 2007; Kringelbach, 2005; Sugrue, Corrado, & Newsome, 2005). Thus, it is not implausible that the type of sensicality judgment task used by Pylkkänen & McElree (2007) might have involved VMF mechanisms for representing, word by word, the current sensicality of the stimuli, which is then used in the end-of-sentence sensicality judgments. In other words, the hypothesis would be that our earlier AMF effect was not associated with the linguistic computations necessary for interpreting an entity-denoting noun as the complement of an event-selecting verb, but rather with the metalinguistic decision of whether such a combination yields a sensical English expression. For this hypothesis to explain the increased AMF amplitudes of coercing nouns, sensicality judgments would need to be harder for coercing than for non-coercing complements.

We assessed this task-related explanation of the AMF effect by testing whether coercion affects the AMF when subjects are simply required to read for comprehension and are not asked to judge the stimuli in any way. A lack of an AMF effect under these circumstances would support a decision-related account of the result reported in Pylkkänen & McElree (2007). In contrast, a positive AMF effect for coercion would suggest that the involvement of the AMF is not task dependant but rather part of the natural processing of coercion.

Additionally, we manipulated coercion in a novel syntactic environment, to further generalize our previous AMF findings. We used the adjectival environment shown in (1), which McElree et al. (2006) have recently shown to elicit the same size behavioral coercion effect as the transitive *begin the book* construction used in Pykkänen & McElree (2007). Here, the target items are able-suffixed adjectives, derived from event-selecting verbs such as *survive*, *finish*, *complete*, and so forth. The adjectives occur inside small clauses whose subjects either denote entities, as in (1a), or events, as in (1b).

- (1a) Coercion (entity noun):
The swimmers imagined the cave *survivable*.
(1b) Control (event noun):
The swimmers imagined the dive *survivable*.

By hypothesis, in order to interpret (1a), the entity-denoting noun *cave* needs to be coerced into an event-predicate (e.g., ‘swimming in the cave’) before it can semantically compose with *survivable*. Consistent with this, speed–accuracy trade-off (SAT) data on this contrast showed expressions such as (1a) to be interpreted more slowly and less accurately than (1b) (McElree et al., 2006). Given that the semantic operation of coercion in (1a) should be the same as in the previously studied *begin the book* construction, we predicted that (1a) should elicit increased AMF amplitudes if the AMF indeed reflects coercion. However, the effect might occur somewhat later than the 400–450 ms time-window implicated in our previous MEG study, given that the coercion-triggering able-adjective is significantly more complex than the coercion-triggering noun in the *begin the book* construction. In the *begin the book* construction, the need for coercion can be detected as soon as the meaning of the monomorphemic *book* has been accessed. In contrast, assessing that coercion is necessary at the able-adjective in expressions such as (1a), the processor must decompose the complex able-adjective *survivable*, access the meaning of the verbal stem *survive*, detect that the verb requires an event-denoting argument which is not provided by the subject of the small clause, and then create the appropriate event-sense. Consistent with the added complexity, McElree et al.’s (2006) SAT data showed able-adjectives to be associated with approximately 200 ms longer processing times than the target nouns in the *begin the book* construction (McElree et al., 2006). To assure the ability to detect a late effect, we analyzed 800 ms of post-stimulus activity.

As stimulus materials, we employed the same sentences that were used in the previous SAT study (McElree et al., 2006). The stimuli consisted of 90 sentence pairs of the general form shown in (1) above. In order to employ as many distinct able-adjectives as possible, the materials also included negative-prefixed versions of able-adjectives, such as *unsurvivable* and *noncontinuable*. Each able-adjective was derived from an event-selecting verb and was the predicate of a small clause whose subject described an entity in the coercion condition and an event in the control condition. The event-denoting subjects were either zero-related to verbs, as in *the dive* or *the fall*, or involved nominalizing gerundive morphology, as in *the filming* or *the carving*. The target adjectives were followed by five words as the spill-over region (this was the only difference to the materials of McElree et al. (2006), where the able-adjective was sentence-final). The first two post-target words were held constant within a pair, but the last three were varied, in order to diversify the materials. Examples of the experimental stimuli are shown in (2)–(4).

- (2a) Coercion: The gymnastics committee judged the beam unmasterable after trying it out themselves.
(2b) Control: The gymnastics committee judged the dance unmasterable after trying many different choreographers.

- (3a) Coercion: The nimble climber imagined the ice *survivable* even though others did not.
(3b) Control: The nimble climber imagined the fall *survivable* even though the experts disagreed.
(4a) Coercion: The ambitious artist envisioned the sculpture *finishable* in time for the exhibition.
(4b) Control: The ambitious artist envisioned the carving *finishable* in time for the sale.

Subjects performed no judgments on the stimuli, as our aim was to assess whether an AMF effect would be obtained in the absence of a decision task. To insure a basic level of attentiveness, half of the trials were followed by comprehension questions.

2. Results

Visual inspection of the individual grandaverages ($n = 12$) revealed an AMF field pattern in a late time-window, at 600–700 ms. Fig. 1 shows sample evoked responses from two subjects, depicting a fronto-medial field pattern with a right-lateral out-going field (red) and a left-lateral re-entering field (blue). To model the cortical generators of the MEG activity elicited by the Coercion and Control conditions, we used distributed Minimum Norm Estimates (MNEs), as in our previous study (Pykkänen & McElree, 2007). MNEs provide an estimation of current density across a large number of sources evenly distributed across the brain surface (Hämäläinen & Ilmoniemi, 1984). These estimates were compared sample by sample between the Coercion and Control conditions. We first performed a global comparison of all activity up to 800 ms post-stimulus onset, to assess whether a ventromedial effect of Coercion is elicited in any time window. Having identified the right time window, we then carried out a subsequent region-of-interest analysis of ventro-medial activity only.

Fig. 2A plots the results of the global comparison. Each source plotted in red represents the center of a spatio-temporal neighborhood showing a reliable amplitude increase for coercion ($p < 0.05$; see ‘Detailed Methods’ for neighborhood criteria). At 650–700 ms, the comparison revealed a clear ventromedial effect of coercion, which appeared somewhat right-lateral. A tendency for right-laterality was observed in many individual subjects in our previous study, as well (Pykkänen & McElree, 2007), although it was not visible in the group data. In addition to the ventromedial effect, the global comparison showed additional effects of coercion at 400–500 ms left-laterally, and at 600–700 ms right-laterally. These regions did not show effects of coercion in our previous study, and are thus potentially attributable to the different construction that was used in the current experiment. However, given that these effects did not pertain to our hypotheses, we refrain from speculating about their functional significance.

In a subsequent analysis, the ventromedial region showing a reliable effect in the global comparison was treated as a region of interest, alongside its left hemisphere homolog, to allow further evaluation of laterality. The mean amplitudes of these regions for the 650–700 ms interval were computed for each subject and condition and were entered into a 2×2 within subjects ANOVA, with Condition (Coercion vs. Control) and ROI (Left vs. Right) as factors. This analysis revealed a reliable main effect of Condition ($F(1,11) = 5.91$; $p < 0.05$), with pairwise comparisons revealing reliably larger amplitudes for coercion in both the left ($p = 0.019$) and the right ROI ($p = 0.003$) (Fig. 2B). Although the right-lateral effect was slightly larger and somewhat more reliable, there was no interaction.

In sum, our results revealed a somewhat right-dominant effect of coercion in ventromedial regions at 650–700 ms.

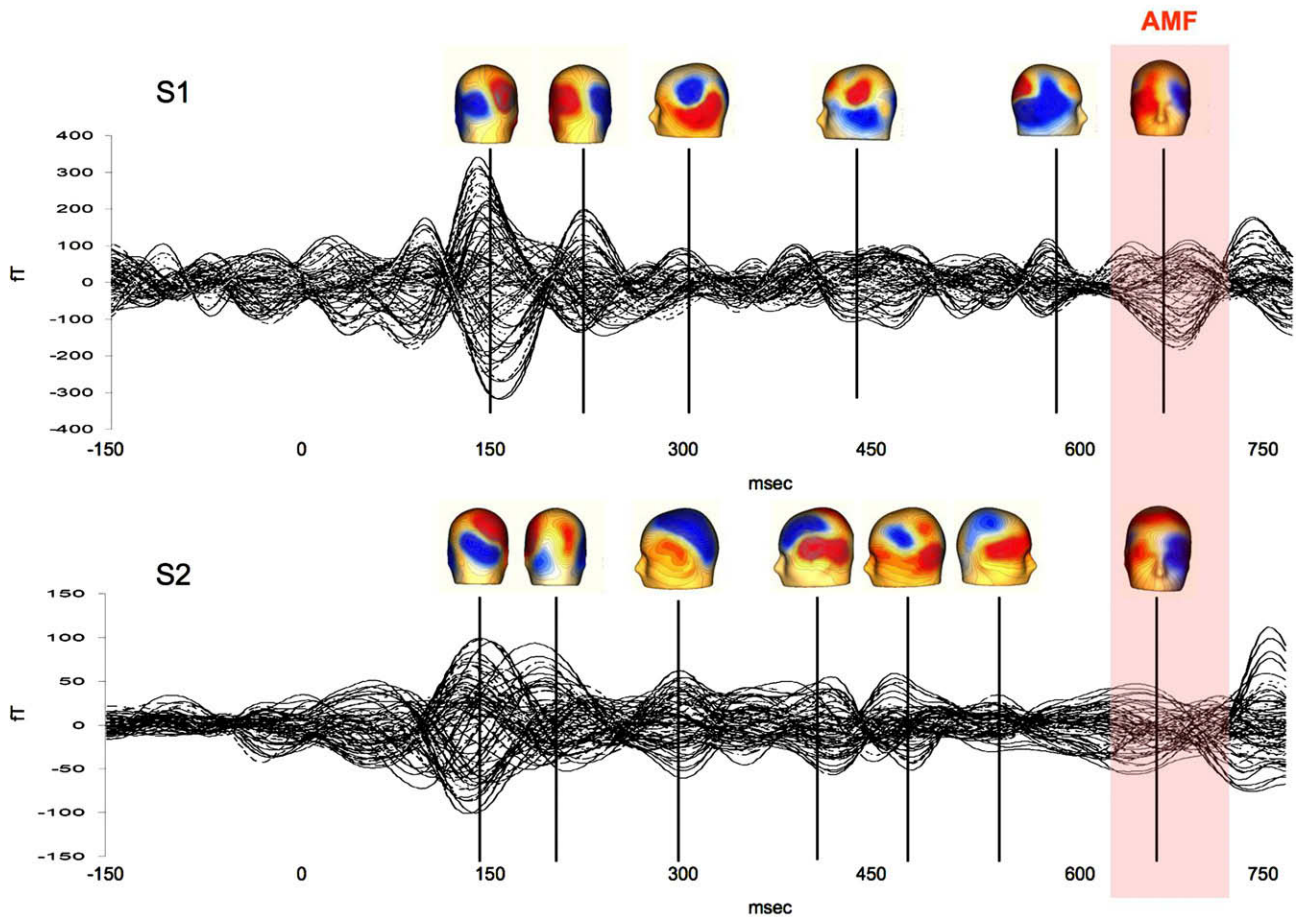


Fig. 1. Sample individual grandaverages from two subjects, showing activity from all the sensors. An AMF field pattern is observed at 600–700 ms (shaded area).

3. Discussion

This study assessed whether the ventromedial prefrontal coercion effect reported in Pykkänen & McElree (2007) was due to task-related decision processes or whether it was the consequence of coercion recruiting mechanisms in a brain area not traditionally associated with linguistic processing. Our results support the latter hypothesis, as a ventromedial prefrontal effect of coercion was obtained even in the absence of an overt decision task. Thus, in addition to playing an important role in various types of non-linguistic higher cognition, the VMF appears to participate in the resolution of semantic type-mismatch in language processing.

Beyond ruling out a task-related explanation of the AMF effect, the present results show that the AMF effect is not dependant on the specific syntactic environment used in Pykkänen & McElree (2007). We previously examined the MEG correlates of complement coercion by measuring it on the coercing complement itself, i.e., on the direct object of expressions such as *the author finished the book*. The distribution of coercion is, however, wider than this, as witnessed by expressions such as *the book is finishable*, which, similarly to the transitive verb-NP context, are interpreted as involving a covert activity (i.e., ‘some activity involving the book is finishable’). If these two syntactic contexts require the same semantic operation of coercion, a similar brain region should be engaged for both types of expressions, even though the target item is a simple noun in one case and a complex adjective in the other. This is exactly what we found: when able-adjectives embedding event-selecting verbs were presented with an entity-denoting subject, they elicited a similar anterior inferior midline effect as entity-

denoting nouns presented after event-selecting verbs. The effect, however, occurred much later for the adjectives, as one would expect given their morphological complexity as well as their much slower behavioral processing times (McElree et al., 2006).

Although our results show that the AMF effect is not dependant on explicit judgments, they do not rule out the possibility that coercion nevertheless shares mechanisms with the tasks that more typically drive the ventromedial prefrontal cortex, such as decision-making or social conduct. As regards social cognition, language comprehension is in some ways a type of a theory of mind task: for two individuals to interact, they must be able to infer an intended message from sensory stimulation. One might then speculate that perhaps mismatching meanings are resolved via some mechanism that is shared with social cognition more generally. In other words, type-mismatch resolution may constitute an interface phenomenon between linguistic and non-linguistic processing (Pykkänen & McElree, 2007; Pykkänen, 2008). A detailed characterization of this hypothesis remains a topic for future research; the aim of our current study was to narrowly focus on the task-related explanation of our previous effect.

4. Conclusion

This study aimed to rule out a task-related explanation of the previously obtained AMF effect of coercion (Pykkänen & McElree, 2007) and to extend the investigation of the neural bases of complement coercion to a novel syntactic context, involving deverbal adjectives. Our results show an AMF effect of coercion in the absence of any explicit judgment task and demonstrate that the

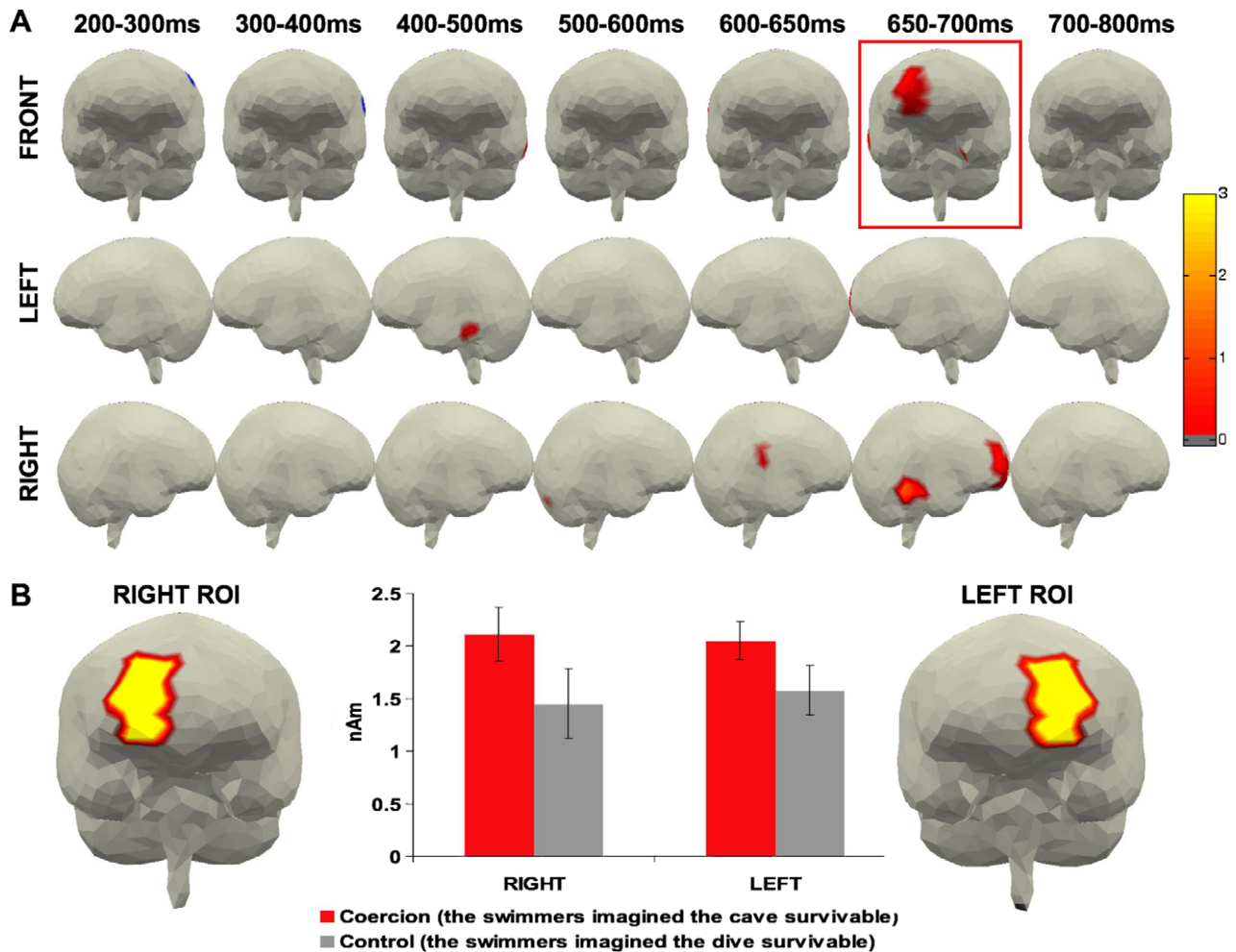


Fig. 2. (A) A global comparison of minimum norm activity (Coercion minus Control). Red regions exhibit a reliable amplitude increase for Coercion. (B) A region of interest analysis on right and left lateral ventromedial activity revealing a bilateral amplitude increase for Coercion.

deverbal adjectives engage a similar brain region as the more familiar type of complement coercion. These results enforce the generality of the AMF coercion effect and show that the ventromedial prefrontal cortex plays a non-decision related role in language processing.

5. Detailed methods

5.1. Participants

Twelve right-handed native English speakers were paid to participate in the study (2 males, ages 20–31). All were undergraduate or graduate students at New York University.

5.2. Materials

Our materials consisted of 90 sentence pairs of the general form shown in (1). In order to employ as many distinct able-adjectives as possible, we also used negative-prefixed versions of able-adjectives, such as *unsurvivable* and *noncontinuable*. Altogether, the materials contained 23 different able-adjectives, most of which were repeated four times within a condition in order to increase the signal-to-noise ratio of the MEG averages. Each participant saw all of the stimuli, but the materials were presented in a pseudorandom order in such a way that the effect of repetition was controlled for between the conditions.

Each able-adjective was derived from an event-selecting verb and was the predicate of a small clause whose subject described an entity in the coercion condition and an event in the control condition. The event-denoting subjects were either zero-related to verbs, as in *the dive* or *the fall*, or involved nominalizing gerundive morphology, as in *the filming* or *the carving*. Half of the matrix verbs selected obligatorily for clausal complements (e.g., *declare*, *presume*) and half optionally, allowing also for an NP argument (e.g., *find*, *imagine*). In the previous behavioral study on the same materials, we found no processing differences for the two different types of matrix verbs (McElree et al., 2006). The target adjectives were followed by five words as the spill-over region. The first two post-target words were held constant within a pair, but the last three were varied, in order to diversify the materials. Examples of the experimental stimuli are shown in (2)–(4) above.

The entity- and event-denoting nouns were matched for frequency of occurrence in print (entity-nouns: 114.5; event-nouns: 87.2; $t(44) = 1.07$, $p = .29$) (Francis & Kucera, 1982) and for their semantic relatedness to the able-adjectives. As a measure of semantic relatedness, we used Latent Semantic Analysis (LSA; Landauer, Foltz, & Laham, 1998). The able-adjectives were morphologically complex, containing in many cases both a suffix (*-able*) and a negative prefix (e.g., *un-* or *non-*). Since little is known about the semantic associations of these types of function morphemes, and since co-occurrence measures were in any case unavailable for most of these rather rare complex adjectives, the verbal stems of

the adjectives were used in the LSA analysis instead (i.e., *continue* for *discontinuable*, and *survive* for *unsurvivable*). Two of the entity-denoting nouns (*laptop* and *protestor*) did not occur in the LSA corpus. The analysis showed no reliable effect of noun type on the co-occurrence estimates, the mean cosine value for entity-denoting nouns being 0.13 and for event-denoting nouns 0.16 ($t(42) = 2.01, p = .11$).

The test materials were combined with 450 filler sentences with different syntactic structures. The fillers were either basic transitive subject–verb–object sentences or they involved a transitive syntax with an added VP-final secondary predicate (e.g., *the police officer saw the suspect loose*).

5.3. Procedure

During the experiment, the participants lay in a dimly lit magnetically shielded room and viewed the experimental stimuli via fiberoptic goggles (Avotec, FL). Each trial started with a fixation point in the middle of the screen. Subjects initiated each trial themselves by pressing a button. Since the trials were self-initiated, subjects were able to take as many breaks as they wished. The sentences were presented in non-proportional Courier font (font size = 70), word by word. Each word stayed on the display for 300 ms and was followed by a 300 ms blank. Half of the sentences were followed by yes-no comprehension questions (e.g., “Did the gymnastics committee judge the beam unmasterable?” for (2a) above or “Was it the nimble climber who imagined the ice survivable?” for (3a)), which the subjects answered by pressing one of two buttons. Before starting the experiment, the participants performed a short practice with six items.

Neuromagnetic fields were recorded with a whole-head, 148-channel neuromagnetometer array (4-D Neuroimaging, Magnes WH 2500) at a sampling rate of 678 Hz in a band between 0.1 and 200 Hz. The recording sessions lasted for about one hour.

5.4. MEG data analysis

Each participant’s MEG data were averaged according to stimulus category. In the averaging, artifact rejection was performed by excluding all responses which contained signals exceeding a certain threshold set individually for each subject according to their general amplitude range (mean threshold = ± 3.6 pT, $SD = .6$ pT). On average 15% of each subject’s data were excluded due to artifacts. Prior to source analysis, the MEG averages were high-pass filtered at 1 Hz and low-pass filtered at 40 Hz.

The previous MEG study on complement coercion that this study built on employed both discrete and distributed source modeling, both of which showed an anterior midline effect of coercion (Pyllkkänen & McElree, 2007). Since in the current study the target item was quite complex, we wished to avoid dipole modeling, as the source solutions would have likely become excessively complex and consequently less reliable. Instead, only distributed source modeling was employed.

As in our previous study, we used Minimum Norm Estimates (MNEs) as the distributed source model (L2-norm). MNEs provide an estimation of current density across a large number of sources evenly distributed across the brain surface (Hämäläinen & Ilmoniemi, 1984). The minimum norm images were calculated in BESA 5.1. Each MNE was based on the activity of 1426 regional sources evenly distributed in two shells 10% and 30% below a smoothed standard brain surface. Regional sources in MEG can be regarded as sources with two single dipoles at the same location but with orthogonal orientations. The total activity of each regional source was computed as the root mean square of the source activities of its two components. The minimum norm images were depth weighted as well as spatio-temporally weighted, using a signal

subspace correlation measure introduced by Mosher & Leahy (1998).

We first performed a global comparison of the MNEs in order to identify a suitable time-window for a subsequent ventromedial region-of-interest analysis. The minimum total power of the current distribution was compared sample by sample between the Coercion and Control conditions. Each observation (i.e., a source amplitude at a time point) was included in a point-by-point *t*-test, but a difference between conditions was considered reliable only when it remained significant ($p < 0.05$) for a period of time and was not limited to a single point in space. Specifically, a difference at a source was considered reliable only if it remained significant for at least 10 temporal samples and if 10 of its closest neighbors also showed a significant effect. Thus each significant effect represented the center of a spatio-temporal neighborhood showing a reliable difference between conditions. In a subsequent analysis, a ventromedial region showing an effect of Coercion in the global comparison was treated as a region of interest in within-subjects analysis of variance (see main text).

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