UC San Diego
UC San Diego Electronic Theses and Dissertations

Title

Beyond the (Linguistically) Expected: Activating Event Knowledge During Real-Time Language Comprehension

Permalink

https://escholarship.org/uc/item/8bs992j2

Author

Metusalem, Ross

Publication Date

2015

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA, SAN DIEGO

Beyond the (Linguistically) Expected: Activating Event Knowledge During Real-Time

Language Comprehension

A dissertation submitted in partial satisfaction of the requirements for the degree

Doctor of Philosophy

in

Cognitive Science

by

Ross Patrick Metusalem

Committee in charge:

      Professor Jeffrey Elman, Chair
      Professor Marta Kutas, Co-Chair
      Professor Seana Coulson
      Professor Victor Ferreira
      Professor Roger Levy

2015

The dissertation of Ross Patrick Metusalem is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

_____

_____

_____

_____
Co-Chair

_____
Chair

University of California, San Diego

2015

DEDICATION

To Mom and Dad, for encouraging me to achieve.

To Sara, for being a role model and friend.

To Liz, for everything.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

I would like to acknowledge Jeff Elman and Marta Kutas for their guidance, support, and patience throughout my graduate studies. I could not have done any of this without them.

I also would like to acknowledge many others who contributed to my training and intellectual development during my Ph.D. studies: members of the Kutas Cognitive Electrophysiology Lab (especially Tom Urbach and Katherine DeLong), members of the UC San Diego Center for Research in Language and Institute for Neural Computation communities, members of the UC San Diego Chancellor's Interdisciplinary Collaboratories research team of which I was a part, Arielle Borovsky, Ken McRae, Ben Bergen, and my committee members, Roger Levy, Vic Ferreira, and Seana Coulson. It takes a village.

Chapter 4, in full, is currently being prepared for publication of the material. Metusalem, R. & Elman, J.L. Dynamic Modulation of Event Knowledge Activation in the Visual World Paradigm. The dissertation author was the primary investigator and author of this material.

VITA

Education

2015   Ph.D., Cognitive Science, University of California, San Diego

2008   M.A., Linguistics, The Ohio State University

2007   B.A., Linguistics, *Summa Cum Laude, With Honors in the Arts & Sciences, With Research Distinction*, The Ohio State University

Research Fields

Language processing, cognitive psychology, cognitive neuroscience, event-related brain potentials (ERPs), eye-tracking

Publications

Metusalem, R., Kutas, M., Urbach, T.P., Hare, M., McRae, K., & Elman, J.L. (2012). Generalized event knowledge activation during online sentence comprehension. *Journal of Memory and Language, 66*, 545-567.

Metusalem, R., Kutas, M., Hare, M., McRae, K., & Elman, J.L. (2010). Generalized event knowledge activation during online language comprehension. In S. Ohlsson & R. Cantrambone (Eds.), *Proceedings of the 32nd Annual Conference of the Cognitive Science Society* (pp. 1058-1063). Austin, TX: Cognitive Science Society.

Metusalem, R. & Ito, K. (2008). The role of L+H* pitch accent in discourse construction. In P.A. Barbosa, S. Madureira, and C. Reis (Eds.), *Proceedings of the Speech Prosody 2008 Conference* (pp. 493-496). Campinas, Brazil, Editora RG/CNPq.

Manuscripts Under Review or in Preparation

Metusalem, R. & Elman, J.L. (in prep). Dynamic modulation of event knowledge activation in the visual world paradigm.

Metusalem, R., Kutas, M., Urbach, T.P., & Elman, J.L. (under review). Hemispheric asymmetry in event knowledge activation during incremental language comprehension: A visual half-field ERP study. *Neuropsychologia*.

Conference Presentations

Metusalem, R., Kutas, M., Urbach, T.P., & Elman, J.L. (2014). *Hemispheric differences in processing the scenario-relevance of words in discourse*. Poster presentation at 20th Annual Architectures and Mechanisms in Language Processing Conference, Edinburgh, UK, September 4-6.

Borovsky, A., Sweeny, K., Metusalem, R., & Elman, J.L. (2013). *Children flexibly use event and verbal knowledge in real-time sentence interpretation*. Poster presentation at the Biennial Meeting of the Society for Research in Child Development, Seattle, WA, April 18-20.

Metusalem, R., Kutas, M., Hare, M., McRae, K., & Elman, J.L. (2010). *ERPs reveal rich event knowledge activation during online language comprehension*. Oral presentation at The Joint Meeting of the Conceptual Structure, Discourse, and Language Conference and the Embodied and Situated Language Processing Workshop, San Diego, CA, September 16-19.

Metusalem, R., Kutas, M., Hare, M., McRae, K., & Elman, J.L. (2010). *Generalized event knowledge activation during online language comprehension*. Oral presentation at the 32nd Meeting of the Cognitive Science Society, Portland, OR, August 11-14.

Metusalem, R., & Ito, K. (2008). *Accentual prominence and contrast representation in discourse development*. Poster presentation at the Third Conference on Tone and Intonation, Lisbon, Portugal, September 15-17.

Metusalem, R. & Ito, K. (2008). *The role of L+H* in discourse construction*. Poster presentation at the Fourth Conference on Speech Prosody, Campinas, Brazil, May 6-9.

Metusalem, R., & Ito, K. (2008). *The effect of contrastive accent in discourse construction*. Poster presentation at the 2008 CUNY Conference on Human Sentence Processing, Chapel Hill, NC, March 13-15.

Teaching Experience

(all at UCSD)

As Instructor:

COGS 153: Language Comprehension (Summer, 2013; 2015)

As Teaching Assistant:

PSYC 111A: Research Methods in Psychology I (Winter, 2015)

COGS 15: Uncensored Intro to Language (Spring, 2012)
COGS 14: Design and Analysis of Experiments (Fall, 2010)
COGS 1: Intro to Cognitive Science (Spring, 2009)

Ad-hoc Reviewer

Annual Conference of the Cognitive Science Society, Neuropsychologia, Frontiers in Language Sciences

Departmental Service

Senior Teaching Assistant, 2013-14

Talk Series Coordinator, 2011-12

Undergraduate Liaison, 2009-11

ABSTRACT OF THE DISSERTATION

Beyond the (Linguistically) Expected: Activating Event Knowledge During Real-Time

Language Comprehension

by

Ross Patrick Metusalem

Doctor of Philosophy in Cognitive Science

University of California, San Diego, 2015

Professor Jeffrey Elman, Chair
Professor Marta Kutas, Co-Chair

Comprehending language describing typical events, such as going to a baseball game or playing in the snow, involves activating general knowledge of the type of event described. Research has demonstrated that event knowledge guides the generation of expectations for upcoming words as sentences are processed in real time, word-by-word. This dissertation begins by examining the activation of concepts that are related to the described event but are not expected to appear in the language (i.e., *linguistically unexpected* concepts). In an event-related brain potential (ERP) experiment, participants read short stories that contained unexpected words related or unrelated to the described event. Unexpected words related to the described event elicited a reduced N400 ERP component relative to unexpected words unrelated to the described event. This result indicates that event knowledge activation during comprehension is not limited to only

this concepts expected to appear in the unfolding sentence. A subsequent ERP experiment utilized visual-half field presentation of critical words to examine asymmetries across the cerebral hemispheres in the activation of linguistically unexpected event knowledge elements. Unexpected words related to the described event elicited a reduced N400 with left visual field (right hemisphere) but not right visual field (left hemisphere) presentation, suggesting a crucial role of the right hemisphere in activating unexpected event knowledge elements. A third experiment investigated the temporal dynamics of event knowledge activation by monitoring eye movements over arrays of images as participants listened to short stories. When a story first established an event context, unmentioned images depicting concepts related to the described event immediately attracted visual attention. As the story elaborated on the event, specifically highlighting one of the images related to the event, comprehenders shifted visual attention to this image and also to a distractor image that had not drawn visual attention when the event context was first established. This finding suggests that comprehenders considered the potential relevance of each image to the unfolding event description at each point in time. Together, these studies advance our understanding of how event knowledge is engaged during language comprehension.

CHAPTER 1:

INTRODUCTION

Several decades ago, the prominent view of real-time language comprehension suggested that the initial processing of each incoming word was influenced only by basic grammatical constraints. The computation of syntactic structure proceeded insulated from the influence of non-grammatical information sources, with semantics computed only after the syntactic structure had been established (e.g., Ferreira & Clifton, 1986; Fodor, 1983; Frazier & Fodor, 1978). However, with numerous demonstrations of the influence of non-grammatical information on the initial computation of syntactic structure (e.g., McRae, Spivey-Knowlton, & Tanenhaus, 1998; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995; Tyler & Marslen-Wilson, 1977), the view of comprehension as modular and syntax-first has been replaced by "constraint-based" views. A key component of the constraint-based approach is the real-time interaction of multiple information sources in guiding the processing of each incoming word (Marslen-Wilson, 1975). Information such as the wider discourse context, pragmatic constraints, the comprehender's own background knowledge, and the communicative intent of the speaker can influence even the earliest moments of the processing of each incoming word.

The research in this dissertation addresses the real-time activation one of these information sources: knowledge of how real-world events typically occur, or *event knowledge*. The term *event* generally refers to any change in state of the universe that is temporally bounded in some way. While some use the term *event* to denote a single action akin to a verb (e.g., "kick" denotes an event in which some entity swings its leg), these are but one simple class of events. Events can extend beyond the level of a single action or occurrence into much larger events, themselves composed of smaller events. For example, a soccer game can be considered an event, composed of many individual

kicking (and other) events.[1] We segment our continuous perceptual experience into events, with event segmentation having consequences for perception and memory (Zacks, Speer, Swallow, Braver, & Reynolds, 2007; Zacks & Tversky, 2001).

As we experience life, we gain knowledge of events and they ways in which they typically play out. For common events, we develop knowledge abstracted across our experiences of the event. This knowledge might contain information about the typical event location, properties of that location, entities involved, actions undertaken, and temporal and causal sequences.[2] This knowledge is key to navigating events as they unfold in the real world. For decades, cognitive science research has appreciated the importance of event knowledge structures, often called *schemas* (Anderson, 1978; Bartlett, 1932) or *scripts* (Schank & Abelson, 1977). A script for a restaurant event, for example, might specify that a patron first enters the restaurant, then is seated at a table, browses the menu, and orders from the waiter. The food is brought out, and the patron eats the food, pays the bill, and exits. Scripts can be specified at a high level for detail and can allow a cognitive agent to navigate many situations; however, the hard coding of event structures proved too rigid to account for the myriad ways in which events can unfold. Nevertheless, research on scripts and other knowledge structures has made clear that to navigate the world, an agent must draw on knowledge of the types of events that take place within it.

---

[1] This dissertation remains agnostic with respect to the exact structure of events. For a cognitive science-oriented review of philosophical approaches to events and event structure, see Zacks and Tversky (2001).

[2] At this stage, more is known about the cues used to discretize continuous signals into events than about the precise content and organization of event knowledge. This dissertation remains agnostic with respect to the latter and assumes only that such knowledge exists and specifies basic information such as that listed.

Event knowledge is important not only for navigating the world, but for understanding language describing that world. One critical role of event knowledge is to guide the anticipation of upcoming input during incremental comprehension, often termed linguistic *expectancy generation*. Incremental comprehension is characterized by expectations for upcoming input at multiple levels (see Delong, Troyer, & Kutas, 2014, for review), and event knowledge plays an important role in the expectancy generation process (Altmann & Mirković, 2009; Elman, 2009; McRae & Matsuki, 2009). This notion is central to the theory of language comprehension put forth by Altmann & Mirković (2009), who argue that, "'Knowledge' of the language can be operationalized as the ability to predict on the basis of the current and prior context…how the language will unfold subsequently, and what concomitant changes in real-world states are entailed by the event structures described by that unfolding language. Such predictions constitute the realization of the mapping between sentence structures and event structures" (p. 586). In this view, language comprehension is intricately linked to event understanding, and it is through expectancy generation, crucially with respect to language *and* the described event, that knowledge of a language is realized.

The claim that language comprehension involves predicting not only how the language will unfold, but also how the described event will unfold, aligns well with research on text comprehension dating back several decades. Theories of how comprehenders process discourse have proposed that comprehension involves creating a unified mental representation of described scenarios, often called *mental models* (Johnson-Laird, 1983) or *situation models* (van Dijk & Kintsch, 1983). In these views, comprehending language goes beyond understanding the presented sentences or the

logical propositions entailed by those sentences. Comprehension involves the construction of mental representations of described scenarios or events that abstract away from the language comprehended and even the propositional content of that language. With respect to the latter, situation model construction often involves drawing upon background knowledge to infer unstated information (Graesser, Millis, & Zwaan, 1997; Marmolejo-Ramos, Elosúa de Juan, Gygax, Madden, & Roa, 2009; Zwaan and Radvansky, 1998). Thus, the mental representations of described events extend beyond the information stated to include additional information filled in from the comprehender's event knowledge.[3]

This brief review has highlighted two important points with respect to event knowledge and language comprehension. First, comprehension involves expectancy generation, and expectancy generation is guided by event knowledge. Second, comprehension involves construction of mental representations of described events that often include unstated information filled in from event knowledge. The research in the dissertation follows directly from these two points. Specifically, it investigates the real-time activation of event knowledge elements beyond those expected to appear in a sentence. In doing so, it bridges modern online sentence processing research with discourse processing research dating back several decades.

Before explaining further, clarification of key terms is necessary. The terms *event* and *event knowledge* have already been defined above. *Event knowledge element* refers to

---

[3] There has been debate regarding the classes of inferences generated during comprehension, particularly with respect to elaborative inference (i.e., an inference that is not necessary to understand the discourse but that enriches the discourse representation). While this debate is not a central focus of the thesis, this issue will be discussed at various points throughout the dissertation.

any specific concept that is a component of the knowledge of a typical event, such as playing soccer or baking a pie. No restriction is placed on the specific relationship between a knowledge element and the event with which it is associated. In this dissertation, concepts constituting event knowledge elements are determined through a norming procedure in which participants are presented with language denoting or describing events and are asked to form a "mental picture" of the event. From this picture, they are asked to list entities that they imagine to be involved in or otherwise present at the event. This procedure allows identification of prominent event knowledge elements while remaining agnostic with respect to how event knowledge is represented and structured, a desirable feature when the representational nature of event knowledge currently is understood at a rather general level. It of course is important to specify the precise nature of event knowledge representation, but that issue is beyond the scope of this dissertation.

Activation refers to an increase relative to baseline in the availability or retrievability of an event knowledge element in long-term memory. The psychological reality of activation is realized in facilitated behavioral reactions to externally presented stimuli (e.g., speeded word naming) and presumably a neural reality, potentially a rise in baseline firing rates of neurons in distributed cortical representations of the activated conceptual information. Two of the three studies in this dissertation assess activation of event knowledge elements through analysis of the N400 event-related brain potential (ERP) component elicited by words in sentences. N400 amplitude is inversely related to the degree to which a presented word (or other meaningful stimulus) aligns semantically with its context (Kutas & Federmeier, 2000, 2011), and reduction in N400 amplitude is

interpreted here as indicating an increase in the activation of the event knowledge element denoted by the presented word. In the third study, activation of an event knowledge element is assessed using eye-tracking, with the degree to which visual attention is allocated to images taken as a index of the relative activation levels of the concepts depicted by those images.

Finally, (*linguistically*) *unexpected* refers to a situation in which the linguistic context does not support the expectation that a given event knowledge element is likely to appear at a particular point in a sentence. Generally speaking, a word that is entirely plausible in context may nevertheless be unexpected (e.g., "turtle" in "The boy saw the turtle"). Unexpected words may in fact be implausible but still relatively interpretable (e.g., "The boy ate the turtle") or grammatically or semantically anomalous (e.g., "The boy smiled the turtle"). The view of expectancy generation taken here assumes that a high degree of contextual constraint is necessary for a particular word or concept to be expected to appear in a sentence. Expectancy generation may take place in the absence of high contextual constraint; in this case, expectancies may be weak and distributed across a large swatch of conceptual information. For the present purposes, an event knowledge element is considered *unexpected* whenever the sentence context is not sufficiently constraining to induce an expectation for that concept to be mentioned next in the sentence. In practice, expectancy is quantified here through a *cloze* task in which participants are given a sentence or discourse stem and asked to provide the word most likely to come next. Any word not provided as a response in this class is considered to be unexpected within the given linguistic context. The studies in Chapters 2 and 3 explicitly deal with processing zero-cloze words. The study in Chapter 4 measures eye movements

over visual images during language comprehension. The linguistic materials in this study do not mention any of the depicted concepts, nor were they designed to induce expectations that the concepts would be mentioned. The text of Chapter 4 refers to these concepts as "unmentioned", but it is further assumed that they are linguistically unexpected.

The remainder of the Introduction will briefly describe the three studies presented in this dissertation. Each addresses a specific issue with respect to the activation of linguistically unexpected event knowledge elements during incremental language comprehension. As each study touches on a different issue related to this general theme, each is accompanied by an independent literature review at the beginning of its respective chapter.

Study 1

The first study, presented in Chapter 2, investigates the scope of event knowledge activation during incremental comprehension. Specifically, it examines whether event knowledge activation is limited to those elements that are expected to appear in the sentence. When the sentence context induces an expectation for a certain knowledge element to appear next in the sentence, is only this element activated at this point? Or does event knowledge activation extend beyond this concept to additional elements that are not expected to appear in the sentence at that point?

Participants read three-sentence discourses describing common events. The final sentence of each was designed to induce an expectation for a particular word to continue the sentence. The sentence was continued either by that word, an unexpected word

related to the described event, or an equally unexpected word unrelated to the described event. (Because the unexpected target words in this study were deemed to be semantically anomalous in context, the term *anomalous* is used in addition to *unexpected*.) Contrasting the ERPs elicited by these three target words types revealed N400 reduction for unexpected words related to the described event relative to unexpected words unrelated to the described event. This result suggests that real-time event knowledge activation is not fully constrained by the sentence context, such that linguistically unexpected event knowledge elements are partially activated during the course of comprehension.

Study 2

The second study, presented in Chapter 3, expands on the finding of the Study 1 by investigating asymmetry across the cerebral hemispheres in the N400 reduction for unexpected event knowledge elements. With the hemispheres exhibiting systematic asymmetries in semantic processes during comprehension, this study serves as an investigation of the neurocognitive mechanisms underlying the activation of unexpected event knowledge elements.

Participants read the sentences and target words from Study 1. Target words were presented to either the right or left visual fields, providing a processing advantage to the contralateral hemisphere. The results showed that N400 reduction for unexpected but event-related words was obtained with left visual field but not right visual field target word presentation, suggesting that the right hemisphere is particularly critical to the effect obtained in Study 1. This finding more generally suggests that activation of

unexpected event knowledge elements is driven by inference processes involved in discourse comprehension. It additionally informs theories of hemispheric asymmetry and cooperation in language processing.

Study 3

The final study examines they dynamics of activation of unexpected event knowledge elements when language is comprehended while simultaneously processing nonlinguistic visual cues in the Visual World Paradigm (VWP). In the VWP, comprehenders view arrays of images or objects and comprehend spoken language related to the arrays in some way (Cooper, 1974). The VWP allows for continuous monitoring of the relative activation levels of the depicted concepts, and in the study in Chapter 4 allowed for investigation of the dynamics of event knowledge activation as a discourse unfolds over time.

Participants viewed arrays of four images while listening to three-sentence discourses describing common events. The discourses established an event context in the first sentence, and results showed that participants rapidly looked to an image strongly related to the described event even though the image was never mentioned (and presumably linguistically unexpected). Participants additionally looked more to an image more weakly related to the described event than to images completely unrelated to the event. Looks to these two images were interpreted as the comprehenders rapidly recognizing a cohort of images that, while unmentioned, were related to the described event. The third sentence of the discourse elaborated on the event in a way meant to draw visual attention to one of the two previously images previously identified as related to the

event. Crucially, participants looked not only to this image, but also to an image locally related to the third sentence but unrelated to the previously established event context (as indicated by no preference to fixate this image when the event context was initially established in the first sentence). This finding suggests that as comprehenders constructed their event representations, they did not initially identify and subsequently winnow down a cohort of event-related concepts. Rather they entertained each image's relationship with the event at each point in time during the unfolding discourse.

Summary

Each study in this dissertation investigates the activation of linguistically unexpected event knowledge elements during real-time language comprehension. The findings provide evidence that real-time comprehension extends to unexpected event knowledge elements (Chapter 2), that this activation is critically supported by the right hemisphere (Chapter 3), and that this activation mediates the dynamic integration of visual and linguistic information as a discourse is processed in real time (Chapter 4). This body of findings will be discussed further in the General Discussion (Chapter 5).

References

Altmann, G.T.M. & Mirković, J. (2009). Incrementality and prediction in human sentence processing. *Cognitive Science, 33*, 583-609.

Altmann, G.T.M. & Kamide, Y. (2009). Discourse-mediation of the mapping between language and the visual world: Eye movements and mental representation. *Cognition, 111*, 55-71.

Anderson, R.C. (1978). Schema-directed processes in language comprehension. In A. Lesgold, J. Pelligreno, S. Fokkema, & R. Glaser (Eds.), *Cognitive psychology and instruction* (pp. 67-82). New York, NY: Plenum.

Bartlett, F.C. (1932). *Remembering*. Cambridge, England: Cambridge University Press.

Cooper, R.M. (1974). The control of eye fixation by the meaning of spoken language. *Cognitive Psychology, 6*, 84-107.

Delong, K.A., Troyer, M., & Kutas, M. (2014). Pre-processing in sentence comprehension: Sensitivity to likely upcoming meaning and structure. *Language and Linguistics Compass, 8*(12), 631-645.

Elman, J.L. (2009). On the meaning of words and dinosaur bones: Lexical knowledge without a lexicon. *Cognitive Science, 33*, 547-582.

Ferreira, F. & Clifton, C. (1986). The independence of syntactic processing. *Journal of Memory and Language, 25*(3), 348-368.

Fodor, J.A. (1983). *Modularity of Mind*. Cambridge, MA: MIT Press.

Frazier, L. & Fodor, J.D. (1978). The sausage machine: A new two-stage parsing model. *Cognition, 6*(4), 291-325.

Graesser, A.C., Millis, K.K., & Zwaan, R.A. (1997). Discourse comprehension. *Annual Review of Psychology, 48*, 163-189.

Johnson-Laird, (1983). *Mental modesl: Towards a cognitive science of language, inference, and consciousness*. Cambridge, MA: Harvard University Press.

Kamide, Y., Altmann, G.T.M., & Haywood, S.L. (2003). Time time-course of prediction in incremental sentence processing: Evidence from anticipatory eye movements. *Journal of Memory and Language, 49*, 133-156.

Kutas, M. & Federmeier, K.D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Sciences, 4*, 463-470.

Kutas, M. & Federmeier, K.D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential (ERP. *Annual Review of Psychology, 62*, 621-647.

Marmolejo-Ramos, F., Elosúa de Juan, M.R., Gygax, P., Madden, C.J., & Roa, S.M. (2009). Reading between the lines: The activation of background knowledge during text comprehension. *Pragmatics & Cognition, 17*(1), 77-107.

Marslen-Wilson, W.D. (1975). Sentence perception as an interactive parallel process. *Science, 189*, 226-228.

McRae, K. & Matsuki, K. (2009). People use their knowledge of common events to understand language, and do so as quickly as possible. *Language and Linguistics Compass, 3*(6), 1417-1429.

McRae, K., Spivey-Knowlton, M.J., & Tanenhaus, M.K. (1998). Modeling the influence of thematic fit (and other constraints) in on-line sentence comprehension. *Journal of Memory and Language, 38*, 283-312.

Schank, R.C. & Abelson, R.P. (1977). *Scripts, plans, goals, and understanding; An inquiry into human knowledge structures.* Hillsdale, NJ: Erlbaum.

Tanenhaus, M.K., Spivey-Knowlton, M.J., Eberhard, K.M., & Sedivy, J.C. (1995). Integration of visual and linguistic information in spoken language comprehension. *Science, 268*, 1632-1634.

Tyler, L.K. & Marslen-Wilson, W.D. (1977). The on-line effects of semantic context on syntactic processing. *Journal of Verbal Learning and Verbal Behavior, 16*(6), 683-692.

van Dijk, T.A. & Kintsch, W. (1983). *Strategies in discourse comprehension.* New York, NY: Academic Press.

Zacks, J.M., Speer, N.K., Swallow, K.M., Braver, T.S., & Reynolds, J.R. (2007). Event perception: A mind-brain perspective. *Psychological Bulletin, 133*(2), 273.

Zacks, J.M., & Tversky, B. (2001). Event structure in perception and conception. *Psychological Bulletin, 127*(1), 3-21.

Zwaan, R.A. & Radvansky, G.A. (1998). Situation models in language comprehension and memory. *Psychological Bulletin, 123*, 162-185.

CHAPTER 2:

Generalized Event Knowledge Activation During Online Sentence Comprehension

Introduction

Despite its great complexity, the world is a highly structured environment. Events in the world are not random, but instead exhibit regularities that people learn throughout their lives. Knowledge of these regularities, for example that police arrest criminals or that glass often breaks when dropped, supports numerous cognitive capacities, including language comprehension. The importance of event knowledge to language comprehension has been appreciated for some time. Work dating back several decades has unequivocally demonstrated that successful comprehension involves engaging real-world knowledge stored in long-term memory (Bransford & Johnson, 1972; Sanford & Garrod, 1981; Schank, 1980; van Dijk & Kintsch, 1983). Some theories of language comprehension invoke the mapping between linguistic input and relevant event knowledge as entirely fundamental to what it is to understand language (Altmann & Mirkovic, 2009; Elman, 2009; Sanford & Garrod, 1998; van Dijk & Kintsch, 1983). Although much early work on discourse comprehension supports this notion, these studies generally do not provide an account of how event knowledge is engaged in real time, as a sentence is comprehended incrementally.

Determining the time-course of event knowledge activation and use is a central issue in developing any theory of online language processing, and this is the central goal of this study. Some theories propose that the early stages of online comprehension are largely informationally encapsulated, with only syntactic and basic lexical information being immediately accessed as a word is processed in real-time (Bornkessel & Schlesewsky, 2006; Frazier, 1978, 1990, 1995; Frazier & Rayner, 1982; Rayner, Carlson, & Frazier, 1983). However, in recent years, accumulating evidence indicates that event

knowledge exerts a rapid influence on incremental comprehension processes, suggesting that the earliest stages of comprehension engage the wealth of world knowledge a comprehender brings to the task of understanding language.

At the level of individual words, lexical priming studies suggest that the processing of isolated words immediately activates knowledge of events of which the words are components. Agent, patient, instrument, and location nouns prime verbs denoting events in which these elements participate (McRae, Hare, Elman, & Ferretti, 2005), and nouns denoting events prime people and objects typically found at those events (Hare, Jones, Thomson, Kelly, & McRae, 2009). Instrument nouns prime objects on which those instruments are typically used, and location nouns prime typical people and objects found at those locations (Hare, Jones, et al., 2009). Chwilla and Kolk (2005) found priming in a word triplet paradigm when the combination of two primes denote an event to which the target word is related (e.g., *director* and *bribe* together prime *dismissal*). Ferretti, Kutas, and McRae (2007) found that priming of event locations by event verbs is modulated by verb aspect: imperfective verbs prime event locations while perfective verbs do not (e.g., *was cooking* primes *kitchen*, but *had cooked* does not), demonstrating that isolated verb processing results in immediate accessibility of likely event locations only when the verb denotes the event as ongoing. This notion is consistent with other experimental work showing that imperfective verbs highlight the internal structure of an event, while perfective verbs promote a representation of the event as a completed whole (Madden & Zwaan, 2003). It is worth noting that these priming results are unlikely to be due to undifferentiated associations between individual lexical items. In Chwilla and Kolk (2005), the individual prime words were not

normatively associated with each other or the target word, meaning that the priming effect most likely resulted from rapid integration of the meanings of the two prime words through mapping onto an event knowledge structure. Likewise, in Ferretti et al. (2007), direct lexical associations cannot account for the obtained effect, as priming of event locations by a single verb depends upon the grammatical form of that verb. If direct associations between lexical items alone were at play, verb aspect should not modulate the priming effect. It thus appears that even in the absence of a sentential or discourse context, language comprehension involves rapid mapping of linguistic input onto event knowledge, resulting in activation of other event-relevant information. Such a finding suggests that mapping linguistic input to event knowledge is a fundamental characteristic of the language comprehension system.

From this conclusion, it follows that event knowledge should exert an immediate influence during online sentence and discourse comprehension. Sentences and discourse provide not only individual content words capable of evoking event knowledge, but also cues as to the relations between these words, providing rich information to be used in mapping linguistic input onto event knowledge. Along these lines, Altmann and Kamide (1999) demonstrated that the thematic fit between a verb and possible patient objects, in combination with concurrent visual input, can drive expectations for postverbal arguments. Participants viewed a scene depicting, for example, a boy, a cake, and several toys. Participants were faster to fixate the target (cake) when they heard *The boy will eat the cake* than when they heard *The boy will move the cake*, with fixation patterns suggesting that participants were able to anticipate the target following the verb *eat* but not following the less restrictive verb *move*. This finding shows that upon encountering

the verb, comprehenders were able to rapidly apply their world knowledge (i.e., that a boy will likely eat something that is edible), in conjunction with visual information (i.e., that the cake is the only edible object in the scene), to anticipate an upcoming referent. Expanding upon this finding, Kamide, Altmann, and Haywood (2003) found that comprehenders launch anticipatory saccades based on the event implied by the integration of an agent noun and following verb – for example, participants were more likely to launch anticipatory saccades to a picture of a motorbike upon hearing *The man will ride…* than upon hearing *The girl will ride….* This finding indicates that comprehenders can integrate information provided at multiple points in a sentence to engage event knowledge, which then, in conjunction with information provided by a visual display, guides anticipatory processing.

Additional evidence for the rapid influence of event knowledge has been obtained in reading time studies. Postverbal patient nouns are read faster when they are plausible given the combination of a preceding agent and verb (Bicknell, Elman, Hare, McRae, & Kutas, 2010) or preceding instrument and verb (Matsuki, Chow, Hare, Elman, Scheepers, & McRae, 2011). These results, like those of Kamide et al. (2003), demonstrate that the online assessment of thematic fit of a post-verbal argument is not determined by the verb alone, but rather by information regarding the real-world event denoted by the verb in combination with its preceding arguments. Verbs therefore appear to encode thematic roles in an event-specific fashion, a conclusion that has major consequences for theories of lexical knowledge (Elman, 2009).

Reading time studies have shown event knowledge to exert a rapid influence in the syntactic domain, as well. Expectations for a reduced relative clause are affected by

the status of the grammatical subject as a typical agent (*The crook arrested by the detective was guilty*) or patient (*The cop arrested…*) of the initial verb (McRae, Spivey-Knowlton, & Tanenhaus, 1998). Similarly, postverbal regions of intransitive sentences are read faster when the subject is a plausible patient of the verb versus a plausible agent (e.g., *into tiny bits* is read faster following *The glass shattered* than following *The brick shattered*), and the converse holds true for transitive sentences (Hare, Elman, Tabaczynski, & McRae, 2009). This finding and that reported by McRae et al. (1998) show that event knowledge exerts an immediate influence on syntactic expectations during incremental comprehension.

Research using the event-related brain potential (ERP) technique has demonstrated that the compatibility of an eliciting word with the described event modulates the amplitude of the N400 component. The N400 is a negative going deflection in the ERP waveform peaking at approximately 400ms following the onset of a word. Its amplitude is inversely related to the eliciting word's degree of contextual fit, which is often captured offline by the word's cloze probability (the proportion of people who provide the word as a continuation of the sentence at that point). N400 amplitude is generally viewed as an index of online meaning processing via semantic memory activation (Kutas & Federmeier, 2000, 2011; Kutas & Hillyard, 1980, 1984). The previously discussed studies by Ferretti et al. (2007), Chwilla and Kolk (2005), and Bicknell et al. (2010) included ERP experiments that showed their obtained reaction time and reading time effects are reflected in N400 amplitude modulations. Hagoort and colleagues have shown that violations of world knowledge that are nevertheless semantically appropriate elicit N400s of similar amplitude to lexico-semantic violations

(Hagoort, Hald, Bastiaansen, & Petersson, 2004). Given that Dutch trains are typically yellow, the target word *white* in *The Dutch trains are white and very crowded* elicits an N400 equal in amplitude to that elicited by *sour* in *The Dutch trains are sour and very crowded*. This amplitude similarity, in addition to similarity in topography, onset, and peak latency of the N400 for the two violation types, suggests that both world knowledge and lexical semantic knowledge influence online meaning processing in a similar fashion, a conclusion consistent with the notion that world knowledge and lexical semantic knowledge are not entirely dissociable (Elman, 2009). These and other ERP studies (e.g., Camblin, Gordon, & Swaab, 2007; Hald, Steenbeek-Planting, & Hagoort, 2007; Otten & Van Berkum, 2007) strongly suggest that general event knowledge engaged during discourse comprehension serves to guide online semantic processing, and that N400 amplitude can serve as an accurate index of this process.

The Scope of Real-Time Event Knowledge Activation

The research discussed above has conclusively demonstrated through a variety of techniques that event knowledge is an important source of information used to guide language comprehension in real time. When we comprehend language about events, we activate knowledge regarding those events and use this knowledge to facilitate online linguistic processing. It is important to note, however, that previous work described above demonstrates facilitated processing exclusively for words that are semantically congruent with the linguistic context. With respect to the scope of event knowledge activation during the course of incremental comprehension, such research allows us to infer that activation includes elements that are congruent with both the event being

described and (crucially) the linguistic context itself. The question we ask here is whether

real-time event knowledge activation extends to elements that are anomalous within the

local linguistic context (i.e., are not predicted by the context) but which are nonetheless

consistent with the global event being described. That is, despite the fact that the

reviewed lexical priming results demonstrate that processing isolated words engages a

range of event knowledge elements, it is possible that during online sentence

comprehension, the cues provided by the unfolding linguistic context constrain event

knowledge activation to only those elements that would constitute semantically congruent

or expected continuations of the sentence at that point. Alternatively, as we hypothesize,

additional event-relevant but contextually anomalous entities might become activated in

comprehenders' minds even when they violate the linguistic context.

To illustrate, consider the passage in (1):

(1) A huge blizzard ripped through town last night. My kids

ended up getting the day off from school. They spent the

whole day outside building a big snowman in the front yard.

Given previous results indicating that comprehenders utilize event knowledge to guide

linguistic expectancy generation, it is likely that upon processing *building a big*, a

comprehender will activate objects often built by children playing in the snow, such as a

snowman or igloo. However, people know more about "playing in the snow" events than

snowmen and igloos, such as the likelihood that the children are bundled up with hats,

mittens, and jackets, but none of these items satisfy the semantic constraints imposed by

the verb *building*. Therefore while these items are salient components of "playing in the

snow" knowledge, the linguistic context suggests that these items should not appear in the sentence at this point. If specific cues provided by the linguistic context interact with activation of event knowledge to yield activation of only those elements that would constitute congruent or expected continuations of the current sentence at that point, it would suggest that event knowledge activation, as it occurs as a sentence is comprehended incrementally, serves mainly to facilitate processing of the linguistic input that the comprehender is likely to receive. On the other hand, the ability of comprehenders to make causal or bridging inferences clearly indicates that language comprehension must engage general event knowledge that is not explicitly stated in the discourse. The issue we address, thus, is how activation of particular elements of event knowledge is constrained in real time by the specific cues present in an unfolding sentential context.

This specific issue speaks directly to the more fundamental question regarding the nature of the mental representations that are dynamically constructed during incremental sentence comprehension. Mental representations of described events are not static, but rather are continuously modified during the course of comprehension. If event knowledge is itself not merely used to guide incremental sentence processing, but is itself a *target* of the comprehension process, then we would expect to find facilitated processing for salient event knowledge elements even at specific times at which the elements do not align with the particular cues provided by the local linguistic context.

This is the hypothesis we pursue here. This hypothesis generally aligns with previous research on inference. This research has demonstrated that discourse comprehension often involves instantiation of relevant, unstated information accessed

from long-term memory (see Graesser, Singer, & Trabasso (1994) and McKoon & Ratcliff (1992) for reviews of inferencing research and theories of inference generation)[4]. While inferencing research has established that discourse comprehension can engage unstated but relevant background knowledge at least in some circumstances, we do not know how such knowledge activation interacts with linguistic contextual cues as a sentence is comprehended incrementally. Research in this area typically employs paradigms in which a probe word or sentence is presented following comprehension of a preceding sentence or discourse. Such paradigms allow one to assess activation of unstated event knowledge after comprehending a discourse, but they do not provide insight into how activation of this knowledge interacts with explicit linguistic cues unfolding in real time. Facilitated processing of a probe following discourse comprehension may show that this knowledge is activated at some point following offset of discourse presentation, but it is an open question whether contextual cues encountered as a sentence is processed incrementally dynamically limit activation of event-relevant information to only that which aligns with the linguistic context.

In fact, there are experimental results suggesting that unfolding contextual cues may limit the scope of event knowledge activation. Traxler, Foss, Seely, Kaup, and Morris (2000) monitored participants' eye movements during reading of sentences such as *The* [*lumberjack/young man*] *chopped the <u>axe</u> early in the morning*, and found no difference in first fixation or gaze duration times for the target word (*axe*) following the different agents (*lumberjack* vs. *young man*). The authors concluded that schematic

---

[4] The degree to which certain types of inference are automatically generated is debated. We will touch upon this issue with respect to the present study in the General Discussion.

knowledge does not drive general activation of words describing event participants during online comprehension. If it did, *axe* should have been read faster following *lumberjack chopped*, because an axe is a prototypical instrument associated with a "lumberjacking" schema. In an earlier study, Kintsch and Mross (1985) found similar results using a cross-modal lexical decision task. Participants listened to brief stories describing common events (e.g., catching a flight) and made a lexical decision to a visually presented word mid-discourse. The authors found only a marginal priming effect for event-associated versus unassociated words (e.g., *gate* vs. *stack* in the airport scenario), and in a version of the experiment employing all-visual presentation, this marginal priming effect disappeared completely. This result, like that found by Traxler et al., suggests that online event knowledge activation does not extend to elements that do not fit the local linguistic context. However, Traxler et al. used only a few sentence-initial words to establish a situation, and Mross and Kintsch tested for activation of ensuing actions. Thus, we believe that these results should not be taken to indicate conclusively that linguistic cues dynamically limit event knowledge activation. The relationship between these studies and the present study is discussed in more detail in the General Discussion.

The Present Study

We investigated the real-time activation of contextually anomalous event knowledge elements during incremental language comprehension. We recorded participants' EEG as they read brief scenarios such as the "playing in the snow" example in (1) above. In each scenario, two sentences established an event context, and a third and

final sentence included one of three target word types. In one condition, participants read a highly expected word (e.g., *building a snowman*; the *Expected* target). In another condition, participants read a contextually anomalous word that was unrelated to the event being described (e.g., *building a towel*; the *Event-Unrelated* target), and in a third, they read an anomalous word that crucially was related to the described event (e.g., *building a jacket*; the *Event-Related* target). ERPs elicited by these three target types were analyzed, with special attention paid to the amplitude of the N400 component.

Given previous N400 results, we predicted that the Expected targets should elicit an N400 of very small amplitude (perhaps even a positivity in the 200-500ms N400 latency range), as they are contextually congruous and on average are highly expected in context. Furthermore, the Event-Unrelated targets should elicit a large N400 because they are contextually anomalous and completely unexpected. The major issue hinges on the amplitude of the N400 elicited by the Event-Related but contextually anomalous targets. If they elicit an N400 equal to the Event-Unrelated targets, it would suggest that fit with the local linguistic context is necessary to observe facilitated processing of Event-Related concepts, and that linguistic cues greatly constrain event knowledge activation in real time. However, if event knowledge activation extends beyond contextually congruent information to include other prominent elements of event knowledge, then the Event-Related targets should elicit a reduced N400 compared to the Event-Unrelated targets.

There are a number of previous ERP studies demonstrating N400 reduction for unexpected contextually inappropriate words based on various relationships between those words and the preceding context or most expected word. Unexpected words elicit a reduced N400 when semantically related to the most expected word (Kutas & Hillyard,

1984), with context-independent semantic category structure likely supporting this effect (Federmeier & Kutas, 1999). Along similar lines, incorrect reinstatement of a categorical anaphor elicits a reduced N400 when the reinstatement is from the same category as the correct antecedent (e.g., *seat* referring to the antecedent *stool*, but being reinstated in a subsequent sentence as *couch*; Ditman, Holcomb, & Kuperberg, 2007). Other work has shown that semantic illusion stimuli elicit N400s of similar amplitude to the most expected word (e.g., *In a recent trial, a ten-year sentence was given to the victim*; Sanford, Leuthold, Bohan, & Sanford, 2010). This effect holds even for words that violate animacy restrictions of a verb when the violating word has been stated previously and constitutes the theme of the discourse (Nieuwland & van Berkum, 2005). In addition, words that violate real-world plausibility can elicit smaller N400s than generally plausible words when the discourse explicitly highlights the implausible situation as acceptable (Nieuwland & van Berkum, 2006). Discourse cues do not completely trump prior knowledge, though; words that align with world knowledge but not the specific discourse message elicit smaller N400s than words that align with neither (Hald et al., 2007; Otten & Van Berkum, 2007).

These findings highlight several important issues with respect to the present study. First, because studies have shown N400 reduction due to semantic relatedness between an unexpected target word and the most expected word, we controlled this relation in our study. Second, because Nieuwland & Van Berkum (2005) found that a contextually anomalous word can elicit a reduced N400 when explicitly mentioned as the theme of the discourse, we ensured that our Event-Related and Event-Unrelated targets were not previously mentioned in their discourse contexts. Finally, the latter studies underscore the

specific theoretical contribution of the present study. Previous research has established that event knowledge can exert an influence on N400 amplitude independently of information provided by the discourse message. For example, when the discourse describes traffic issues and road layout in Venice, *canals* nonetheless elicits a similar N400 to *roundabouts* following *The city of Venice has many…* (Hald et al., 2007). However, no study has investigated how association with a described event affects the N400 elicited by a word that is anomalous at a particular point in the linguistic stream. In doing so here, this study seeks to determine whether event knowledge elements that violate the local linguistic context are active during the course of incremental comprehension. Reduction of the N400 elicited by a contextually anomalous but event-related word would indicate that incremental comprehension involves activation of event knowledge elements beyond those supported by the local linguistic context. Uncovering such an extended scope of event knowledge activation would add to our knowledge of how information in long-term memory is engaged during the course of comprehension and would inform all theories regarding how people comprehend language about real-world events.

<div align="center">Methods</div>

Participants' EEG was recorded while they read three-sentence scenarios describing typical events. The dependent measure was the amplitude of the N400 elicited by three types of target words: a highly expected word, a contextually anomalous word that was related to the described event, and an equally anomalous word that was unrelated to the event. Based on numerous studies in which cloze probability of targets

has been manipulated, we anticipated that the Expected targets would elicit the lowest amplitude N400 response. Because both the Event-Related and Event-Unrelated targets were zero-cloze and generally nonsensical in context, one possibility is that their N400 responses would not differ from one another, but would be significantly greater than the Expected targets. However, if activation of event knowledge extends to elements that violate the linguistic context, we would observe a three-way contrast: Expected targets would elicit the lowest amplitude N400, Event-Unrelated targets would elicit the largest, and Event-Related targets would elicit an N400 intermediate to these two extremes.

Participants

Thirty undergraduates (22 women; ages 18 to 22 years) at the University of California, San Diego completed the ERP experiment for course credit. All were right-handed, native monolingual English speakers, and none reported any history of learning or reading disabilities or neurological or psychiatric disorders.

Stimuli

The experimental stimuli consisted of 72 scenarios similar to that presented in (1) above. Each scenario consisted of three sentences. The first two sentences were designed to establish the event context. The third sentence contained one of three possible target words: the most expected word (the Expected target), a contextually anomalous word that was related to the event described (the Event-Related target), or a contextually anomalous word that was unrelated to the event (the Event-Unrelated target).

We began by creating 72 three-sentence scenarios in which the first two sentences were complete, and the third sentence terminated at a point at which we believed that a specific noun would be deemed highly likely to come next. In a cloze task, participants read the scenarios and provided the word they believed would be most likely to continue each story. Thirty UCSD undergraduates (23 women; all native English speakers), none of whom participated in the ERP experiment, completed the cloze task through an online form. Cloze probability was calculated as the proportion of participants who provided a particular response for a given scenario. For each scenario, the word with the highest cloze probability was chosen as the Expected target. Across the 72 scenarios, the mean cloze probability of the Expected target was 0.81 (range = 0.367 to 1.00; SD = 0.17).

Following the cloze task, we used the scenarios with the Expected targets filled in to probe comprehenders' knowledge of people or objects that were unstated but highly likely to be components of the described events. Responses were used to select the Event-Related targets. Participants were instructed to read each scenario and to "paint a mental picture" of the event being described. They were told that these mental pictures would probably include various people and objects that were present at the event but not explicitly mentioned in the text itself. They were asked to list up to five of these people/objects for each scenario. Forty-five UCSD undergraduates (26 women; all native English speakers), none of whom participated in the ERP experiment or previous cloze task, completed the task through an online form. Responses for each scenario were given weighted scores based on order of mention (5 points for the first response, 4 for the second, etc.). The highest scoring response that was not provided as a response in the cloze study (i.e., was zero-cloze) was chosen as the Event-Related target. In a few

instances, the highest scoring Event-Related target was deemed by the authors to constitute a sensible continuation of the sentence despite not being provided as a response in the cloze task. In these cases, the next highest scoring zero-cloze response was chosen. This was to ensure that each Event-Related target, although highly likely to be part of the described event, would be truly anomalous in context. Across the 72 scenarios, the mean score for the Event-Related targets was 92.4 (range = 38 to 171; SD = 35.3). The maximum possible score for a given item, had every participant provided the same item as their first choice for that scenario, was 225 (45 subjects x score of 5).

We then constructed Event-Unrelated targets by shuffling the Event-Related targets across scenarios. This ensured that the Event-Related and Event-Unrelated targets consisted of the same lexical items, thereby controlling lexical factors across the two conditions. The 72 experimental items were split into three rotation groups of 24 scenarios each, allowing for three lists to be constructed by rotating each group through the three conditions. Each scenario thus appeared once in each list and once in each condition across the three lists. To minimize variability across the lists, the rotation groups were matched on the following factors: mean cloze probability, log frequency, and orthographic length of the Expected targets; mean event-relatedness score, log frequency, and orthographic length of the Event-Related targets. Event-Related targets were then shuffled across the scenarios within each rotation group to obtain the Event-Unrelated targets. Event-Unrelated targets were shuffled ensuring that each was zero-cloze. In all but two of the 72 scenarios, Event-Unrelated targets had event-relatedness

scores of zero[5]. In addition, the shuffling was done in such a way as to match the Event-Related and Event-Unrelated targets within each scenario for animacy and concreteness. The norming results are presented in Table 2.1. Following these norming procedures, additional material was added to the final sentence of each scenario to make each target word sentence-medial. All experimental items are presented in the Appendix.

One final issue concerned ensuring that the two anomalous target types were not associated with the Expected targets. Previous studies have shown that a contextually inappropriate word can elicit a reduced N400 when closely associated with the most expected word (Federmeier & Kutas, 1999). We quantified the degree of association between the Expected target and the two anomalous target types using the University of South Florida Free Association Norms (Nelson, McEvoy, & Schreiber, 2004). From Nelson et al.'s norms, we looked for a forward association from the Expected target (the cue) to either the Event-Related or Event-Unrelated target (the response). Of the 72 experimental scenarios, 65 contained Expected targets that appeared in the Nelson norms; mean association scores for the Event-Related and Event-Unrelated targets were calculated across these 65 items; mean associative strength was calculated across these items. The mean associative strength was 0.0005 for the Event-Related targets, and 0.0001 for the Event-Unrelated targets. Therefore, associative strengths for Event-Related and Event-Unrelated targets correspond to one response per two thousand participants and one response per ten thousand participants, respectively. These extremely low scores,

---

[5] The two exceptions had extremely low event-relatedness scores of 1 and 3. It is worth noting that the presence of non-zero event-relatedness scores in the Event-Unrelated targets would only serve to mask the hypothesized effect.

and the small, statistically nonsignificant difference between them were deemed

acceptable for the purposes of the study.

Each scenario was accompanied by a simple yes/no comprehension question (also

provided in the Appendix). These were included to ensure that participants read each

scenario for comprehension. In addition to the 72 experimental items, 24 filler items were

included. Like the experimental scenarios, each of these items consisted of three

sentences describing a real-world event. None contained any contextually anomalous

words. These fillers were included to achieve an even number of trials containing

anomalous and non-anomalous words.

Table 2.1: Norming results for the three rotation groups and the stimuli set overall.

		Group 1	Group 2	Group 3	Overall
Expected	Cloze probability	0.81	0.80	0.80	0.81
	Log frequency	6.95	7.01	6.88	6.95
	Orthographic length	5.58	5.71	5.75	5.68
Event-Related	Cloze probability	0.00	0.00	0.00	0.00
	Log frequency	6.89	6.91	6.76	6.86
	Orthographic length	5.96	5.96	5.71	5.87
	Event-relatedness	91.17	89.71	96.21	92.36
Event-Unrelated	Cloze probability	0.00	0.00	0.00	0.00
	Event-relatedness	0.00	0.13	0.04	0.06

Procedure

Participants sat in a soundproofed, electromagnetically shielded chamber and read

each scenario from a computer monitor. They were instructed to read the scenarios

carefully, as they would be required to answer a comprehension question following each scenario. The first two sentences of each scenario were presented in paragraph format. Once participants understood them, they pushed a button to advance to the final sentence. A small red cross then appeared at the center of the screen to cue participants to avoid behaviors such as blinking, eye movements, and muscle tension, which could introduce artifacts into the EEG signal. The final sentence was presented directly above the cross one word at a time (rapid serial visual presentation, RSVP) with a 350ms stimulus onset asynchrony (SOA), divided into a 200ms stimulus duration and a 150ms inter-stimulus interval (ISI). After the offset of the final word, participants answered a yes/no comprehension question by pushing a button with their left or right hand (e.g., left for "No", right for "Yes"). Yes/no hand was counterbalanced across participants.

The experiment was divided into five blocks, with the first block containing 20 trials and the remaining four blocks containing 19 trials each. Participants were able to request a short break within or between blocks. The entire experimental session, including preparation of EEG recording, lasted approximately two hours. Ten participants were randomly assigned to each of the three lists. Stimulus presentation order was fully randomized for each participant.

Immediately following the experiment, each participant completed an Author Recognition Test and the Magazine Recognition Test. These tests were local adaptations of the earlier tests described in Cunningham (1990) and Stanovich and Cunningham (1992). ART/MRT questionnaires consisted of 80 author names/magazine titles, 40 real and 40 fake. Participants were told to mark each author/magazine they knew to be real and to avoid guessing. Scores were calculated as number of correct IDs minus the

number of false positives across both tests. Stanovich and Cunningham (1992) present these tests as measures of print exposure, and show that performance on these tests correlates with measures of analytic intelligence, vocabulary, verbal fluency, reading comprehension, and history and literature knowledge. We hypothesized that performance on these tests might also reflect individual differences in participants' knowledge of real-world events, which aligns with Stanovich and Cunningham's proposal that increased print exposure contributes to a richer world knowledge base than that supported by individual experience alone. With ART/MRT performance likely capturing individual differences in linguistic proficiency and world knowledge, we hypothesized that varying performance on these tests might coincide with individual differences in N400 responses to the Event-Related and Event-Unrelated target words.

EEG Recording and Processing

EEG was recorded from 26 tin electrodes distributed evenly across the scalp, referenced online to the left mastoid and re-referenced offline to the average of the left and right mastoids. Electrodes were placed on the outer canthus and infraorbital ridge of each eye to monitor eye movements and blinks. All electrode impedances were kept below 5 KΩ. EEG was amplified with Nicolet amplifiers with a bandpass of 0.016 to 100 Hz and digitized at a rate of 250 Hz. A diagram of the scalp electrodes is provided in Figure 2.1.

To obtain ERPs for the three target word types, each participant's EEG was time-locked to target word onset and averaged within each condition across a 2044ms epoch, relative to a 500ms pre-stimulus baseline. Trials contaminated by blinks, muscle tension (EMG), channel drift, and/or amplifier blocking were discarded before averaging. Approximately 9% of target word epochs were rejected due to such artifacts, with losses distributed approximately evenly across the three conditions. Individual participant averages were then averaged together to obtain a grand average ERP for each condition. Each participant's performance on the comprehension questions was assessed before entering the participant's data into the analysis. All participants scored at least 89% correct on the 72 target comprehension questions, indicating that they read the scenarios for comprehension as instructed, and therefore no participant's data were excluded.

Hemisphere	Right	RLPf, RMPf, RLFr, RMFr, RLTe, RMCe, RLOc, RMOc
	Left	LLPf, LMPf, LLFr, LMFr, LLTe, LMCe, LLOc, LMOc
Laterality	Lateral	LLPf, LLFr, LLTe, LLOc, RLPf, RLFr, RLTe, RLOc
	Medial	LMPf, LMFr, LMCe, LMOc, RMPf, RMFr, RMCe, RMOc
Anteriority	Prefrontal	LLPf, LMPf, RLPf, RMPf
	Frontal	LLFr, LMFr, RLFr, RMFr
	Parietal	LLTe, LMCe, RLTe, RMCe
	Occipital	LLOc, LMOc, RLOc, RMOc

Figure 2.1: Layout of the 26 electrodes across the scalp. The embedded table summarizes the electrode groupings for analysis of the scalp distribution of N400 effects. Filled-in electrodes were included in the distributional analyses.

Results

N400 Amplitude

Figure 2.2 displays the grand average target word ERPs for the 26 scalp

electrodes from 500ms pre-stimulus to 1000ms post-stimulus, arranged according to the

distribution of electrodes across the scalp presented in Figure 2.1. The N400 can be seen

as a negative-going deflection in the ERP waveform peaking at approximately 400ms

post-stimulus. To analyze N400 amplitude differences across the three conditions, mean

ERP amplitudes from 200-500ms were entered into a repeated measures ANOVA with

three levels of Condition and 26 levels of Electrode. A main effect of Condition was

obtained ($F(2,58) = 38.33$, $\varepsilon_{GG} = 0.7756$, $p < .001$), as was a Condition-by-Electrode

interaction ($F(50,1450) = 7.26$, $\varepsilon_{GG} = 0.1075$, $p < .001$).[6]

Planned comparisons revealed the critical pattern of results in which the Event-

Related condition lay statistically between the Expected and Event-Unrelated conditions.

N400 amplitude in the Event-Unrelated condition was significantly greater (i.e., more

negative) than the Event-Related condition ($F(1,29) = 13.00$, $p < .01$; no interaction with

Electrode), which in turn was greater than the Expected condition ($F(1,29) = 35.44$, p

$< .001$; Condition-by-Electrode interaction: $F(25,725) = 7.77$, $\varepsilon_{GG} = 0.097$, $p < .001$).

This graded N400 effect can be seen clearly in the waveforms, beginning at

approximately 200ms post-stimulus and peaking around 400ms. (See Figure 2.3 for a

close-up of the midline parietal electrode site.) In summary, the Event-Related targets

elicit a reduced N400 compared to the Event-Unrelated targets, with both types of

---

[6] For *F*-tests with more than one degree of freedom in the numerator, we report *p*-values for
Greenhouse-Geisser epsilon-adjusted degrees of freedom (Greenhouse & Geisser, 1959), the
unadjusted degrees of freedom, and the value of the Greenhouse-Geisser epsilon.

anomalous targets eliciting larger N400s than the Expected targets. In other words, the

N400 effect for the Event-Unrelated targets (i.e., the N400 amplitude difference between

the Event-Unrelated and Expected targets) is larger than that for the Event-Related targets

(i.e., the difference between the Event-Related and Expected targets), as illustrated by the

difference waves presented in Figure 2.4.
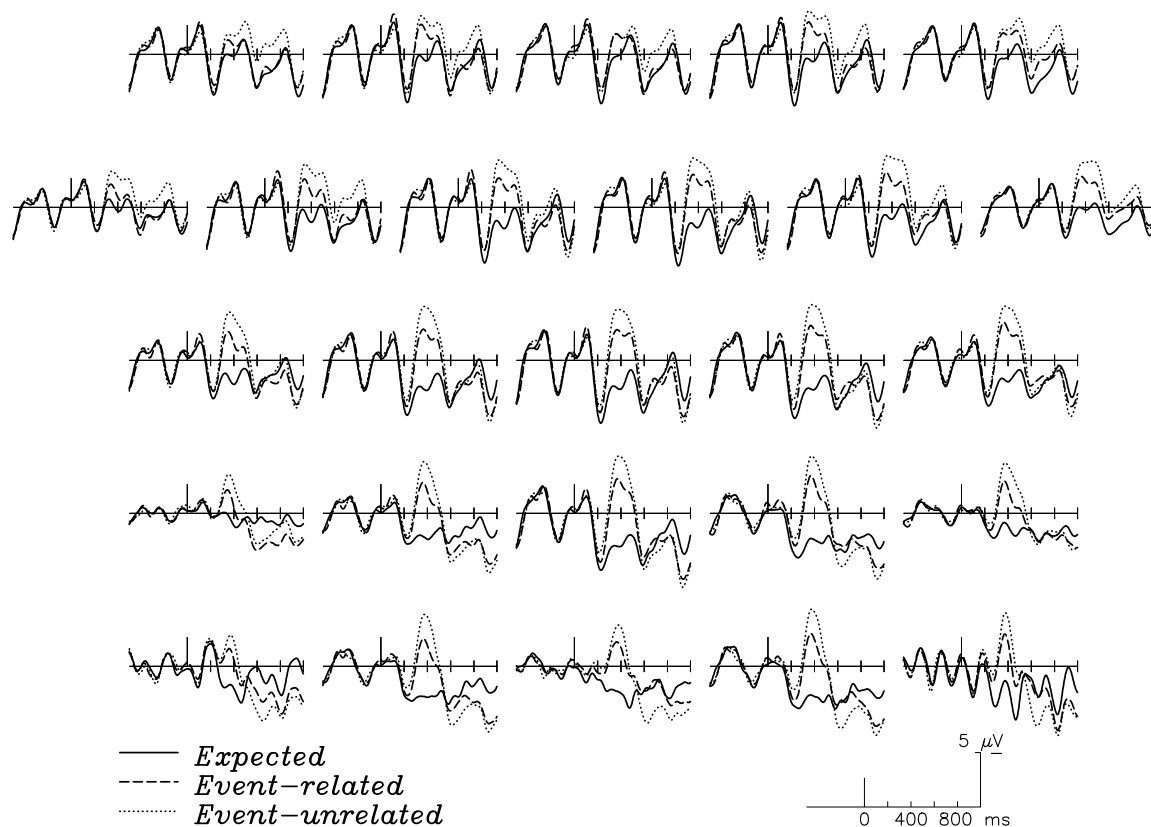
Figure 2.2: Grand average ERPs elicited by target words in the three conditions. Ticks on the x-axis mark 200ms intervals from target word onset. Negative voltage is plotted up.

Because we argue that the differences in N400 amplitude in the three conditions

reflect the activation of event knowledge during online comprehension, and with

ART/MRT performance providing an indirect measure of both linguistic proficiency and general world knowledge, we analyzed the relationship between ART/MRT performance and N400 amplitude. Participants were assigned to two groups according to a median split on ART/MRT performance. The high scoring group consisted of the top 15 scorers ($M = 24.5$, $SD = 5.5$); these were separated from the bottom 15 scorers ($M = 12.7$, $SD = 4.4$). In an omnibus ANOVA with within-subjects factors of Electrode (26 levels) and Condition (3 levels) and a between-subjects factor of ART/MRT Group (2 levels), Group did not interact with Condition ($F(2,56) = 0.13$, $\varepsilon_{GG} = 0.7711$, $p > .8$), and there was no three-way interaction between Group, Condition, and Electrode ($F(50,1400) = 1.36$, $\varepsilon_{GG} = 0.1071$, $p > .2$).
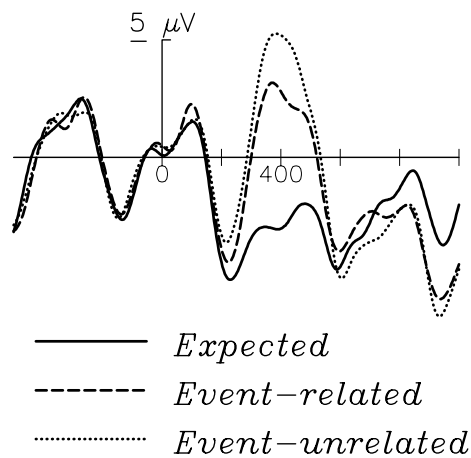
Figure 2.3: Grand average ERPs at the midline parietal electrode (MiPa).

However, a separate analysis of each ART/MRT group suggests that individual differences may be present. The bottom 15 participants show an effect of Condition in the

omnibus ANOVA, $F(2,28) = 16.51$, $\varepsilon_{GG} = 0.7234$, $p < .001$, and a Condition-by-Electrode interaction, $F(50,700) = 6.52$, $\varepsilon_{GG} = 0.0850$, $p < .001$, but the pairwise comparison between the Event-Related and Event-Unrelated conditions shows only a marginal effect of Condition ($F(1,14) = 3.81$, $p = .071$), and no Condition-by-Electrode interaction ($F(25,350) = 1.15$, $\varepsilon_{GG} = 0.1821$, $p > .3$). The numerical difference between Event-Related and Event-Unrelated N400s was 0.891μV. The top 15 participants show an effect of Condition in the omnibus ANOVA ($F(2,28) = 21.37$, $\varepsilon_{GG} = 0.8152$, $p < .001$), and a marginal Condition-by-Electrode interaction ($F(50,700) = 2.26$, $\varepsilon_{GG} = 0.0928$, $p = .059$). Importantly, the pairwise comparison between the Event-Related and Event-Unrelated conditions shows a significant effect of Condition ($F(1,14) = 10.06$, $p < .01$), and no Condition-by-Electrode interaction ($F(25,350) = 1.02$, $\varepsilon_{GG} = 0.1176$, $p > .3$). The numerical difference between Event-Related and Event-Unrelated target N400s was 1.297μV. These analyses therefore are suggestive of ART/MRT-based individual differences, though the current design and data do not allow us to make definitive conclusions about the nature of such possible differences at this time. We present this analysis simply to highlight the potential for individual differences in activation of event knowledge during online language comprehension. Such individual differences are worthy of future investigation, but will not be discussed further.
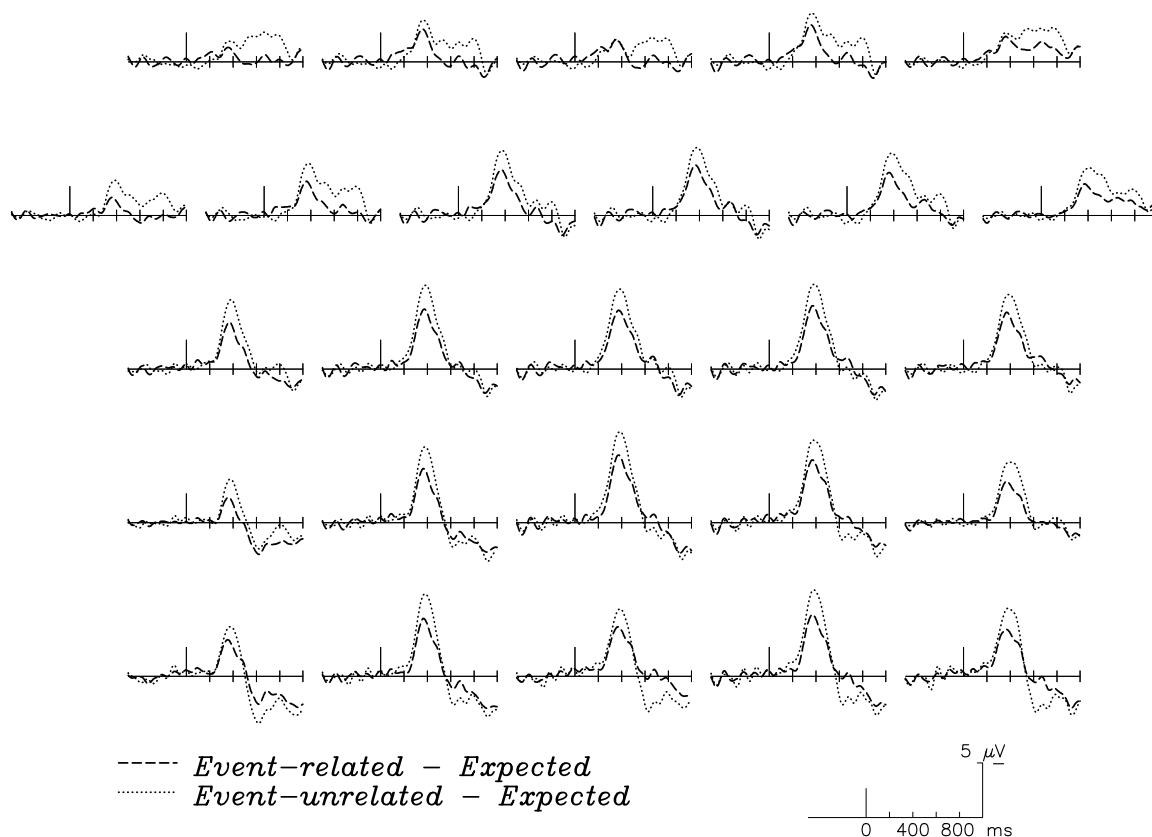
Figure 2.4: Difference waves reflecting the size of N400 effects in the Event-Related and Event-Unrelated conditions.

Scalp Distribution

The graded N400 effect is generally widespread across the scalp but appears most prominently at medial posterior sites. Figure 2.4 contains ERP difference waves (Event-Related minus Expected and Event-Unrelated minus Expected) that portray the size of the N400 effect for each anomalous target type at each electrode. Figure 2.5 presents scalp topographies of mean amplitude in the 200-500ms window for the two N400 effects. The scalp distributions of the two N400 effects were assessed by analyzing mean amplitudes from 200 to 500ms of the difference between each anomalous target type and the

Expected targets. Mean amplitudes were entered into a repeated measures ANOVA with

two levels of Difference (Event-Related minus Expected vs. Event-Unrelated minus

Expected), two levels of Hemisphere (right vs. left), two levels of Laterality (lateral vs.

medial), and four levels of Anteriority (prefrontal vs. frontal vs. parietal vs. occipital).[7]
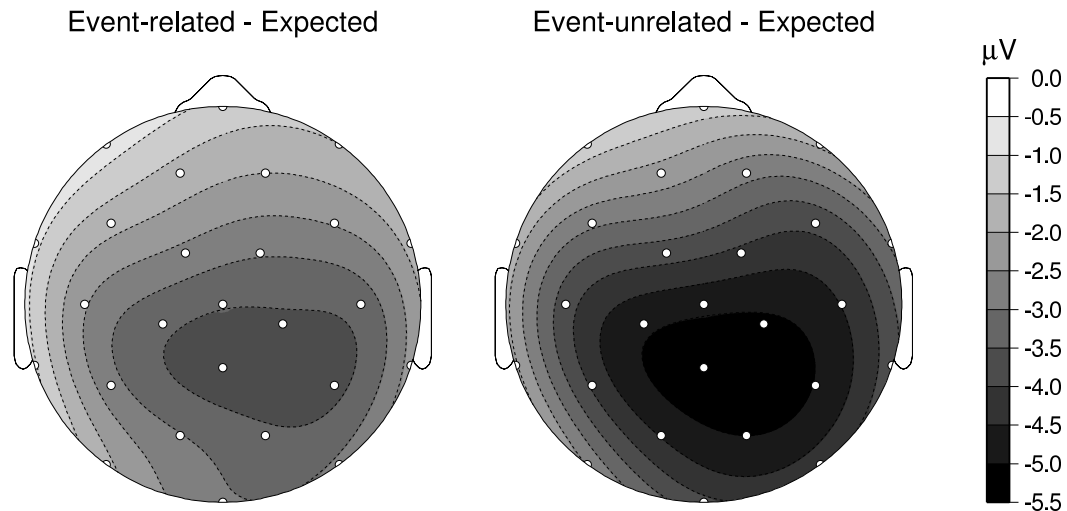
Figure 2.5: Scalp topographies of the N400 effects in the Event-Related and Event-Unrelated conditions. The left plot reflects the N400 effect for the Event-Related targets, and the right the Event-Unrelated targets. Values correspond to mean amplitude 200-500ms post-stimulus onset.

The results show a main effect of Difference ($F(1,29) = 12.71, p < .01$), again

showing that the N400 effect is larger for the Event-Unrelated condition than the Event-

Related condition. The analysis also shows main effects of Hemisphere ($F(1,29) = 25.78$,

$p < .001$), Laterality ($F(1,29) = 23.52, p < .001$), and Anteriority ($F(3, 87) = 7.01, \varepsilon_{GG} =$

$0.3824, p < .05$). The main effect of Hemisphere indicates that N400 effects were larger

over the right than left hemisphere, and the main effect of Laterality indicates that N400

effects were larger over medial than lateral sites. The main effect of Anteriority results

---

[7] See Figure 2.1 for electrode groupings applied in this distributional analysis.

from larger N400 effects at frontal ($t(29) = 3.54$, $p < .01$) and parietal ($t(29) = 3.29$, $p < .01$) sites than at prefrontal sites.[8] A Hemisphere-by-Laterality interaction ($F(1,29) = 14.61$, $p < .001$) indicates that while right medial sites show larger N400 effects than left medial sites ($t(29) = 3.83$, $p < .001$), the drop-off from medial to lateral sites is larger in the left ($t(29) = 5.98$, $p < .001$) than right ($t(29) = 3.21$, $p < .01$) hemisphere. A Laterality-by-Anteriority interaction ($F(3,87) = 10.32$, $\varepsilon_{GG} = 0.7602$, $p < .001$) reveals that the effect of Anteriority is reliable at medial sites (prefrontal vs. frontal: $t(29) = 4.71$, $p < .001$; prefrontal vs. parietal: $t(29) = 4.64$, $p < .001$) but not lateral sites (all $t(29) < 1.89$, $p > .07$). However, a three-way interaction between Hemisphere, Laterality, and Anteriority ($F(3,87) = 3.15$, $\varepsilon_{GG} = 0.7191$, $p < .05$) suggests that this Laterality-by-Anteriority interaction holds only in the left hemisphere. Right lateral sites show an effect of Anteriority that becomes statistically nonsignificant after controlling for multiple comparisons (prefrontal vs. frontal: $t(29) = 2.05$, $p < .05$; prefrontal vs. parietal: $t(29) = 2.45$, $p < .05$), while left lateral sites do not show even marginal effects of Anteriority (all $t(29) < 1.31$, $p > .2$).

On the whole, these results indicate that the N400 effects are largest at right centro-parietal sites and decrease in size moving laterally and toward the front of the scalp. This right-lateralized, centro-parietal distribution is typical of that found in many N400 studies. In this analysis, none of the distributional factors interacted with Difference, indicating that the distribution of the N400 effects in the Event-Related and Event-Unrelated conditions were statistically equivalent.

---

[8] In both experiments, all post-hoc t-tests are two-tailed paired-sample tests using Bonferroni-adjusted alpha values to correct for multiple comparisons.

Late Window Analysis

Although we generated no predictions regarding effects outside of the N400 time window, we conducted an analysis of the 500-900ms post-stimulus window in which late positive effects typically arise. We entered mean amplitudes from 500-900ms into a repeated measures ANOVA with three levels of Condition and 26 levels of Electrode. The results show no main effect of Condition ($F(2,58) = 0.59$, $\varepsilon_{GG} = 0.785$, $p > .5$) but do show a reliable Condition-by-Electrode interaction ($F(50,1450) = 7.06$, $\varepsilon_{GG} = 0.1009$, $p < .001$). Looking at the ERPs in Figure 2.2, it generally appears that at anterior electrodes, the Event-Unrelated targets elicit a greater negativity than the other two target types, with this difference being slightly more prominent over the left hemisphere. At posterior electrodes, the Event-Unrelated targets elicit a greater positivity than the other two target types until approximately 800ms, at which point the Event-Related targets begin to exhibit a positive shift, as well. The presence of effects in the late window is worth noting, but because this experiment was not designed to investigate late positivity effects, we conduct no further analyses in this time window. We return to this late effect briefly in the General Discussion.

LSA Subset Analysis

The finding of N400 reduction for Event-Related relative to Event-Unrelated targets may be interpreted in at least two ways. It may be the case that N400 reduction for arises through construction of a mental representation of the described event that combines both explicitly stated information and additional knowledge of the comprehender. Under this account, the observed effect is driven by discourse

comprehension processes and the mental representations they serve to construct. Yet, recall that previous studies have shown direct lexical priming between elements of event knowledge, even in the absence of normative association (Hare, Jones, et al., 2009). Presumably, processing an isolated word does not give rise to a detailed mental representation of an event along the lines of that constructed through comprehension of a full discourse, but yet it can prime event knowledge elements either through direct association or through some mediating knowledge structure. An alternative explanation for the results is that this type of priming is at play. Under this account, the mental representation constructed through processing the full discourse context is not necessary to observe N400 reduction for Event-Related targets. Instead, only the presence of associated words in the preceding context is required. This contrasts with the former interpretation of the results, which argues that a full, coherent mental representation of the described event drives the effect. To illustrate, consider the "playing in the snow" example in (1). Under the discourse processing account, *jacket* elicits a reduced N400 because it refers to additional knowledge activated to enrich the representation of the specific event described by the full discourse. Under the priming account, *jacket* elicits a reduced N400 simply because it is preceded by one or more content words that prime it directly, with the mental representation of the event described by the discourse as a whole playing no role.

Contrary to the lexical priming account, previous research suggests that effects of lexical priming during discourse comprehension are generally weak or nonexistent. Camblin, Gordon, and Swaab (2007) report a series of experiments addressing the role of lexical associative priming and higher-level discourse information in online sentence

comprehension. Using eye-tracking and ERP measures, the authors examined responses to contextually congruent words that either did or did not align with the general discourse context and either were or were not preceded by a direct lexical associate. Across all experiments, they generally found that effects of discourse context were immediate and strong, while effects of an immediately preceding lexical associate were delayed and weak, if present at all. Reliable effects of lexical association arose only when single sentences were presented in isolation or when texts were made incoherent through scrambling of words. Camblin et al. conclude that "automatic spread of activation, as a function of associative relations between words, does not contribute to processing of words in sentences that are part of a larger discourse" (p. 126). With the scenarios in the present experiment providing relatively rich discourse contexts before target presentation, the findings presented by Camblin et al. strongly suggest that lexical priming is not at play here.

Despite this evidence suggesting that lexical associative priming does not affect the processing of words embedded in full discourses, we conducted an analysis addressing this alternative account directly. First, we sought to quantify the level of association of our Event-Related and Event-Unrelated targets with their preceding context words. If the Event-Related targets were more strongly associated with the individual context words than were the Event-Unrelated targets, we would have evidence suggesting that the present results could be driven by direct priming of the Event-Related targets through activation of the semantic representations of one or more key content words (as opposed to construction of a mental representation of the described event as a whole). To quantify lexical semantic associations, we utilized Latent Semantic Analysis

(Landauer, Foltz, & Laham, 1998), which captures semantic association between individual words or groups of words through co-occurrence statistics computed over large-scale corpora. In investigating lexical priming between event associates (e.g., *hospital* and *doctor*), Hare, Jones, et al. (2009) demonstrated that LSA captures lexical priming between associated elements of event knowledge that do not exhibit association in a standard free-association task. Hare, Jones, et al. argue that LSA captures priming between event associates because words associated with a common event should often co-occur together in text describing that type of event. Because it is plausible that our Event-Related targets were preceded by context words denoting event associates more often than the Event-Unrelated targets, the present analysis required a measure capable of capturing priming between event associates. We therefore chose LSA over free association norms due to its ability to capture such associations. [9]

   We obtained LSA scores using the one-to-many application on the LSA website at lsa.colorado.edu. We computed the cosine between each target word and its entire preceding context, using the General Reading – Up to First Year of College topic space with 300 factors. We found a statistically significant difference between the Event-Related and Event-Unrelated targets: the mean association score for the Event-Related targets was 0.27, and the mean score for the Event-Unrelated targets was 0.22, $t(71) =$

---

[9] Hare, Jones, et al. (2009) conclude that LSA actually may overestimate priming between event associates, with LSA incorrectly predicting priming from instrument nouns to people who typically use those instruments, which was a relation for which Hare, Jones, et al. did not find priming. This potential for LSA to overestimate priming between event associates is actually a strength for the current analysis: overestimation of such priming should, if anything, bias the analysis toward finding the Event-Related targets to be more closely associated with preceding context words than the Event-Unrelated targets. LSA may therefore bias the analysis in favor of the lexical priming interpretation of the results.

3.032, $p < .01$. The LSA association scores therefore provide support for the lexical priming interpretation of the results.

To further examine the possibility that lexical priming drove the present results, we identified a subset of the 12 experimental items that showed the largest differences between LSA association scores for the Event-Related and Event-Unrelated targets. We then reanalyzed the data excluding these 12 items. In the remaining 60 experimental items, the new mean LSA score for the Event-Related targets was 0.24, and for the Event-Unrelated targets was 0.23 ($t(59) = 0.5216, p = .60$). An analysis of the ERPs identical to that described above again showed that the Event-Related targets elicit smaller N400s than do the Event-Unrelated targets ($F(1,29) = 13.7, p < .001$). This result, combined with the findings presented by Camblin et al. (2007) suggesting that lexical priming exerts at most a weak influence during discourse comprehension, strongly suggests that the observed N400 reduction for Event-Related targets is a discourse-level phenomenon, resulting from online activation of generalized event knowledge during the construction of a coherent mental representation of the described event.

Discussion

The present findings demonstrate that event knowledge activation during the course of incremental language comprehension extends to elements that are anomalous in the linguistic context. The results show that a contextually anomalous word elicits a reduced N400 if that word is related to the described event. An analysis of a subset of experimental items suggests that this N400 reduction does not result from priming of the Event-Related targets by the activation of lexical semantic representations of individual

content words. While priming results suggest that event knowledge can be considered a component of lexical semantics, the subset analysis showed that when lexical semantic associations are controlled, N400 reduction for the Event-Related targets still holds. This indicates that the effect results from discourse-level comprehension processes that engage generalized event knowledge to construct a detailed mental representation of the described event. Furthermore, the emergence of an effect in the N400 time window indicates that this activated knowledge influences processing within several hundred milliseconds of word onset.

Various researchers have proposed that meaning construction during comprehension involves the formation and dynamic updating of a coherent mental representation of the described event (e.g., Altmann & Kamide, 2009; Altmann & Mirkovic, 2009; Zwaan & Radvansky, 1998). Event knowledge is generally believed to play an important role in this process, but the degree to which unmentioned elements of event knowledge become activated as part of an event representation has remained unclear. Along these lines, Zwaan and Radvansky (1998) discuss studies of the activation of implied instruments during comprehension and note that mixed results indicate that subtle contextual factors play a large role in determining whether or not an unmentioned but implied instrument becomes active as part of an event representation. Utilizing ERPs, this study suggests that a wealth of unstated information regarding described events is activated during online language processing.

This issue is directly relevant to previous work on inference, where research has focused on the types of inferences that are automatically generated during language comprehension (Graesser et al., 1994; McKoon & Ratcliff, 1992). Theories differ as to

which types of inferences they propose to be generated automatically, but it is generally

assumed that inference generation is limited in scope and does not extend to elements

simply by virtue of generally being part of a described event. For example, Alba and

Hasher (1983) and Seifert, McKoon, Abelson, and Ratcliff (1986) have shown that

inferences based on "filling in schema information" are not made, at least when

inferences are tested after the presentation of a sentence or scenario. The present study

did not strictly control potential types of inferences triggered by the scenarios, or the

relation of the Event-Related targets to any such inferences. The Event-Related targets

were chosen because participants indicated that they were likely to be present during the

described event. It is therefore unclear on the surface how activation of the Event-Related

targets in our study (which we do not consider to be full-blown inferences) might be

related to inference generation as it is typically portrayed in the literature. However, in

general, the Event-Related targets were not required to make statements in the discourse

locally coherent, nor did they correspond to causal or bridging inferences. For example,

there is nothing in the "playing in the snow" scenario that requires jackets to be inferred,

inferring jackets is not at all useful for establishing textual coherence, and it would be

highly unlikely that participants would report that they actually had read the word *jacket*.

The online activation of general event-relevant information at points at which

inferring it is not necessary may support inference generation processes. During

incremental comprehension, activation of a range of salient event knowledge elements

would allow such information to be readily available when a related inference becomes

necessary. In the "playing in the snow" scenario in (1), there is no clear mapping between

jacket and some inference necessary to understand the discourse, but if the text were to

trigger such an inference down the line (e.g., *It began to snow some more, so Tommy put his hood up*), the information necessary to support the inference would be active. Thus, activation of generalized event knowledge may facilitate rapid generation of inferences during incremental comprehension.

The present findings also relate to previous studies in which it has been demonstrated that unexpected or anomalous words that are related to the most expected word elicit faster reaction times and smaller N400 amplitudes than do equally unexpected or anomalous words unrelated to the most expected word (Federmeier & Kutas, 1999; Kleiman, 1980; Kutas & Hillyard, 1984; Kutas, Lindamood, & Hillyard, 1984; Kutas, 1993; Schwanenflugel & LaCount, 1988). These "related oddball" findings are generally interpreted as showing that sentence processing involves word pre-activation or expectancy generation, a claim that is supported by additional findings (Altmann & Kamide, 1999; DeLong, Urbach, & Kutas, 2005; Kamide, et al., 2003). Under this account, sentence contexts pre-activate words with certain semantic characteristics, with the most expected word receiving greatest activation but semantically similar words also receiving partial activation regardless of fit with the linguistic context. Early studies of this effect did not control for the nature of the relationship between the most expected word and the critical word, leaving open multiple possibilities for what information (e.g., associative, categorical, event knowledge, etc.) actually drives linguistic prediction. Federmeier and Kutas (1999) controlled this relationship by measuring ERPs to unexpected words that specifically shared semantic features with the expected word. They found N400 reduction for these words relative to unexpected and unrelated words, indicating that context-independent category structure in long-term memory drives

prediction of upcoming words. Sentential contexts drive activation of sets of semantic features possessed by concepts that are likely to come next, such that an unexpected word that matches some of these features will elicit a smaller N400 than an equally unexpected word that does not match those features.

The N400 reduction for the Event-Related anomalous targets observed in this study suggests that event knowledge also is an important knowledge source for driving linguistic prediction. In the present study, Event-Related anomalous targets did not share semantic features with the Expected targets (e.g., *jacket* does not share features with *snowman*), suggesting that semantic feature overlap such as that in Federmeier and Kutas is not responsible for the present results. In addition, it is uncertain if the stimuli in Federmeier and Kutas and other "related oddball" studies involved unexpected or anomalous targets that were not only related to the most expected word in some way, but also to the described event. It is therefore an open question as to what extent event knowledge can account for these previous findings. It is likely that multiple information sources drive linguistic prediction, with relatively context-independent semantic category knowledge interacting with more context-dependent representations of described events. The nature of interaction among different information sources in driving linguistic prediction is worthy of future study.

Conflicting Findings

As discussed in the introduction, Traxler et al. (2000) and Kintsch and Mross (1985) present results that seem to demonstrate that online event knowledge activation does not extend to contextually anomalous elements. There are, however, several

important differences between the present study and those by Traxler et al. and Kintsch and Mross that may explain the discrepancy. First, the dependent measures differ: Traxler et al. measured fixation times during reading, and Kintsch and Mross measured lexical decision times to probe words presented mid-discourse. It is possible that the N400, a neural measure of semantic processing, is sensitive to the activation of event knowledge in a way that lexical decision times and fixation times during reading are not. Second, we collected norming data in order to choose Event-Related targets that were strongly related to the described event. Although Traxler et al. collected plausibility norms indicating that their implausible target words were contextually anomalous, it is unclear whether they controlled for the relationship of their target words with the events denoted by the preceding context. It is possible that their target words were not as centrally related to the described events as were our Event-Related targets. Kintsch and Mross chose their scenario-related target words by consulting script norms collected by Galambos (1982), choosing a word that related in some way to what a reader might expect to be mentioned as the next activity in an ongoing description of a common event. It is possible that while the script norms capture how a reader might expect a story to progress, the particular words chosen by Kintsch and Mross as probe words nevertheless did not correspond to central components of the event knowledge activated by the preceding discourse.

One final difference relates to the degree of contextual buildup. Traxler et al.'s stimuli established event contexts through only a few words preceding the target, whereas the present study used multiple context sentences. Traxler et al.'s stimuli thus may not have provided sufficient contextual buildup for generalized event knowledge activation to occur by the time participants encountered the critical words. The same cannot be said of

Kintsch and Mross, however, with their stimuli involving several context sentences before target word presentation. Still, given the myriad differences between the present study and those by Traxler et al. and Kintsch and Mross, along with the fact that those studies ultimately were designed to address different questions than that addressed here, the present findings still firmly support the conclusion that online language comprehension involves activation of event knowledge elements that violate the linguistic context.

Late Window Effect

The results showed an effect of the experimental manipulation on mean ERP amplitude in the 500-900ms time window. Analyses in the late time window were limited to omnibus ANOVAs due to the fact that this study was not designed to address late effects, and detailed analyses in the late window based on visual identification of potential differences may capitalize on chance. Still, the presence of an effect merits brief discussion.

Past research has demonstrated a link between late positivities and syntactic processing (e.g., Friederici, Hahne, & Mecklinger, 1996; Osterhout & Holcomb, 1992), but as detailed by Kuperberg (2007), numerous studies have demonstrated more recently that late postivities are elicited by certain types of semantic violations as well. Some studies (e.g., Kuperberg, Caplan, Sitnikova, Eddy, & Holcomb, 2006; Nieuwland & Van Berkum, 2005) may be interpreted as indicating generally that late positivities might be linked in some way to the eliciting word's status as related or unrelated to the described event, but the exact relationship between late positivities and eliciting words' association

with described events remains unclear. Given that our manipulation was one of event-relatedness, our results may suggest that late effects elicited by semantic violations are in some way modulated by the eliciting word's degree of relation to the described event. Ultimately, our study was not designed to investigate late effects elicited by semantic violations and offers no ready explanation for that obtained, so we simply note the presence of an effect in the late time window and acknowledge that such effects merit future study.

Why?

At the outset, we alluded to a deep and troublesome question that is often avoided in sentence processing research: What is the target of language understanding? Of course, there is probably not a single target. Language can be used for many purposes. Task and strategic demands undoubtedly play a large role in determining what information a comprehender will extract and focus on at any given time. Some tasks may focus attention on the sound structure; others on identifying specific words; others might focus attention on well-formedness of grammatical structure. The present study suggests that under at least the task circumstances involved here, comprehenders have as one important target the construction of mental representations of events and situations. Furthermore, these mental representations are sufficiently potent and influential that they participate in comprehenders' processing of and perhaps expectancies about upcoming words, even to the point where they expect (or conversely, are able to quickly integrate) words that do not make sense in the local linguistic context but are appropriate in the context of the event being described.

Why would comprehenders do this? We suggest two (mutually compatible) possibilities. The first is that the activation of generalized event knowledge is so central to language understanding that it cannot be turned off. Event knowledge may be so fundamental in language understanding that its influence on other levels of processing cannot be suppressed.

The second possibility is that processing discourse at a high level of analysis (in our task, the general description of an event), sometimes at the expense of full and accurate processing based on explicit linguistic cues, is adaptive when compared to full and accurate processing at all levels of analysis. That is, it may be advantageous for information that aligns with a higher-level representation of the described event to be active even when in conflict with direct bottom-up cues present in the linguistic stream. Kukona, Fang, Aicher, Chen, and Magnuson (2011) present evidence suggesting, as the present findings do, that activation of event or thematic knowledge proceeds in partial independence of explicit prediction of contextually appropriate words. Utilizing visual world eye-tracking, Kukona et al. found that upon hearing *Toby arrests the…* participants were more likely to fixate a police officer than other distractors not related to an arresting event, even though *police* constitutes a poor patient of *arrest* and a proper patient (a crook) was depicted. Thus, thematic knowledge regarding an *arresting* event drives eye movements to a depicted policeman even though this conflicts with bottom-up interpretation of linguistic input (i.e., *policeman* should not be predicted to come next). Kukona et al. suggest that activation of thematically appropriate but contextually incongruent information can serve discourse comprehension functions such as establishing complex relations among discourse referents and facilitate connection of

information presented in a discourse with knowledge stored in long-term memory. Limiting activation of information to only that which is likely to appear in the upcoming linguistic input could be detrimental to these functions. Processing language beyond the level of the particular words received or likely to appear next may be critical to complex discourse comprehension functions achieved through the real-time engagement of generalized event knowledge.

Conclusion

Event knowledge exerts a strong and rapid influence on language comprehension processes. With respect to the scope of real-time event knowledge activation, this study has demonstrated that as a discourse is processed incrementally, activation of event knowledge extends beyond those elements that are congruent with local linguistic cues to include other salient event knowledge elements that might constitute anomalous continuations of the linguistic stream at that point. This activated information influences online processing within several hundred milliseconds of word onset, and supports both linguistic prediction and higher-level discourse comprehension functions.

Acknowledgements

reviewers for helpful comments and suggestions. This work was supported by NICHD grants HD053136 and HD022614, and NIA grant AG008313.

Chapter 2, in full, is a reprint of material as it appears in Metusalem, R., Kutas, M., Urbach, T.P., Hare, M., McRae, K., & Elman, J.L. (2012). Generalized event knowledge activation during online sentence comprehension. *Journal of Memory and Language, 66*, 545-567. The dissertation author was the primary investigator and author of this paper.

Appendix

The 72 experimental items. Target word position in the context is underscored. Target words are listed in the following order: Expected (top), Event-Related (middle), Event-Unrelated (bottom). The comprehension question answers are provided in parentheses.

Item	Context	Targets	Comprehension Question
1	Elizabeth was standing at the intersection waiting for the light to change. All of a sudden she saw a car barrel through the red light. A moment later, she heard a terrible _____ come from down the street.	crash policeman conductor	Was somebody driving recklessly? (Yes)
2	For several months, there had been burglaries in the neighborhood. Many people thought they knew who the crook was. Finally, he was caught when he set off somebody's _____ one night.	alarm police doctor	Was the crook eventually caught? (Yes)
3	I think it's important to start the day right. Every morning, I make sure to eat a hearty breakfast. Sometimes there's almost no room left on my _____ once I finish dishing up.	plate eggs hotdogs	Do I usually eat a modest breakfast? (No)
4	The band was very popular, and Joe was sure the concert would be sold out. Amazingly, he was able to get a seat down in front. He couldn't believe how close he was when he saw the group walk out onto the _____ and start playing.	stage guitar barn	Did Joe get stuck with a bad seat? (No)
5	My Aunt Bettie was very popular in our family. When she died, lots of people gathered to pay their respects. Her three brothers and three sisters all gave very moving _____ during the service.	speeches coffins drinks	Was Aunt Bettie liked by the rest of the family? (Yes)
6	Traveling these days is much less fun than it used to be. Now you have to deal with worries about terrorism. It can take several hours to make it through _____ and find your gate.	security luggage vegetables	Has the threat of terrorism made travel more difficult? (Yes)
7	I'm very sluggish when I wake up. Sometimes it takes me an hour to get ready in the bathroom. I often end up staring blankly at myself in the _____ for a while.	mirror toothbrush eggs	Am I usually energetic in the morning? (No)
8	Debbie is more of a risk taker than she should be. She loves to gamble but really isn't very good at card games. Last night, she had a rough time playing _____ at the casino.	poker dealer salesman	Is Debbie a good card player? (No)
9	Many people think living in the country is easy. But I grew up on a farm and I know there are some downsides. What I hated most was being woken up early each morning by the _____ outside my window.	rooster barn boots	Did I grow up on a farm? (Yes)
10	My friend Julie spends all her time exercising. The machine she likes the most is the treadmill. By the time she's done, she's drenched in _____ and breathing very heavily.	sweat towel couch	Does Julie exercise frequently? (Yes)
11	Going to the movies is great fun. Before the show starts, I like to get a snack. There's nothing like	popcorn soda	Is chocolate my favorite snack?

	watching the show while eating a big box of _____ covered with butter.	car	(No)
12	Bob and Linda celebrated their 25th anniversary recently. Their kids wanted to do something nice for them. So they all got together and threw a big _____ at the beach.	party family coral	Did Bob and Linda get married last year? (No)
13	Michelle had a toothache for several months. She knew she should do something about it, but held off. She finally got checked out when she was told she could get some anesthetic to reduce the _____ and ease her discomfort.	pain dentist driver	Did Michelle eventually see somebody about her toothache? (Yes)
14	The parents were very excited about their new baby girl. One of the first things they did was to get her baptized in their church. The baby liked baths, so she smiled when she was sprinkled with _____ on her forehead.	water priest dealer	Did the baby enjoy getting baptized? (Yes)
15	During the summer, many people like to cook outdoors. Everybody has different preferences for what to make. My father likes both hot dogs and _____ but his favorite is bratwurst.	hamburgers grills booths	Do people like to cook indoors during the summer? (No)
16	Getting divorced is always difficult. Even when people get along, there are many details to work out. If there are children, the hardest part is the question of who gets _____ of them.	custody lawyer priest	Is getting divorced a simple matter? (No)
17	The summer is a great time to go the beach. It's true you have to bring a lot of things with you, but that's OK. The only thing I don't really like is that your food gets full of _____ and attracts lots of ants.	sand towel rod	Do you need to bring a lot of things with you when you s pend the day at the beach? (Yes)
18	If you live in a city, the best way to see unusual animals is to go to the zoo. There are all kinds of exotic animals that children don't normally see. Sometimes, however, the kids are scared by the roar of the _____ and scream in terror.	lion cages dress	Do kids sometimes get scared at the zoo? (Yes)
19	A favorite American pastime during the summer is going to a ballgame. Of course, people occasionally get rowdy. My sister gets really upset when people drink too many _____ and start acting crazy.	beers hotdogs cages	Does my sister like it when people drink a lot at the ballgame? (No)
20	After a day of off-roading, my truck was covered in mud. I parked it out on the driveway to give it a wash. When I started, I realized that I had forgotten to turn on the _____ on the side of the house.	hose soap gun	Did I take my truck to the car wash? (No)
21	The case of Bill the Butcher was the largest that this court had ever tried. The entire town came out to hear the opening statements. Once they were finished, the prosecution called its first _____ to the stand.	witness lawyer receptionist	Did the opening statements draw a large crowd? (Yes)
22	This spring, I decided to start growing my own vegetables. I bought a variety of seeds and planted them in my backyard. I made sure to choose a spot that got plenty of _____ during the day.	sun dirt money	Did I start a vegetable garden? (Yes)

23	My parents were very happy when my sister finally got married. At the ceremony, my father looked so proud. My mother started crying when the couple recited their _____ and proclaimed their love.	vows ring dirt	Were my parents worried about my sister getting married? (No)
24	I usually take the bus to work in the morning. It was over twenty minutes late on Friday. To top it off, when it finally came I realized that I didn't have any _____ to pay the fare.	money driver teacher	Did the bus arrive on time on Friday? (No)
25	The restaurant down the street is known for its lousy service. One time, I actually caught a waiter taking a bite of someone's dinner. I immediately asked to speak with the _____ about the waiter's conduct.	manager food poles	Is it common to have bad service at the restaurant? (Yes)
26	A huge blizzard swept through town last night. My kids ended up getting the day off from school. They spent the whole day outside building a big _____ in the front yard.	snowman jacket towel	Did my kids play outside on their day off from school? (Yes)
27	My dad had a lot of trouble when I took him skiing for the first time. It took him forever just to figure out how to stand up. Then he fell when he tried to get onto the _____ with his skis crossed.	lift poles food	Is my dad a good skier? (No)
28	Jackie is a very methodical poker player. During the high-stakes tournament, she was even more careful than usual. Every few hands, she made sure to count her _____ silently to herself.	chips table water	Was Jackie playing carelessly during the poker tournament? (No)
29	My friend Mike went mountain biking recently. He lost control for a moment and ran right into a tree. It's a good thing he was wearing his _____ or he could have been seriously hurt.	helmet dirt table	Did Mike crash on his bike? (Yes)
30	It's generally a good idea to drive slowly and obey traffic laws. If you don't, you're likely to get pulled over. It's always a terrible feeling when the officer issues you a _____ and sends you on your way.	ticket license helmet	Is it a good idea to obey traffic laws? (Yes)
31	I used to love taking field trips with my elementary school. We got out of class for the day, and we usually went someplace fun. I would always get excited when we were about to board the _____ and head off.	bus teacher salesman	Were my field trips usually boring? (No)
32	We're lucky to live in a town with such a great art museum. Last week I went to see a special exhibit. I finally got in after waiting in a long _____ and paying an entrance fee.	line painting toothbrush	Did I see a special exhibit at the aquarium? (No)
33	I took my friends to the desert for a few days of camping. After a couple hours of hiking, we found a good spot to spend the night. The weather was so nice that we didn't even pitch a _____ or use our sleeping bags.	tent fire hammer	Did we have nice weather on our camping trip? (Yes)
34	Jenny had a really difficult math exam earlier this week. She was so worried about being late that she arrived twenty minutes early. As soon as she arrived, she made sure to sharpen her _____ and find a seat.	pencil calculator bed	Did Jenny arrive early to the test? (Yes)
35	My friends and I played a game of pond hockey over	skates	Are all my friends

	the weekend. It was clear from the beginning that one of my friends had never played before. The poor guy couldn't even lace up his _____ or hold his stick properly.	puck glass	experienced hockey players? (No)
36	Filming for the new movie was getting underway, and the crew was ready to shoot the first scene. One of the cameramen mentioned that she was getting some really bad glare in the shot. Somebody quickly dimmed the _____ and the director called action.	lights actors turkeys	Did the cameraman complain about the lights being too dim? (No)
37	A high profile bank was robbed yesterday afternoon. The robbers entered through the back and made their way to the lobby. All the customers froze when they saw several masked men pointing _____ and threatening to shoot.	guns money dirt	Were there customers present during the bank robbery? (Yes)
38	It's a good idea to get some reading material before going on a long trip. I tend to go to the library the day before I leave. Last time I went, I was shocked to find out that I owed a huge _____ for something I had already returned.	fine book tire	Do I usually go to the library before going on a trip? (Yes)
39	Shopping at the used car lot can be a stressful ordeal. Even if you find a car you like, you never know if it has any problems. Just make sure to have a good look under the _____ before buying anything.	hood salesman policeman	Can you be certain whether or not a used car has problems? (No)
40	My little brother doesn't know how to swim, but we still bring him along when we go to the pool. One time, he fell into the deep end while no one was looking. He was quickly brought to safety by the _____ and given to our mother.	lifeguard water parachute	Is my brother a good swimmer? (No)
41	Last Saturday I laid around watching television into the middle of the night. I eventually found myself watching an infomercial for some new cleaning product. I wanted to change the channel, but I couldn't find the _____ anywhere.	remote couch brush	Was I watching TV late at night? (Yes)
42	Even the laziest people clean up around the house every once in a while. The worst part is always the bathroom. When you tackle the toilet, it's good to wear some _____ to guard against bacteria.	gloves bleach blood	Is the bathroom the worst part of cleaning the house? (Yes)
43	The airlines are getting so stingy that they don't even provide free food anymore. A lot of people complain that they no longer get a complimentary meal on long flights. I'd be happy just to get a bag of _____ or some crackers.	peanuts drinks fire	Do all the airlines still provide complementary meals? (No)
44	We had our entire family over to our house for Thanksgiving this year. My mother set the table as if the President were coming for dinner. She laid out a nice tablecloth and even lit a couple _____ for effect.	candles turkeys runners	Did we set the table for an ordinary dinner? (No)
45	The last presidential election drew an incredible number of voters. My polling place had a line out the door when I arrived on election day. I waited three hours before I was finally able to cast my _____ and head to work.	vote booths coffins	Did a lot of people vote in the election? (Yes)

46	My sister was only twenty when she won a Grammy for her first album. She seemed so nervous as she gave her acceptance speech. Her voice was shaky as she spoke into the _____ and thanked everyone.	microphone dress painting	Was my sister young when she won her Grammy? (Yes)
47	Jeremy is a great athlete despite being prone to injury. During his last high school football game, he was knocked unconscious twice. That still didn't stop him from scoring the winning _____ with only seconds remaining.	touchdown helmet license	Did Jeremy sprain his ankle during the football game? (No)
48	Living in San Diego is great if you love to surf. The downside is that the water can be freezing during the winter. You'll be sorry if you go out without wearing your _____ or at least a shirt.	wetsuit surfboard grills	Is the winter water warm enough to surf in just your bathing suit? (No)
49	Raja likes to go to the supermarket early in the morning to avoid the crowds. He usually brings his daughter along. She always insists on riding in the _____ while Raja pushes.	cart vegetables luggage	Does Raja try to do his shopping when the store isn't crowded? (Yes)
50	My husband and I had some nice red wine with dinner last night. He's so clumsy that he ended up spilling some all over me. At least my shirt was dark enough to partially hide the _____ for the rest of the evening.	stain glass car	Was I wearing a dark shirt? (Yes)
51	Andy was excited to get his driver's license, but he was afraid he wouldn't pass the parallel parking section of the test. He tried to remain calm as he checked his mirrors and began. Unfortunately, he ended up failing for knocking over too many _____ and had to retake the test.	cones instructors clowns	Did Andy pass his driver's test? (No)
52	Having major surgery is never a pleasant experience. You lie in a sterile room next to an operating table full of scary tools and devices. As if the anxiety isn't enough, you usually have to deal with a cold draft up your _____ while you wait to begin.	gown doctor police	Can major surgery be a pleasant experience? (No)
53	I used to love getting my hair cut when I was a kid. I got so excited every time I walked into barbershop. I would giggle with joy as I hopped into the _____ and greeted the barber.	chair scissors guitar	Did I enjoy haircuts as a child? (Yes)
54	Tanya was totally pumped to be skydiving for the first time. When it was her turn to jump, she got a huge smile on her face. She didn't hesitate at all before leaping out of the _____ head first.	plane parachute soda	Was Tanya excited to be skydiving? (Yes)
55	When Maya's laptop was stolen, she went to the Apple store to buy a replacement. She wanted to make sure to get one with a fast processor. She also had tons of files to store, so she wanted a lot of _____ as well.	memory salesman dentist	Did Maya do her computer shopping online? (No)
56	My friends and I took a cross-country road trip after graduating from college. We ended up getting lost somewhere in the middle of Nevada. We eventually decided to stop and ask for some _____ at a gas station.	directions car box	Did we stop because we were out of gas? (No)
57	I helped my neighbor build a shed recently, and we	roof	Did we run out of

	managed to run into a few problems. First, we realized that we didn't make the doorway the right size. Then we didn't have enough shingles to finish the _____ so we returned to the store.	hammer surfboard	shingles? (Yes)
58	The doctor was running very late, which was not uncommon. Mary couldn't wait any longer and decided to reschedule her check-up. So she asked if she could make another _____ for the following week.	appointment receptionist lawyer	Did Mary try to reschedule her appointment? (Yes)
59	Marathons take a lot out of you, and it's important not to get dehydrated. Ralph had been doing OK up until mile twenty-six. As he rounded the final bend, someone gave him some _____ and cheered him on.	water runners actors	Did Ralph compete in a triathlon? (No)
60	Having serious car trouble is the worst. Aside from being unable to drive, it's hard to find a mechanic you can trust. You never know if you're being charged a fair _____ or not.	price tire medal	Is it easy to find a trustworthy mechanic? (No)
61	Little kids love to go to the circus. There are always exotic animals, and children find the acts very exciting. The scariest act is of course when the lion tamer puts his head inside the lion's _____ while the crowd gasps in horror.	mouth clowns instructors	Are there any scary acts at the circus? (Yes)
62	The Olympic ice skating competition is always well attended. Last year, the winner was the favorite, who was extremely popular. The crowd roared with delight as she took her place on the _____ and waved to her fans.	podium medal book	Was the winner of the competition popular? (Yes)
63	The boxing match had gone on for seven rounds, and both contestants were exhausted. One of them had sustained serious injuries and finally fell to the mat. Worried about his condition, the referee declared the other fighter the _____ and ended the match.	winner blood bleach	Did the referee end the match because one of the fighters cheated? (No)
64	I started taking an introductory painting course a few weeks ago. During the first class, the instructor had a very hard time giving even a simple demonstration. It was clear that he didn't have much teaching _____ and wouldn't be a good instructor.	experience brush jacket	Did my painting class start out well? (No)
65	Nadia went snorkeling in the Great Barrier Reef while on vacation in Australia. She found it to be more beautiful than she had ever imagined. After several hours of swimming around, she still couldn't bring herself to climb back in the _____ and head to shore.	boat coral family	Did Nadia enjoy her time at the Great Barrier Reef? (Yes)
66	Music fans have a lot of different tastes when it comes to live performances. A lot of people like to go to rock concerts, but I prefer a symphony. My favorite part is the string _____ because I love the violin.	quartet conductor lawyer	Do I prefer a symphony over a rock concert? (Yes)
67	Moving to a new house is always a huge hassle. If you do it yourself, the whole ordeal can last several days. Things go much faster if you hire a moving _____ to help you.	company box ring	Is moving to a new house an easy job to do alone? (No)

68	The climb up Mount Whitney is beautiful but very challenging. Manny and Julia were tired but looking forward to what they knew awaited them at the top. Finally, they rounded the last bend and were awed by the magnificent _____ of Owens Valley below.	view boots scissors	Did Manny and Julia go hiking down by the river? (No)
69	The last time Tommy went hunting, he was nearly shot by another hunter. He was creeping quietly through the woods when the other hunter almost mistook him for a deer. It's a good thing he was wearing his orange _____ over his camouflage.	vest gun soap	Was Tommy almost shot by another hunter? (Yes)
70	I used to spend a lot of Saturday mornings fishing with my dad. We would wake up early and load the car with all of the equipment. We always brought a bucket of worms to use as the _____ even though worms grossed me out.	bait rod puck	Did I used to go fishing with my dad? (Yes)
71	I usually fall asleep pretty quickly. Sometimes, though, if I've had a busy day I find it hard to wind down. Then I find the best thing is to read a good _____ or magazine.	book bed towel	Do I like to watch TV when I can't fall asleep? (No)
72	It can be difficult to find a decent parking spot downtown. A lot of the time you have to park on the street. That's why it's always good to have some change to feed the _____ or you might get a ticket.	meter car calculator	Is it easy to find good parking downtown? (No)

References

Alba, J. W., & Hasher, L. (1983). Is memory schematic? *Psychological Bulletin, 93*, 203-231.

Altmann, G. T. M., & Kamide, Y. (1999). Incremental interpretation at verbs: restricting the domain of subsequent reference. *Cognition, 73*(3), 247-264.

Altmann, G. T. M., & Kamide, Y. (2009). Discourse-mediation of the mapping between language and the visual world: Eye movements and mental representation. *Cognition, 111*(1), 55-71.

Altmann, G. T. M., & Mirković, J. (2009). Incrementality and prediction in human sentence processing. *Cognitive Science, 33*(4), 583-609.

Bicknell, K., Elman, J. L., Hare, M., McRae, K., & Kutas, M. (2010). Effects of event knowledge in processing verbal arguments. *Journal of Memory and Language, 63*(4), 489-505.

Bornkessel, I. & Schlesewsky, M. (2006). The extended argument dependency model: A neurocognitive approach to sentence comprehension across languages. *Psychological Review, 133*(4), 787-821.

Bransford, J. D., & Johnson, M. K. (1972). Contextual prerequisites for understanding: Some investigations of comprehension and recall1. *Journal of Verbal Learning and Verbal Behavior, 11*(6), 717-726.

Brysbaert, M., & New, B. (2009). Moving beyond Kučera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior Research Methods, 41*(4), 977-990.

Camblin, C. C., Gordon, P. C., & Swaab, T. Y. (2007). The interplay of discourse congruence and lexical association during sentence processing: Evidence from ERPs and eye tracking. *Journal of Memory and Language, 56*, 103-128.

Chwilla, D. J., & Kolk, H. H. J. (2005). Accessing world knowledge: Evidence from N400 and reaction time priming. *Cognitive Brain Research, 25*(3), 589-606.

Cunningham, A. E., & Stanovich, K. E. (1990). Assessing print expsoure and orthographic processing skill in children: A quick measure of reading experience. *Journal of Educational Psychology, 82*, 733-740.

DeLong, K. A., Urbach, T. P., & Kutas, M. (2005). Probabilistic word pre-activation during language comprehension inferred from electrical brain activity. *Nature Neuroscience, 8*(8), 1117-1121.

Ditman, T., Holcomb, P. J., & Kuperberg, G. R. (2007). The contributions of lexico-semantic and discourse information to the resolution of ambiguous categorical anaphors. *Language and Cognitive Processes, 22*(6), 793-827.

Elman, J. L. (2009). On the meaning of words and dinosaur bones: Lexical knowledge without a lexicon. *Cognitive Science, 33*, 1-36.

Federmeier, K. D., & Kutas, M. (1999). A rose by any other name: Long-term memory structure and sentence processing. *Journal of Memory and Language, 41*(4), 469-495.

Ferretti, T. R., Kutas, M., & McRae, K. (2007). Verb Aspect and the Activation of Event Knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*(1), 182-196.

Frazier, L. (1978). *On comprehending sentences: Syntactic parsing strategies.* Unpublished PhD, University of Connecticut.

Frazier, L. (1990). Parsing modifiers: Special purpose routines in the human sentence processing mechanism? In D. A. Balota & G. B. Flores D'Arcais (Eds.), *Comprehension processes in reading* (pp. 303-330). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Frazier, L. (1995). Constraint satisfaction as a theory of sentence processing. *Journal of Psycholinguistic Research Special Issue: Sentence processing: I, 24*(6), 437-468.

Frazier, L., & Rayner, K. (1982). Making and correcting errors during sentence comprehension: Eye movements in the analysis of structurally ambiguous sentences. *Cognitive Psychology, 14*(2), 178-210.

Friederici, A. D., Hahne, A., & Mecklinger, A. (1996). Temporal structure of syntactic parsing: Early and late event-related brain potential effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*(5), 1219-1248.

Galambos, J. A. (1982). Normative studies of six characteristics of our knowledge of common activities. *Cognitive Science Tech. Rep. 14*, Yale University.

Graesser, A. C., Singer, M., & Trabasso, T. (1994) Constructing inferences during narrative text comprehension. *Psychological Review, 101*(3), 371-395.

Greenhouse, S. W., & Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika, 24*, 95-112.

Hagoort, P., Hald, L., Bastiaansen, M., & Petersson, K. M. (2004). Integration of word meaning and world knowledge in language comprehension. *Science, 304*(5669), 438-438.

Hald, L. A., Steenbeek-Planting, E. G., & Hagoort, P. (2007). The interaction of discourse context and world knowledge in online sentence comprehension. Evidence from the N400. *Brain Research, 1146*, 210-218.

Hare, M., Elman, J. L., Tabaczynski, T., & McRae, K. (2009). The wind chilled the spectators but the wine just chilled: Sense, structure, and sentence comprehension. *Cognitive Science, 33*, 610-828.

Hare, M., Jones, M., Thomson, C., Kelly, S., & McRae, K. (2009). Activating event knowledge. *Cognition, 111*(2), 151-167.

Kamide, Y., Altmann, G. T. M., & Haywood, S. L. (2003). The time-course of prediction in incremental sentence processing: Evidence from anticipatory eye movements. *Journal of Memory and Language, 49*(1), 133-156.

Kintsch, W. & Mross, E. F. (1985). Context effects in word recognition. *Journal of Memory and Language*, *24*, 336-349.

Kleiman, G. M. (1980). Sentence frame contexts and lexical decisions: Sentence-acceptability and word-relatedness effects. *Memory & Cognition*.

Kukona, A., Fang, S-Y., Aicher, K. A., Chen, H., & Magnuson, J. S. (2011). The time course of anticipatory constraint integration. *Cognition, 119*, 23-42.

Kuperberg, G. R. (2007). Neural mechanisms of language comprehension: Challenges to syntax. *Brain Research, 1146*, 23-49.

Kuperberg, G. R., Caplan, D., Sitnikova, T., Eddy, M., & Holcomb, P. J. (2006). Neural correlates of processing syntactic, semantic, and thematic relationships in sentences. *Language and Cognitive Processes, 21*(5), 489-530.

Kutas, M. (1993). In the company of other words: Electrophysiological evidence for single-word and sentence context effects. *Language and Cognitive Processes, 8*(4), 533-572.

Kutas, M. & Federmeier, K. D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Sciences, 4*(12), 463-470.

Kutas, M. & Federmeier, K. D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology, 62*, 621-647.

Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207*, 203-205.

Kutas, M., & Hillyard, S. A. (1984). Brain potentials during reading reflect word expectancy and semantic association. *Nature, 307*, 161-163.

Kutas, M., Lindamood, T. E., & Hillyard, S. A. (1984). Word expectancy and event-related brain potentials during sentence processing. In S. Kornblum & J. Requin (Eds.), *Preparatory States and Processes* (pp. 217-237). Hillsdale, NJ: Erlbaum.

Landauer, T. K., Foltz, P. W., & Laham, D. (1998). Introduction to Latent Semantic Analysis. *Discourse Processes, 25*, 259-284.

Madden, C. J., & Zwaan, R. A. (2003). How does verb aspect constrain event representations? *Memory & Cognition, 31*(5), 663-663.

Matsuki, K., Chow, T., Hare, M., Elman, J. L., Scheepers, C., & McRae, K. (2011). Event-based plausibility immediately influences on-line language comprehension. *Journal of Experimental Psychology: Learning, Memory and Cognition, 37*, 913-934.

McKoon, G. & Ratcliff, R. (1992). Inference during reading. *Psychological Review, 99*(3), 440-466.

McRae, K., Hare, M., Elman, J. L., & Ferretti, T. R. (2005). A basis for generating expectancies for verbs from nouns. *Memory and Cognition, 33*, 1174-1184.

McRae, K., Spivey-Knowlton, M. J., & Tanenhaus, M. K. (1998). Modeling the influence of thematic fit (and other constraints) in on-line sentence comprehension. *Journal of Memory & Language, 38*(3), 283-312.

Nelson, D. L., McEvoy, C. L., & Schreiber, T. A. (2004). The University of South Florida free association, rhyme, and word fragment norms. *Behavior Research Methods, Instruments, & Computers, 36*(3), 402-402.

Nieuwland, M. S., & Van Berkum, J. J. A. (2005). Testing the limits of the semantic illusion phenomenon: ERPs reveal temporary semantic change deafness in discourse comprehension. *Cognitive Brain Research, 24*, 691-701.

Nieuwland, M. S. & Van Berkum, J. J. A. (2006). When peanuts fall in love: N400 evidence for the power of discourse. *Journal of Cognitive Neuroscience, 18*(7), 1098-1111.

Osterhout, L. & Holcomb, P. J. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language, 31*(6), 785-806.

Otten, M., & Van Berkum, J. J. A. (2007). What makes a discourse constraining? Comparing the effects of discourse message and scenario fit on the discourse-dependent N400 effect. *Brain Research, 1153*, 166-177.

Rayner, K., Carlson, M., & Frazier, L. (1983). The interaction of syntax and semantics during sentence processing: Eye movements in the analysis of semantically biased sentences. *Journal of Verbal Learning & Verbal Behavior, 22*(3), 358-374.

Sanford, A. J., & Garrod, S. C. (1981). *Understanding Written Language: Explorations of Comprehension Beyond the Sentence*. Chichester, UK: John Wiley & Sons, Ltd.

Sanford, A. J., & Garrod, S. C. (1998). The role of scenario mapping in text comprehension. *Discourse Processes, 26*(2), 159-190.

Sanford, A. J., Leuthold, H., Bohan, J., & Sanford, A. J. S. (2010). Anomalies at the borderline of awareness: An ERP study. *Journal of Cognitive Neuroscience, 23*(3), 514-523.

Schank, R. C. (1980). Language and memory. *Cognitive Science, 4*(3), 243-284.

Schwanenflugel, P. J., & LaCount, K. L. (1988). Semantic relatedness and the scope of facilitation for upcoming words in sentences. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14*(2), 344-354.

Seifert, C. M., McKoon, G., Abelson, R. P., & Ratcliff, R. (1986). Memory connections between thematically similar episodes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12*, 220-231.

Stanovich, K. E., & Cunningham, A. E. (1992). Studying the consequences of literacy within a literate society: The cognitive correlates of print exposure. *Memory and Cognition, 20*, 51-68.

Traxler, M. J., Foss, D. J., Seely, R. E., Kaup, B., & Morris, R. K. (2000). Priming in sentence processing: Intralexical spreading activation, schemas, and situation models. *Journal of Psycholinguistic Research, 29*(6), 581-595.

van Dijk, T. A., & Kintsch, W. (1983). *Strategies in Discourse Comprehension*. New York, NJ: Academic Press.

Zwaan, R. A., & Radvansky, G. A. (1998). Situation models in language comprehension and memory. *Psychological Bulletin, 123*, 162-185.

CHAPTER 3:

Hemispheric Asymmetry in Event Knowledge Activation During Incremental Language

Comprehension: A Visual Half-Field ERP Study

Introduction

Language often describes scenarios or events. Comprehending such language entails mapping between linguistic input and knowledge stored in semantic memory of the type of event described, such as the typical event location, entities and actions involved, and temporal and causal relations. Research suggests that event knowledge supports incremental (i.e., word-by-word) language comprehension, including linguistic expectancy generation (Altmann & Mirković, 2009; Elman, 2009; McRae & Matsuki, 2009). Additionally, event knowledge activation can extend beyond those elements expected to appear in the unfolding sentence to include elements that constitute semantic anomalies in sentence context (Metusalem et al., 2012). Given this complex interplay between linguistic input and event knowledge, specifying the neural basis of event knowledge activation during incremental comprehension is an important goal. The present study advances this goal by investigating asymmetries across the cerebral hemispheres in the activation of semantic information that is related to a described event but is semantically anomalous in sentence context. While understanding the neural basis of event knowledge activation is important in its own right, the utility of this investigation extends further; against the backdrop of previous research suggesting systematic functional asymmetries across the hemispheres in the activation of semantic information triggered by linguistic input, this investigation informs our understanding of the functional properties of event knowledge activation more generally. The present study thus examines event knowledge activation with respect to both its neural basis and functional profile.

Activating Event Knowledge During Incremental Comprehension

Sentence and discourse comprehension can be characterized as construction of a mental representation of the described scenario or event, often called a mental or situation model (Johnson-Laird, 1983; Van Dijk & Kintsch, 1983; Zwaan & Radvansky, 1998). Constructing such representations crucially involves integrating linguistic input with general knowledge stored in semantic memory of the type of event described, and comprehenders deploy this knowledge to guide comprehension as a sentence unfolds word-by-word (Altmann & Mirković, 2009; Elman, 2009; McRae & Matsuki, 2009). For example, the influence of event knowledge on the processing of post-verbal patient nouns has been demonstrated in reading times (Bicknell, Elman, Hare, McRae, & Kutas, 2010; Matuski et al., 2011), anticipatory looking behavior in the Visual World Paradigm (Borovsky, Elman, & Fernald, 2012; Kamide, Altmann, & Haywood, 2003; Kukona, Fang, Aicher, Chen, & Magnuson, 2011) and event-related brain potentials (ERPs; Bicknell et al., 2010). Bicknell et al.'s participants read sentences such as *The mechanic checked the brakes* or *The journalist checked the brakes*, in which the critical patient noun *brakes* is congruent with knowledge of what a mechanic might check, but is incongruent with knowledge of what a journalist might check. They found that the congruence of the patient noun with the event implied by the combination of the preceding agent and verb influenced the amplitude of the N400 ERP component. The N400 is a negative-going deflection in the ERP waveform peaking around 400ms after the onset of a word or other potentially meaningful stimulus, and its amplitude is inversely related to the degree to which the stimulus aligns with or is expected in its context (Kutas & Hillyard, 1980, 1984; see Kutas and Federmeier, 2000, 2011 for

review) – the greater the semantic fit between a word and its context, the smaller the N400 (assuming other factors are held constant). Bicknell et al. found that N400 amplitude was smaller for congruent relative to incongruent patient nouns, indicating that the brain's response to these words was affected by the fit between the word and the event implied by the preceding sentential context within several hundred milliseconds of word onset.

Additional sentence comprehension research has suggested that event knowledge influences the processing of syntactic structures (Hare, Elman, Tabaczynski, & McRae, 2009; McRae, Spivey-Knowlton, & Tanenhaus, 1998) and that grammatical cues such as verb aspect serve to differentially activate event knowledge (Ferretti, Kutas, & McRae, 2007). Outside of sentence comprehension research, lexical priming studies have shown that processing of isolated words activates knowledge of events with which those words are associated (Chwilla & Kolk, 2005; Hare, Jones, Thomson, Kelly, & McRae, 2009; McRae, Hare, Elman, & Ferretti, 2005), suggesting that activating event knowledge is a central component of the brain's response to individual words as well as sentences.

Noting the centrality of event knowledge to incremental comprehension, Altmann and Mirković (2009) assert that comprehension fundamentally entails mapping between sentence and event structures in the service of predicting how the language (and described event) will unfold in time. This notion highlights an interesting question with respect to event knowledge activation during incremental comprehension. Many concepts might relate to the type of event being described, but at a specific point in a sentence, only some (or none) of these will be expected to appear in the immediately upcoming linguistic input. Is real-time event knowledge activation limited to only these elements?

Metusalem et al. (2012) investigated this question in an ERP experiment in which participants read three-sentence discourses describing typical events. The third sentence always presented a sentence-medial word that was either strongly expected (Expected), related to the described event but semantically anomalous in sentence context (Event-Related), or unrelated to the described event and semantically anomalous in sentence context (Event-Unrelated; e.g., *A huge blizzard swept through town last night. My kids ended up getting the day off from school. They spent the whole day outside building a big* [*snowman* / *jacket* / *towel*] *in the front yard.*) They found a three-way split in amplitude of the N400, with Expected targets eliciting the smallest N400, Event-Unrelated targets eliciting the largest N400, and Event-Related targets eliciting an intermediate N400. This finding has been replicated (Amsel, DeLong, & Kutas, 2015; see Huettig, in press). Metusalem et al. interpreted N400 reduction for the Event-Related targets as indicating that at any point in a particular sentence the real-time activation of event knowledge is extends beyond those words that are expected to appear to include words that are semantically anomalous in sentence context.

During incremental comprehension, how does the brain activate contextually anomalous but event-related information? The present study addresses this question by investigating if and how the cerebral hemispheres differ with respect to this process. As will now be reviewed, the cerebral hemispheres appear to exhibit functional asymmetries in the activation of semantic information during language comprehension. In the context of this research, the present study additionally advances our understanding the functional properties of event knowledge activation.

Hemispheric Asymmetries In Language Comprehension

Hemispheric asymmetries in language have been appreciated since the early discoveries by Broca (1861) and Wernicke (1874) of profound language deficits following lesion to only the left hemisphere. Much subsequent research has been based on a view of the left hemisphere as the dominant hemisphere for language, although modern functional imaging has made clear that language processing is supported by a complex bilateral brain network (Gernsbacher & Kaschak, 2003; Grodzinsky & Friederici, 2006; Hickok & Poeppel, 2007; Price, 2012). Within this network, the left and right hemispheres exhibit systematic functional asymmetries in semantic processing during sentence and discourse comprehension.

Processing of a word in sentence context is highly sensitive to the message, or propositional content, of the sentence or discourse. Early work suggested that only the left hemisphere is sensitive to message-level semantic cues in the processing words in sentences and discourse (e.g., Faust, Kravetz, & Babkoff, 1993; see Faust (1998) for review), though this view was soon revised to include a degree of sensitivity to message-level cues by the right hemisphere (Chiarello, Liu, & Faust, 2001). ERP studies have made clear that the both hemispheres are sensitive to message-level cues, but in different ways (Coulson, Federmeier, Van Petten, & Kutas, 2005; Federmeier & Kutas, 1999b; Federmeier, Mai, & Kutas, 2005; Wlotko & Federmeier, 2007, 2013). ERP studies on hemispheric asymmetries in the semantic processing of words in sentence and discourse contexts typically focus on the N400 component and utilize visual half-field presentation of critical words. Visual half-field methods lateralize presentation of a target stimulus to either the right or left visual field. Only the hemisphere contralateral to the visual field of

presentation receives direct sensory input, and processing proceeds unilaterally through area V2; the ipsilateral hemisphere receives information only via subsequent callosal transfer, which is delayed and can result in loss of information fidelity (see discussion by Banich, 2003). Visual half-field presentation thus provides a processing advantage to the contralateral hemisphere, and observation of differing responses to the same stimulus when presented to the left versus right visual fields can support inferences regarding hemispheric asymmetries in processing.[10] Visual half-field presentation methods have been used to great effect in both behavioral and ERP studies of hemispheric asymmetries in language processing (see Chiarello, 1988, Federmeier, 2007, and Federmeier, Wlotko, and Meyer, 2008, for reviews).

Federmeier and Kutas (1999a,b) found evidence that the hemispheres differ in their use of message-level cues to pre-activate semantic features of likely upcoming words. In an experiment utilizing central presentation of target words (1999a), they demonstrated that unexpected words from the same semantic category as an expected word (within-category violations) elicit a reduced N400 relative to an equally unexpected word that does not belong to the same category as the expected word (between-category violations; e.g. smaller N400 to *pines* than *roses* following *They wanted to make the hotel look more like a tropical resort, so along the driveway they planted rows of…*, where *palms* is expected). They showed that N400 reduction for within-category violations was

---

[10] It is important to note that due to interhemispheric communication in the healthy adult brain, studies using visual half-field presentation methods cannot support strong inferences that attribute a process exclusively to one hemisphere. Visual half-field methods provide a processing advantage to the contralateral hemisphere but do not rule out involvement of the ipsilateral hemisphere. No claims in this paper regarding visual half-field studies are meant to imply that a cognitive process is carried out exclusively in one hemisphere or the other, but only that one hemisphere appears to play a greater or more central role than the other hemisphere in that process.

larger for more highly constraining contexts, suggesting that when strong message-level cues are available, the brain more strongly pre-activates semantic features of likely upcoming input. Under this view, N400 amplitude then captures the degree to which the presented word matches the pre-activated semantic features. In a visual half-field version of the experiment (1999b), they found that right visual field/left hemisphere (RVF/LH) presentation of target words led to the same pattern as with central presentation: the smallest N400 for expected words, largest for between-category violations, and intermediate for within-category violations. With left visual field/right hemisphere (LVF/RH) presentation, they observed a two-way split in N400 amplitudes, with expected words eliciting a smaller N400 than both within- and between-category violations, which patterned together. The authors argued that left hemisphere processing appears to apply message-level context in top-down fashion to pre-activate semantic features of likely upcoming input.

The notion of the left hemisphere making greater top-down use of message-level context has been bolstered by several additional findings. The N400 elicited by an expected word is reduced by the presence of lexical associates in the preceding sentence context only for LVF/RH presentation, indicating that the left hemisphere more strongly weights message-level context over lexical associations than does the right hemisphere (Coulson et al., 2005). In addition, expected words elicit larger amplitude P2 ERP components in strongly constraining versus weakly constraining contexts with RVF/LH but not LVF/RH presentation, suggesting that left hemisphere processing utilizes message-level context to generate high-level perceptual predictions for upcoming words (Federmeier et al., 2005). Finally, N400 reduction for expected relative to unexpected

words in weakly constraining contexts is greater for RVF/LH than LVF/RH presentation, suggesting that left hemisphere processing supports a boost to the activation level of expected words when message-level constraint is present but weak (Wlotko & Federmeier, 2007, 2013).

Right hemisphere processing of words in sentence and discourse contexts is affected by message-level cues, as well (Federmeier, Wlotko, & Meyer, 2008). Expected words generally elicit smaller N400s than unexpected words with LVF/RH presentation, just as with RVF/LH presentation (Coulson et al., 2005; Federmeier & Kutas, 1999b; Wlotko & Federmeier, 2007, 2013). Expected words elicit smaller N400s in strongly constraining than in weakly constraining contexts with LVF/RH presentation, even when the effect of lexical association is controlled (Federmeier et al., 2005). The question then is not whether, but in what way, the right hemisphere is sensitive to message-level contextual cues during processing.

Research suggests that the right hemisphere processes message-level context in support of high-level discourse comprehension functions (Johns, Tooley, & Traxler, 2008). The right hemisphere seems to support establishing coherence across multiple sentences (Hough, 1990; Robertson et al., 2000; Schneiderman, Murasugi, & Saddy, 1992; St. George, Kutas, Martinez, & Sereno, 1999; Wapner, Hamby, & Gardener, 1981). For example, behavior of right hemisphere damaged patients (Hough, 1990; Schneiderman et al., 1992) and functional imaging of healthy individuals (St. George et al., 1999) suggest that the right hemisphere uses information regarding the discourse topic or theme to integrate information across multiple sentences. Furthermore, the right hemisphere has been shown to support comprehension of numerous forms of nonliteral

language, including novel metaphors (Cardillo et al., 2012; Mashal & Faust, 2009;

Mashal, Faust, Hendler, & Jung-Beeman, 2007), indirect requests (Foldi, 1987), irony

(Eviatar & Just, 2008), sarcasm (Giora et al., 2000; Shamay-Tsoory, Tomer, & Aharon-

Peretz, 2005), and humor (Brownell, Michel, Powelson, & Gardner, 1983; Coulson &

Williams, 2005; Coulson & Wu, 2005; Gardner, Ling, Flamm, & Silverman, 1975).

Interestingly, the right hemisphere seems to support the literal interpretation of idiomatic

expressions, as well (Mashal, Faust, Hendler, & Jung-Beeman, 2008), suggesting that the

right hemisphere does not simply support nonliteral interpretations, but the maintenance

of alternative or subordinate meanings of ambiguous input. Indeed, numerous priming

studies indicate a role for the right hemisphere in maintaining multiple or alternative

interpretations of ambiguous input (Atchley, Keeney, & Burgess, 1999; Burgess &

Simpson, 1988; Faust & Chiarello, 1998).

The right hemisphere also appears to play an important role in inference (Beeman,

1993; Brownell, Potter, & Bihrle, 1986; Beeman, Bowden, & Gernsbacher, 2000; Mason

& Just, 2004; Virtue et al., 2006). A distinction is often made between bridging or

coherence inferences, which are required to maintain discourse coherence across

sentences, and elaborative or predictive inferences, which can be generated to enrich the

discourse representation but are not required to maintain coherence.[11] Beeman et al.'s

(2000) participants performed a cross-modal naming task as they listened to stories that

promoted an inference corresponding to a target word presented to either the right or left

---

[11] "Predictive inference" refers to inferences about unmentioned but likely upcoming events or consequences of previously stated events, and should not be confused with "prediction" as referring to the anticipation of upcoming linguistic input. Predictive inference can be thought of as a subtype of elaborative inference, and to avoid confusion, the remainder of this paper will use the term "elaborative inference", including with reference to Beeman et al. (2000), who specifically tested predictive inference.

visual field. For example, one story described a space shuttle launch but never mentioned the launch itself, and *launch* was the target word. At early points in the story, the target word probed an elaborative inference (e.g. *The shuttle sat on the ground in the distance, waiting for the signal to be given*), and at later points in the story probed a coherence inference (*After a huge roar and a bright flash, the shuttle disappeared into space*). They found that targets probing elaborative inferences were primed only with LVF/RH presentation, and that targets probing coherence inferences were primed only with RVF/LH presentation. This finding indicates that the right hemisphere may be responsible for maintaining activation of unstated information that is not necessary to maintain discourse coherence, but nevertheless enriches the discourse representation.

In sum, the cerebral hemispheres exhibit functional asymmetries in the processing of message-level context. The left hemisphere appears to make top-down use of message-level cues in order to pre-activate semantic features of likely upcoming input. The right hemisphere, on the other hand, appears to use message-level context to activate a wide array of conceptual information in the service of higher-level comprehension functions, such as elaborative inference generation. With these functional asymmetries in mind, we now turn to the present study.

The Present Study

During incremental comprehension, event knowledge elements can be activated even at points in a sentence in which they are unexpected and constitute semantic anomalies (Metusalem et al., 2012). With the goal of better understanding how the brain activates event knowledge during incremental comprehension, the present study

investigates if and how the cerebral hemispheres differ with respect to this process. We utilize the stimuli from Metusalem et al. (2012) in conjunction with the visual half-field ERP methodology described above. Analyses focus on the amplitude of the N400 elicited by the Expected, Event-Related, and Event-Unrelated anomalous target words, presented to either the right or left visual field.

With the left hemisphere appearing to engage in the pre-activation of semantic features of likely upcoming input, and with event knowledge being a crucial component of linguistic expectancy generation, it is possible that the left hemisphere processes are crucial to Metusalem et al.'s findings. However, the Event-Related and Event-Unrelated targets in that study were semantically anomalous in sentence context, making it unlikely that they would be activated by a left hemisphere mechanism that makes top-down use of context cues to guide expectancy generation. Perhaps then it is likely that right hemisphere processes underlie the activation of contextually anomalous but event-related information. This hypothesis would align with the notion of the right hemisphere as using message-level context not for expectancy generation, but rather for higher-level discourse functions such as elaborative inference generation. We therefore predicted that with LVF/RH but not RVF/LH presentation of Metusalem et al.'s target words, we will observe reduction in N400 amplitude for Event-Related relative to Event-Unrelated targets. Such a finding not only would contribute to our knowledge of the neural basis of event knowledge activation, specifically in terms of hemispheric asymmetries, but also would be consistent with an underlying functional distinction in the activation of event knowledge for generation of linguistic expectancies and of elaborative inferences.

Methods

Participants

Sixty-one undergraduates (25 male, 23 female; mean age: 21.5 years, age range: 18-33 years) at the University of California, San Diego, participated for course credit. All were native English speakers with normal or corrected-to-normal vision. All were right handed, and none reported any left handed immediate family members. None reported any cognitive or neurological deficits. Thirteen participants' data were excluded due to excessive EEG artifacts, resulting in 48 participants' data being included in the analysis. This relatively large number of participants was run due to the relatively small number of items per condition available for the experiment (see *Stimuli*).

Stimuli

Participants read the 72 three-sentence discourses from Metusalem et al. (2012). The first two sentences of each item established the event context. The third and final sentence presented one of three types of target word: highly expected (Expected), related to the described event but semantically anomalous in sentence context (Event-Related), or unrelated to the described event and semantically anomalous in sentence context (Event-Unrelated). All target words appeared in sentence-medial position. Stimulus generation began with creation of three-sentence discourses in which the third sentence was deemed to create a strong expectation for a specific word to appear. Expected target words were then obtained via a cloze task. Thirty UCSD undergraduates read each discourse up to the word preceding target position and provided the word they felt was most likely to come next. For each item, cloze probability for a word was calculated as

the proportion of participants that provided that word as a continuation of the discourse, and the word with the highest cloze probability was chosen as the Expected target word. Expected targets had a mean cloze probability of 0.81, indicating that they were strongly expected in context.

The Event-Related targets were obtained via a norming task in which a separate group of 45 UCSD undergraduates read each discourse up to and including the Expected target word and were asked to "paint a mental picture" of the described event. They were then asked to list up to five people or objects they imagined as being present at or involved with the event but were not mentioned in the discourse itself. Each participant's responses for an item were given a weighted score based on order of mention: five points for the first listed response, four points for the second, three points for the third, two points for the fourth, and one point for the fifth. Within each item, scores for a given response were then summed across the 45 participants, yielding a highest possible event-relatedness score of 255 (if all 45 participants provided the same response in first position). The highest scoring response that was both zero-cloze according to the previous cloze task and deemed to be semantically anomalous in sentence context was chosen as the Event-Related target. Event-Related targets had a mean event-relatedness score of 92.36.

After this procedure, the 72 experimental items were split into six different groups of 12 items, allowing six experimental lists to be created by rotating each item group through the six conditions (where a condition is defined at the intersection of target word type and visual field of presentation). To minimize variability across the lists, the rotation groups were matched as closely as possible on the following factors: Expected target

cloze probability, length, orthographic neighborhood size, and log frequency per 51 million words; Event-Related target length, orthographic neighborhood size, log frequency, and event-relatedness norming score. Orthographic neighborhood sizes were taken from the Medical College of Wisconsin Orthographic Wordform Database (http://www.neuro.mcw.edu/mcword/), and word frequencies were taken from the SUBTLEXus corpus (Brysbaert & New, 2009; http://subtlexus.lexique.org/).

After creation of the six rotation groups, Event-Related targets were shuffled across items within each group to obtain the Event-Unrelated targets, thereby matching Event-Related and Event-Unrelated target words on all lexical variables. All Event-Unrelated targets were zero-cloze and had an event-relatedness norming score of zero. Care was taken to match Event-Related and Event-Unrelated targets within each item for degree of contextual anomaly. The full set of experimental items is provided in the Appendix.

The six groups were then rotated through each condition to create six experimental lists containing 12 items per condition. Each item appeared exactly once per list and exactly once in each condition across all lists. Each list also included 24 filler items. All fillers were three sentence discourses describing common events and did not contain any contextually anomalous words. The inclusion of 24 fillers thus brought the total proportion of trials containing anomalous words to 50% for each list. Presentation of experimental and filler items was pseudo-randomized separately for each participant, such that no more than three trials in a row contained anomalous words or target words presented to the same visual field. Each list was seen by eight of the 48 participants included in the analysis.

Procedure

Participants sat in a dimly lit, sound attenuated, electromagnetically shielded chamber as they read the stimuli from a computer monitor. Each trial began with the first two sentences of the discourse presented in paragraph format at the center of the screen. Once the participants read and understood the sentences, they pressed a button to advance to the final sentence. A fixation cross then appeared at screen center, and participants were instructed to fixate the cross without blinking. The final sentence was then presented word-by-word via rapid serial visual presentation (RSVP) with a 500ms stimulus onset asynchrony (SOA) and a 200ms stimulus duration, yielding a 300ms interstimulus interval (ISI). All words except the target flashed one at a time centered immediately above the fixation cross. The target words appeared either to the right or left of central fixation, with 2 degrees visual angle between the inner edge of the word and screen center: For targets presented to the right visual field, two degrees separated the left edge of the word and screen center; for targets presented to the left visual field, two degrees separated the right edge of the word and screen center. In the setup used, participants were seated such that the nasion was 44 inches from the computer monitor, with two degrees of visual angle corresponding to 1.54 inches across the screen. Note that the RSVP parameters used here are different than those from Metusalem et al. (2012), who used a 350ms SOA and 150ms ISI. A slower RSVP rate was used here due to the first author's impression that the rate used by Metusalem et al. (2012) did not allow adequate time for reliable recognition of the laterally presented target words. This aligns with research showing that word recognition is slower for words presented peripheral to the point of fixation (Bouma, 1978; Rayner & Morrison, 1981; Schiepers, 1980).

After offset of the final word, the fixation cross remained on the screen for an additional 1400ms. The comprehension question appeared 1000ms following the offset of the fixation cross and remained on the screen until the participant entered a response with a button press of either the right or left hand. Yes/no response hand was counterbalanced across participants. Following the participant's response, the screen went blank for 1500ms, and then the next trial began.

Before the beginning of the experiment, participants completed 12 practice trials to familiarize themselves with the experimental procedure. These trials followed the same procedure outlined above. After the experiment, each participant completed adaptations of the Author and Magazine Recognition Tests described by Cunningham and Stanovich (1990) and Stanovich and Cunningham (1992). These were administered to form the basis of an analysis of individual differences parallel to that reported by Metusalem et al. (2012). As in Metusalem et al.'s study, performance was scored as the number of correct identifications minus the number of false alarms across both tests.

EEG Recording & Processing

Participants' electroencephalograms were recorded via 26 tin electrodes embedded in an elastic cap. Electrodes were spaced across the scalp in a laterally symmetric quasi-geodesic pattern of equilateral triangles (see Figure 3.1). Additional electrodes were placed over the left and right mastoids, as well as adjacent to the outer canthus and over the infraorbital ridge of each eye to monitor for eye movements and blinks. EEG was referenced online to the left mastoid and re-referenced offline to the

average of the right and left mastoids. All electrode impedences were kept under 5 KΩ. Data was amplified with a band pass 0.01-100 Hz and digitized at 250 Hz.

The raw EEG was screened for artifacts before subsequent averaging and analysis. Target word epochs extended from 100ms pre-stimulus onset to 920ms post-stimulus onset. All epochs containing blinks, eye movements, excessive muscle tension, amplifier blocking, or excessive channel drift were rejected; importantly, any target epochs containing horizontal eye movements, which could have been launched to fixate a laterally presented target word, were rejected. Overall, 7.35% of target epochs were rejected, with the following rejection rates for each condition: Expected, RVF/LH – 8.68%; Expected, LVF/RH – 5.90%; Event-Related, RVF/LH – 9.03%; Event-Related, LVF/RH – 5.03%; Event-Unrelated, RVF/LH – 8.85%; Event-Unrelated, LVF/RH – 6.60%. Following artifact rejection, time-domain average ERPs for each condition were calculated relative to a 100ms pre-stimulus baseline.

Data Analysis

Several statistical analyses were conducted on mean ERP voltage measures in separate time windows. The first was 75-175ms post-stimulus, meant to capture the amplitude of the visual N1 component. Visual N1 amplitude is known to be larger over scalp sites contralateral to the visual field of presentation; N1 amplitude analyses thus allowed us to investigate the effectiveness of lateralized presentation of target words in biasing initial processing to the contralateral hemisphere.

The next analysis window was 200-500ms, corresponding to the N400. This time window keeps with that used by Metusalem et al. (2012) in their analysis of N400

amplitude. All N400 amplitude analyses were conducted on the N400 effects: the mean

amplitude 200-500ms of the Event-Related minus Expected and the Event-Unrelated

minus Expected difference ERPs. Analysis directly comparing the N400 effects for the

Event-Related and Event-Unrelated targets in the two visual fields focused on a subset of

channels that showed the greatest reduction in N400 effect amplitude for Event-Related

versus Event-Unrelated targets in the Metusalem et al.'s Experiment 1. Taking the data

from that experiment, we calculated mean amplitude from 200-500ms of the Event-

Related minus Expected and Event-Unrelated minus Expected difference ERPs as a

measure of the size of N400 effects for the two anomalous conditions. At each of the 26

channels, we subtracted the amplitude of the N400 effect for Event-Related targets from

that for the Event-Unrelated targets. All channels were then rank ordered according to

this N400 amplitude difference, with channels showing more negative values (i.e., greater

reduction of N400 effect for Event-Related relative to Event-Unrelated targets) ranked

higher. The top half of channels were then chosen for analyses of N400 amplitude. The

channels in this subset are underlined in the scalp diagram depicted in Figure 3.1.

Analysis of N400 effect scalp topography was conducted on the same subset of 16

electrodes analyzed in Metusalem et al.'s scalp topography analysis. These electrodes are

colored in on the scalp diagram in Figure 3.1.

Analyses in these time windows were conducted with repeated measures

ANOVAs and t-tests as indicated in *Results*. For F-tests with more than one numerator

degree of freedom, the Greenhouse-Geisser (1959) adjustment to degrees of freedom was

used to correct for possible violations of sphericity. In these instances, reported F-test

results include the uncorrected degrees of freedom, the Greenhouse-Geisser epsilon (ε_{GG}),

and the p-value for the corrected degrees of freedom. For families of follow-up tests

larger than two, Bonferroni corrected alpha values were used to control the family-wise

error rate.

The final time window of analysis was from 500-900ms. Metusalem et al.

observed effects in this time window; specifically, a frontal negativity for Event-

Unrelated targets relative to the other two target types, and a posterior positivity for both

anomalous target types relative to Expected targets, with a seemingly earlier onset for

Event-Unrelated targets. As no specific hypotheses regarding late effects were made for

that study or for the present experiment, exploratory analyses were conducted to assess

the presence of any late effects here. These analyses utilized a mass univariate analysis

technique implemented in MATLAB in the Mass Univariate ERP Toolbox (Groppe,

Urbach, & Kutas, 2011a; http://openwetware.org/wiki/Mass_Univariate_ERP_Toolbox).

Four separate analyses were conducted, one for each difference ERP resulting from

subtraction of the ERPs to Expected targets from ERPs to each of the two anomalous

target types, separately for each visual field. Each analysis consisted of a series of two-

tailed t-tests on difference ERP amplitudes at every channel and time point from 500-

900ms, resulting in 2,626 t-tests per analysis. For example, the analysis for Event-Related

targets with RVF/LH presentation consisted of subtracting ERPs to Expected targets with

RVF/LH presentation from those for Event-Related targets with RVF/LH presentation.

At every channel and time point, a two-tailed single sample t-test with 47 degrees of

freedom was conducted on the amplitude of this difference ERP to detect positive or

negative deviations from zero. False discovery rate was controlled at the 0.05 level (see

below). Statistically significant results in the family of tests were taken to indicate a

reliable difference in ERP amplitude between the Event-Related and Expected targets for RVF/LH presentation.

To protect against a large proportion of Type I errors in these test families, an adaptive two-stage false discovery rate (FDR) control introduced by Benjamini, Krieger, and Yekutieli (2006) was employed to determine statistically significant deviations from zero while controlling FDR at the 0.05 level. While this FDR control procedure is guaranteed to work only when tests are independent, simulations have suggested that accurate FDR control is achieved even when tests are correlated (Groppe, Urbach, & Kutas, 2011b). This analysis method was chosen because it allows for exploring differences between conditions in the absence of a priori hypotheses regarding the direction, timing, or scalp distribution of differences, and because it achieves a desirable balance between statistical power and Type I error rate control.

Results

Comprehension Question Accuracy

Before analysis of ERP data, each participant's comprehension question accuracy on target trials was assessed to determine if the participant understood the target discourses. Across the 48 participants, mean percent of comprehension questions answered correctly was 96% (range: 85% to 100%); only two participants scored below 90% accuracy. Errors did not vary systematically by condition. Comprehension question accuracy was deemed acceptable for all participants, and no data were excluded based on comprehension question performance.

N1 Amplitude

Figure 3.1 shows the ERPs for the three target types at all 26 channels, separately for left and right visual field presentation. For all targets in both visual fields, the N1 can be seen as a negative-going wave peaking around 150ms post-stimulus onset. The N1 appears largest over posterior sites over the hemisphere contralateral to the visual field of presentation, a pattern commonly found with lateralized presentation of visual stimuli. Analysis of N1 amplitude confirmed this pattern. Mean ERP amplitude from 75-175ms was entered into a Target (Expected vs. Event-Related vs. Event-Unrelated) x Visual Field (RVF/LH vs. LVF/RH) x Hemisphere (right vs. left hemisphere channels) x Channel (11 non-midline channels within each hemisphere) ANOVA. A statistically significant Visual Field x Hemisphere interaction ($F(1,47)=48.30$, $p<0.0001$) revealed that with RVF/LH presentation, N1 amplitude was larger at left than right hemisphere channels (-1.30 μV vs. -0.63 μV; $t(47)=-4.41$, $p<0.0001$), whereas with LVF/RH presentation, N1 amplitude was larger at right than left hemisphere channels (-1.20 μV vs. -0.62 μV; $t(47)=-4.05$, $p<0.001$). Analysis also revealed a Visual Field x Hemisphere x Channel interaction ($F(10,470)=16.19$, $\varepsilon_{GG}=0.1928$, $p<0.0001$), indicating that the Visual Field x Hemisphere interaction varied across the scalp. There was no main effect of or interactions involving Target (all $p>0.17$). In sum, N1 amplitude was larger at channels over the hemisphere contralateral to the visual field of presentation, providing evidence that lateralized presentation of target words was effective in biasing visual processing to the hemisphere contralateral to the visual field of presentation.

N400 Effect Amplitude

In the canonical time window and centro-parietal scalp region of the N400, Expected targets elicited more positive ERPs than the Event-Related and Event-Unrelated targets for both RVF/LH and LVF/RH presentation (Figure 3.1). Differences between the visual fields become apparent when comparing the Event-Related and Event-Unrelated target ERPs. With RVF/LH presentation, ERPs at centro-parietal channels appear to be of very similar amplitude for both anomalous target types in the 200-500ms analysis window. With LVF/RH presentation, however, the ERPs in this time window are more negative for Event-Unrelated targets than for Event-Related targets. Figure 3.2 shows close-ups of ERPs at the midline parietal electrode, where this difference between visual fields can be seen clearly. This pattern of results aligns with the prediction that the N400 effect for Event-Related targets would be reduced relative to that for Event-Unrelated targets with LVF/RH but not RVF/LH presentation.

Right Visual Field / Left Hemisphere

Left Visual Field / Right Hemisphere

N400

·········· Event-Unrelated   ------ Event-Related   ——— Expected
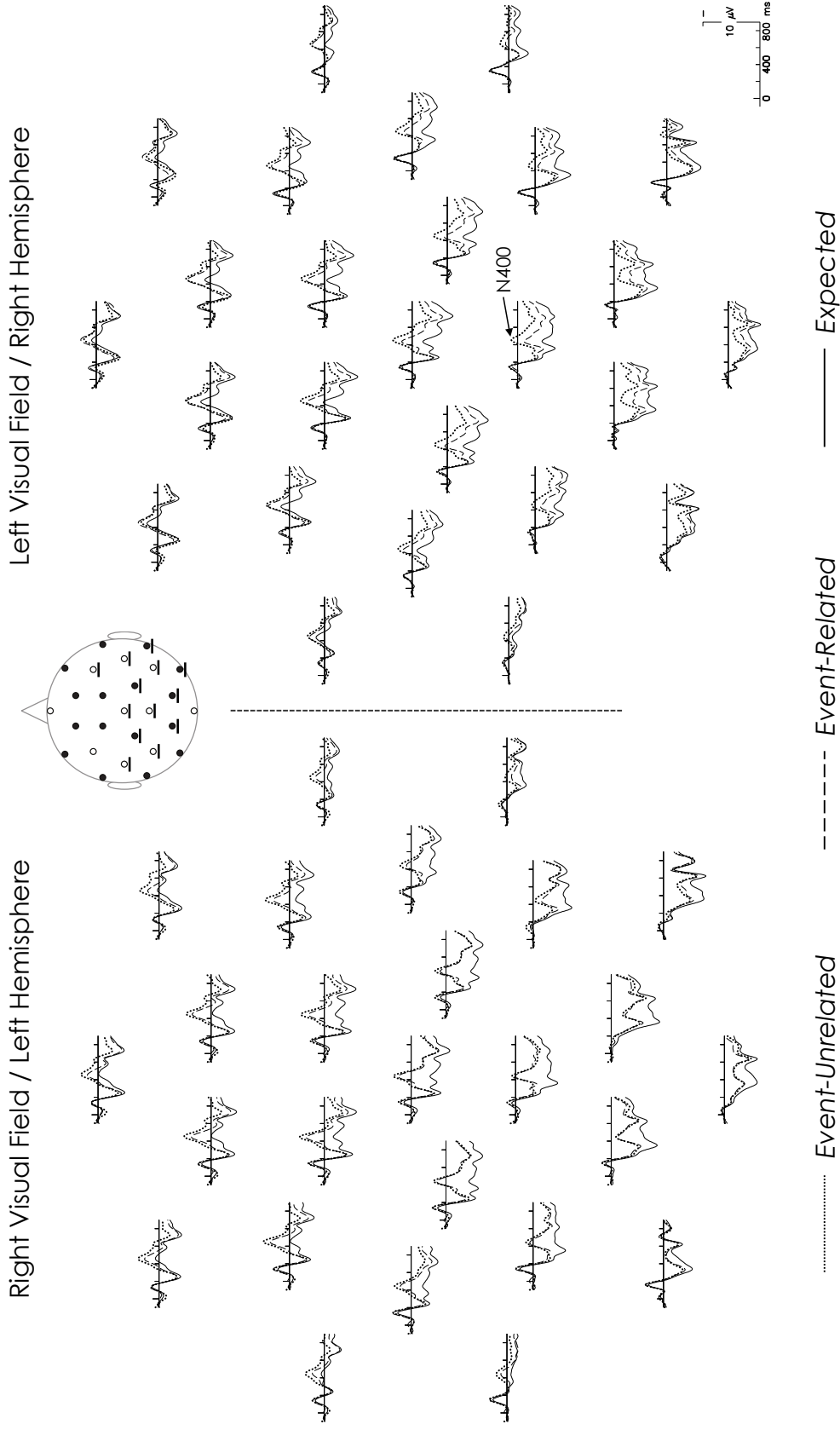
Figure 3.1: Grand average ERPs at the 26 scalp electrodes for the three target word types, for both right visual field / left hemisphere (RVLF/LH) and left visual field / right hemisphere (LVF/RH) presentation. Ticks on the x-axis represent 200 ms intervals. Negative voltage is plotted up. A diagram of scalp electrode placement is provided. Channels included in analysis of N400 effect amplitudes are underlined. Channels included in the analysis of N400 effect scalp distribution are darkened.

N400 effect amplitudes for Event-Related and Event-Unrelated targets were entered into a Difference (Event-Related N400 effect vs. Event-Unrelated N400 effect) x Visual Field x Channel (13 channels in the previously mentioned subset) ANOVA. The analysis did not reveal main effects of Difference ($F(1,47)=3.17$, $p=0.081$) or Visual Field ($F(1,47)=1.39$, $p=0.244$). It did reveal a main effect of Channel ($F(12,564)=9.54$, $\varepsilon_{GG}=0.2754$, $p<0.001$), simply indicating that the size of N400 effects varies across channels, on average across all levels of Visual Field and Difference.
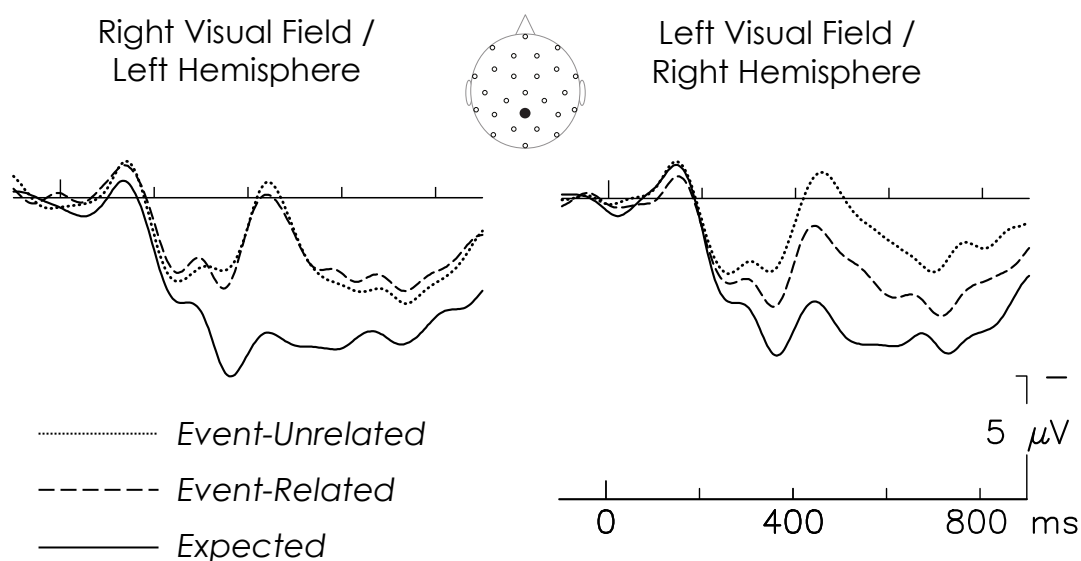
Figure 3.2: Grand average ERPs at the midline parietal electrode for the three target word types, for both RVF/LH and LVF/RH presentation.

Critically, the analysis also revealed a Difference x Visual Field x Channel interaction ($F(12,564)=2.98$, $\varepsilon_{GG}=0.2867$, $p=0.027$), suggesting differences across the visual fields in how the relationship between Event-Related and Event-Unrelated N400 effects varies across the channels. Follow-up Difference x Channel ANOVAs conducted

separately for each Visual Field showed the N400 effect for Event-Related targets to be smaller than that for Event-Unrelated targets only with LVF/RH presentation. Analysis of data obtained with LVF/RH presentation revealed a main effect of Difference ($F(1,47)$=4.66, p=0.036), with the N400 effect for Event-Related targets smaller than that for Event-Unrelated targets (-1.71 µV vs. -2.52 µV). The Difference x Channel interaction did not reach significance ($F(12,564)$=2.12, ε_{GG}=0.2763, p=0.094). In contrast, analysis of data obtained with RVF/LH presentation did not show a main effect of Difference (Event-Related=-2.60 µV; Event-Unrelated=-2.95 µV) or a Difference x Channel interaction (both p>0.25).

The presence of a reduced N400 effect for Event-Related targets relative to Event-Unrelated targets for LVF/RH presentation but not RVF/LH presentation could be driven by changes in N400 effect amplitude across the visual fields for either condition. That is, the N400 effect for Event-Related targets could be reduced with LVF/RH presentation relative to RVF/LH presentation, the N400 effect for Event-Unrelated targets could be increased with LVF/RH presentation relative to RVF/LH presentation, or some combination of both. To investigate this, we conducted Visual Field x Channel ANOVAs separately for Event-Related and Event-Unrelated N400 effects. For the Event-Unrelated N400 effect, analysis did not reveal a main effect of Visual Field or a Visual Field x Channel interaction (both p>0.50). For the Event-Related N400 effect, analysis did not show a main effect of Visual Field but did reveal a Visual Field x Channel interaction ($F(12, 564)$=2.67, ε_{GG}=0.3223, p=0.036). While 12 of the 13 channels in this analysis showed a larger (i.e., more negative) Event-Related N400 effect for RVF/LH than LVF/RH presentation, lower-tailed t-tests comparing RVF/LH presentation to LVF/RH

presentation at each channel did not reveal any statistically significant differences after Bonferroni correction; however, t-tests at five adjacent channels showed p-values of less than 0.05: LMCe (left medial central), RMCe (right medial central), MiPa (midline parietal), LDPa (left dorsal parietal), and LMOc (left medial occipital). No evidence of differences in N400 effect size between visual fields was found for Event-Unrelated targets. This pattern of results suggests that the difference in N400 effect amplitude between Event-Related and Event-Unrelated targets observed for LVF/RH but not RVF/LH presentation was likely driven by a reduction in N400 effect amplitude for Event-Related targets for LVF/RH relative to RVF/LH presentation.

To assess the presence of differences across individuals in the degree of N400 reduction for Event-Related relative to Event-Unrelated targets, participants were divided into two groups based on a median split of performance on the Author and Magazine Recognition Tests (ART/MRT), and analyses of N400 effect amplitude paralleling those above were conducted for each group. Metusalem et al. (2012) found that for central target word presentation, the top half of ART/MRT performers showed evidence of N400 reduction for Event-Related targets, while the bottom half did not, and suggested that perhaps increased print exposure, or possible enrichment of general knowledge resulting from increased print exposure, was related to greater N400 reduction for Event-Related targets. In the present study, the low-scoring group (mean ART/MRT score=12.04, standard deviation=2.74) did not show any main effects or interactions involving Difference or Visual Field (all p>0.10). The high-scoring group (mean ART/MRT score=26.00, standard deviation=6.44) did show a significant Difference x Visual Field x Channel interaction ($F(12, 276)=2.65$, $\varepsilon_{GG}=0.2876$, $p=0.047$). Follow-up Difference x

Channel ANOVAs within each Visual Field for this group did not reveal a significant main effect of Difference or a Difference x Channel interaction for either Visual Field (all p>0.14). Thus, evidence of ARM/MRT-based individual differences in this study is limited to the significant Difference x Visual Field x Channel interaction observed only for the top-scoring ART/MRT group. While Metusalem et al. tentatively argued that the high-scoring ART/MRT group drove N400 reduction for Event-Related targets with central presentation, we do not find conclusive evidence that this is the case with lateralized presentation. Further research is needed to determine if and how individuals differ with respect to activation of contextually anomalous event knowledge elements during incremental comprehension.

N400 Effect Scalp Distribution

As is typical for visually presented words, the N400 effects are broadly distributed, generally peaking over centro-parietal regions of the scalp, with a slight exception for the Event-Related N400 effect from LVF/RH presentation, which appears slightly frontally distributed relative to the others (Figure 3.3). The scalp distribution of N400 effects was analyzed according to the procedure used by Metusalem et al. (2012). N400 effects for the channel subset mentioned in *Methods* above and indicated in the scalp diagram in Figure 3.1 were entered into a Difference x Visual Field x Hemisphere (right vs. left hemisphere channels) x Laterality (medial vs. lateral channels) x Anteriority (prefrontal vs. frontal vs. parietal vs. occipital channels) ANOVA.
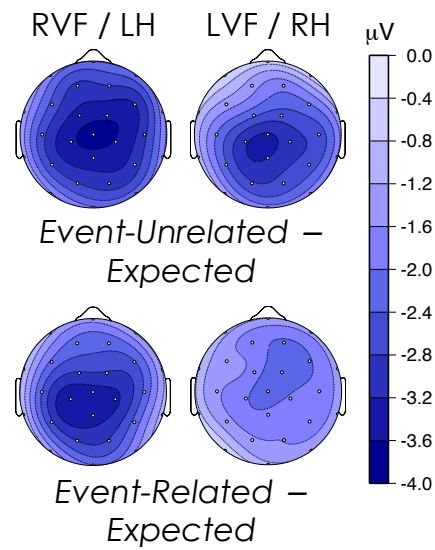
(A) Target Word ERPs
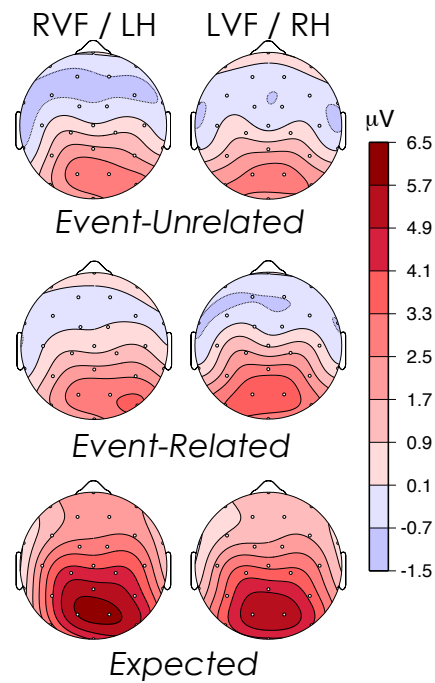
(B) Difference ERPs

Figure 3.3: Scalp topographies of mean ERP amplitude from 200-500ms post-stimulus onset. (A) Topographies for target word ERPs. (B) Topographies for the difference ERPs representing the N400 effects for Event-Related and Event-Unrelated target words.

A main effect of Laterality revealed that N400 effects were larger over medial than lateral sites (-2.58 µV vs. -1.20 µV; F(1,47)=51.26, p<0.0001). A Laterality x Hemisphere interaction (F(1,47)=4.48, p=0.04) indicated that this effect of Laterality varied across the right and left hemisphere channels. Follow-up two-tailed t-tests revealed a drop-off in N400 effect size from medial to lateral channels for both the right (-2.62 µV vs. -1.40; t(47)=-6.31, p<0.0001) and left hemisphere scalp regions (-2.54 µV vs. -1.00 µV; t(-7.03), p<0.0001), though numerically the drop-off is greater in the left hemisphere. Right and left hemisphere channels showed no difference at medial channels (-2.62 µV vs. -2.54 µV; t(47)=-0.82, p=0.42), but did show a trend at lateral channels for larger N400 effects at right than left hemisphere scalp regions that failed to reach significance after Bonferroni correction (-1.40 µV vs. -1.00 µV, t(47)=-2.07, p=0.04). This pattern of effects indicates that N400 effects are larger over medial than lateral sites at both the right and left hemispheres, and suggests a slightly right-lateralized scalp distribution typical of N400 effects to visually presented words.

Analysis also revealed a Laterality x Anteriority interaction (F(3,141)=10.56, ε_{GG}=0.7080, p<0.0001). Twelve two-tailed t-tests were conducted to assess pairwise differences between the levels of Anteriority separately for medial and lateral channels. Lateral channels did not show any differences between levels of Anteriority (all p>0.25). Medial Channels, however, showed that N400 effects were larger at frontal than prefrontal sites (-2.70 µV vs. -2.15 µV, t(47)=-3.49, p=0.001). No other comparisons were statistically significant after Bonferroni correction (all p>0.01). Taken together with the effect of Laterality showing larger N400 effects over medial than lateral sites, this pattern of effects generally indicates that the largest N400 effects are observed medially

over the frontal, temporal/parietal, and occipital sites, which again is typical of N400 effects elicited by visually presented words.

Finally, the analysis revealed a Difference x Visual Field x Anteriority interaction ($F(3,141)=4.38$, $\varepsilon_{GG}= 0.4034$, $p=0.0338$). To follow-up this three-way interaction, separate Difference x Anteriority ANOVAs were conducted for RVF/LH and LVF/RH presentation. No statistically significant main effects or interactions were found for RVF/LH presentation (all $p>0.22$). A Difference x Anteriority interaction was found for LVF/RH presentation ($F(3,141)=4.14$, $\varepsilon_{GG}=0.4060$, $p=0.039$), indicating that scalp topography factors interacted with Difference only for LVF/RH presentation. Twelve two-tailed t-tests were conducted comparing the levels of Anteriority separately within each level of Difference for LVF/RH presentation. No comparisons between levels of Anteriority approached significance for the Event-Related N400 effect (all $p>0.30$). For the Event-Unrelated N400 effect, the difference between frontal and prefrontal sites approached significance after Bonferroni correction, showing larger N400 effect amplitude at frontal than prefrontal sites (-1.71 µV vs. -1.03 µV, $t(47)=-2.86$, $p=0.0063$). No other comparisons approached statistical significance after correction (all $p>0.025$). This pattern of effects suggests that the Difference x Visual Field x Anteriority interaction was driven by a difference in the effect of Anteriority between the Event-Unrelated and Event-Related N400 effects obtained with LVF/RH presentation. Specifically, the Event-Unrelated N400 effect exhibits a strong centro-parietal peak that drops off significantly at more anterior channels, while the Event-Related N400 effect shows a broader and slightly more frontal distribution.

Late Window (600-900ms)

In general, both anomalous conditions in both visual fields appear to elicit sustained negativities relative to the Expected condition from 500-900ms post-stimulus, albeit with variability in amplitude and scalp distribution. With RVF/LH presentation, centro-parietal channels appear to show negativities of similar amplitudes for both anomalous target types. These negativities appear to become smaller at occipital channels, while at frontal and prefrontal channels the negativity for Event-Related targets seemingly fades while that for Event-Unrelated targets remains. With LVF/RH presentation, centro-parietal channels appear to show a three-way split, with both anomalous target types going more negative than Expected targets, and with this relative negativity appearing larger for Event-Unrelated targets. These differences appear to become smaller both at occipital and frontal and prefrontal channels.

The mass univaritate analyses confirmed that both anomalous conditions in both visual fields elicited negativities relative to the Expected targets (Figure 3.4, darkened cells indicate a statistically significant negative deviation from zero after FDR control). In general, the negativity was statistically reliable at more channels and time points for Event-Unrelated than Event-Related targets and for LVF/RH than RVF/LH presentation. For Event-Unrelated targets with LVF/RH presentation, the negativity is reliable at a large majority of time points and channels throughout the 500-900ms window. With RVF/LH presentation, the negativity to Event-Unrelated targets is reliable widely across the scalp from 500ms to ~650ms. After that, the effect ceases to be reliable at temporal and occipital channels, while generally remaining reliable over other scalp regions. Event-Related targets show a negativity from 500-600ms at central and posterior

channels for both visual fields of presentation. LVF/RH presentation also shows the negativity to be reliable at frontal channels in this time window. Unlike the Event-Unrelated targets, the Event-Related targets in both visual fields show little evidence of a negativity at frontal channels after ~650ms, although occasional clusters of significant tests suggest that the negativity to Event-Related targets may be sustained throughout the 500-900ms window, only with a smaller amplitude than the negativity to the Event-Unrelated targets, making it harder to detect statistically.

Perhaps most interestingly, the data show no evidence of a positivity relative to the Expected targets for either anomalous target type in either visual field. This contrasts with Metusalem et al.'s report of a posterior positivity to both anomalous target types, with a seemingly earlier onset for Event-Unrelated targets. Metusalem et al. also reported a frontal negativity to Event-Unrelated targets relative to the other two target types. Analyses here also reveal a negativity to Event-Unrelated targets at frontal sites, although the connection with the frontal negativity observed by Metusalem et al., if any, is unclear.

Analyses in the 500-900ms window thus lead to two conclusions: First, the late positivity observed by Metusalem et al. was not found here. Second, both anomalous target types in both visual fields elicit negativities relative to the Expected condition following the N400 time window, with the negativities being reliable at a greater number of channels and time points for Event-Unrelated targets and for LVF/RH presentation.

RVF / LH   LVF / RH

Event-Unrelated − Expected

Event-Related − Expected
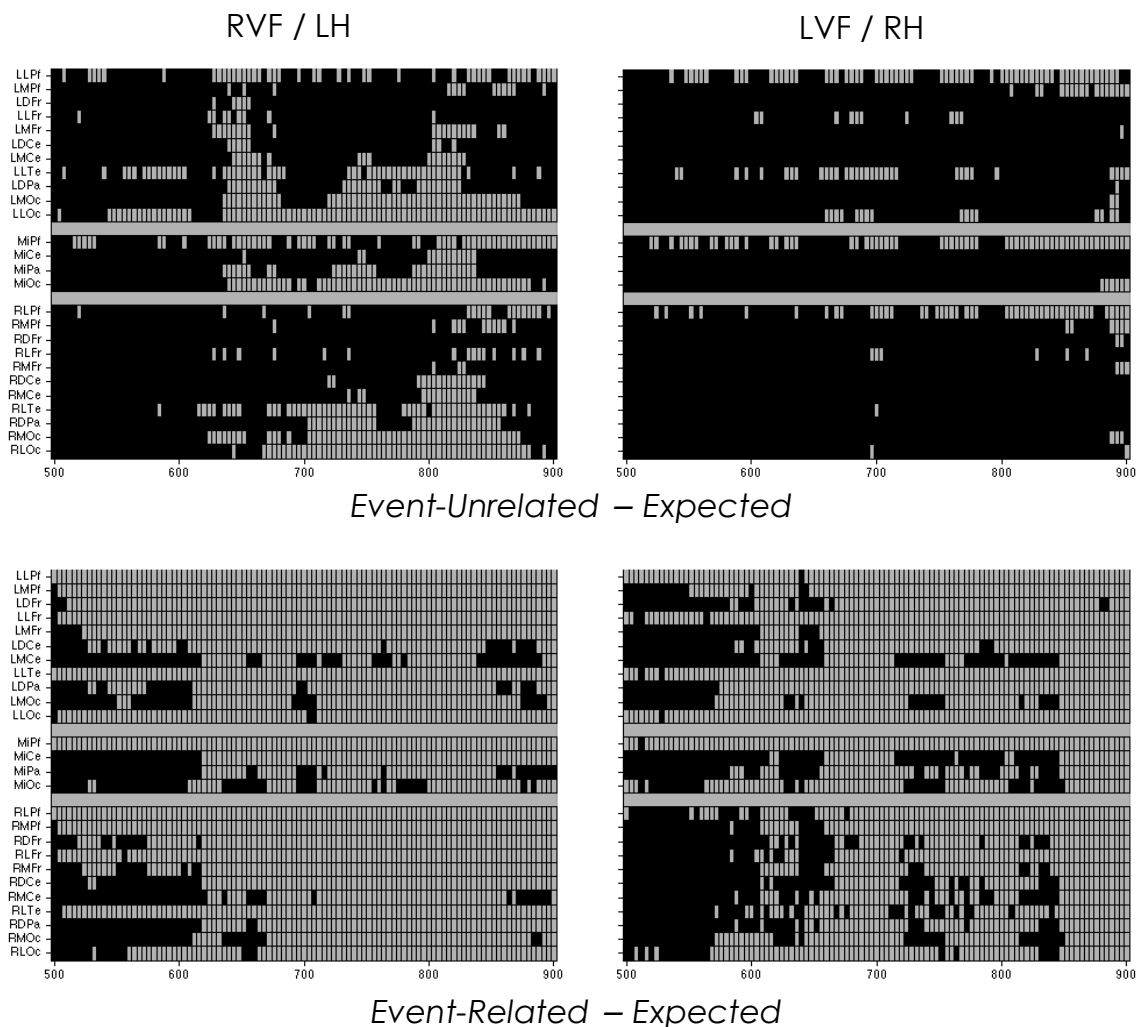
Figure 3.4: Raster plots representing the results of the mass univariate tests conducted in the 500-900ms window. Time is represented on the x-axis with ticks at 100ms intervals. Electrodes are split into three groups along the y-axis: left hemisphere (top group), midline (middle group) and right hemisphere (bottom group). Electrodes in each group are listed in order of anteriority, with prefrontal at group top and occipital at group bottom. Darkened cells indicate a statistically significant negative deviation from zero in the indicated difference ERP, after FDR control.

Discussion

The present study sought to advance our understanding of how the brain activates

contextually anomalous but event-related information during incremental language

comprehension, specifically through investigation of asymmetries across the cerebral hemispheres in this process. Participants' EEG was recorded as they read short stories in which a sentence-medial word in the final sentence was either highly expected (Expected), semantically anomalous in the linguistic context but related to the described event (Event-Related), or semantically anomalous but unrelated to the described event (Event-Unrelated). Visual half-field presentation of target words was utilized to assess hemispheric asymmetries in the brain's responses to these target words. With RVF/LH and LVF/RH presentation, both anomalous Event-Related and Event-Unrelated targets elicited larger N400s than Expected targets. This finding aligns with previous research suggesting that sentence and discourse processing in both hemispheres is affected by message-level cues (Coulson et al., 2005; Federmeier & Kutas, 1999b; Wlotko & Federmeier, 2007). Crucially, the N400 effect for Event-Related targets was reduced relative to that for Event-Unrelated targets with LVF/RH presentation, while no difference was found between Event-Related and Event-Unrelated N400 effect amplitudes obtained with RVF/LH presentation. This finding suggests an asymmetry across the hemispheres in the activation of contextually anomalous but event-relevant information; specifically, activation of such information appears to rely strongly on right hemisphere processes. Additionally, this finding more generally informs our understanding of the functional properties of event knowledge activation with respect to expectancy generation and inference. With the Event-Related targets being semantically anomalous in sentence context, it is unlikely that they were expected to appear in their sentence contexts. In addition, because the Event-Related targets did not probe concepts necessary to maintain discourse coherence (i.e., coherence inferences), they can be

argued to probe elaborative inferences. The present findings thus align with previous research suggesting that the generation of linguistic expectancies and of elaborative inferences, both of which draw upon event knowledge, are crucially supported by the left (Federmeier & Kutas, 1999b) and right (Beeman et al., 2000) hemispheres, respectively. The present study thus provides evidence suggesting a functional distinction between event knowledge activation for elaborative inference and expectancy generation.

Inference

Comprehending discourse often involves inferring information that has not been stated but is relevant to the discourse. A number of studies have suggested that right hemisphere processes are important for inference generation (Beeman, 1993; Beeman et al., 2000; Brownell et al., 1986; Mason & Just, 2004; Virtue et al., 2006). At a broad level, a distinction is generally drawn between coherence inferences (i.e., those necessary to maintain coherent connections between sentences in a discourse) and elaborative inferences (i.e., those that capture likely outcomes of stated events or fill in additional information regarding a described event). Beeman et al. (2000) maintain that elaborative inference generation relies on the right hemisphere, and when discourse coherences breaks down and inference is required to re-establish coherence, concepts activated through elaborative inference are selected by the left hemisphere for further processing. This finding suggests that both hemispheres support inference, with the right hemisphere specifically important to activation of information related to elaborative inferences.

The discourses in the present study involved no coherence breaks, and with the Event-Related targets obtained by asking people to visualize and elaborate on described

events, the Event-Related targets can be considered to probe elaborative inferences. The present finding of N400 reduction for Event-Related targets with LVF/RH presentation thus is consistent with the notion that elaborative inference generation relies upon the right hemisphere. N400 reduction for Event-Related targets observed with central presentation (Metusalem et al., 2012) may indeed reflect elaborative inference generation, suggesting that elaborative inference affects the processes indexed by the N400 elicited by a word that is semantically anomalous in sentence context. This notion is consistent with previous research showing that the N400 elicited by a centrally presented, semantically congruous word is reduced when that word corresponds to an elaborative inference relative to when it does not (St. George, Mannes, & Hoffman, 1997).

Finally, if the present finding does reflect elaborative inference generation, and if the left hemisphere is critical for generation of coherence inferences (Beeman et al., 2000), one might predict that a study identical to the present one, except with Event-Related targets that exclusively probe coherence inferences, would find N400 reduction for Event-Related targets relative to Event-Unrelated targets with RVF/LH but not LVF/RH presentation. Such a finding would provide further evidence that inference generation underlies the activation of contextually anomalous event knowledge elements, and that hemispheric asymmetries in this process depend upon the discourse status of the inferred concept.

Expectancy Generation

Incremental language comprehension involves the generation of expectations for words or concepts likely to appear in the upcoming input (Altmann & Mirković, 2009;

DeLong, Troyer, & Kutas, 2014; Federmeier, 2007). Federmeier and Kutas (1999a,b) provided evidence that semantic feature information plays an important role in this process, and specifically that left hemisphere processes support pre-activation of the semantic features of likely upcoming words. Additional research further supports the notion of the left hemisphere being important for expectancy generation (Federmeier et al., 2005; Wlotko & Federmeier, 2007; see Federmeier (2007) for discussion).

Like semantic feature information, event knowledge is believed to play an important role in expectancy generation, as well (Altmann & Mirković, 2009; Elman, 2009; McRae & Matsuki, 2009). Metusalem et al. (2012) argued that the finding of N400 reduction for Event-Related targets with central presentation support the role of event knowledge in expectancy generation. They proposed that during incremental comprehension, the brain activates concepts that align with the general type of event being described, and those concepts that meet additional constraints, such as those on semantic features (e.g. the patient of the verb *build* should possess the features of objects that are commonly built), are likely to receive further activation and therefore be more strongly expected to appear. Under the notion that the left hemisphere crucially supports expectancy generation, the present finding of N400 reduction for Event-Related targets with LVF/RH but not RVF/LH presentation raises an important question: Does N400 reduction for Event-Related targets observed here and by Metusalem et al. (2012) relate to expectancy generation, and if so, how?

There are at least two possibilities. First, N400 reduction for Event-Related targets may be unrelated to expectancy generation, contrary to Metusalem et al.'s interpretation of their results. It could be that left hemisphere processes generate

expectancies independently of right hemisphere processes. Under this view, both hemispheres engage event knowledge during incremental comprehension, but while the right activates a range of event knowledge elements, the left independently activates only those elements that satisfy additional constraints imposed on expectancy generation by the linguistic context. Because the Event-Related targets do not meet these constraints, they would not be activated by the left hemisphere. Right hemisphere processes then would not be necessary for expectancy generation to achieve specificity at the level of events, and more generally, this view would suggest a strong functional dissociation between event knowledge activation for expectancy generation and for elaborative inference generation. Another possibility is that left hemisphere processes draw upon right hemisphere event knowledge activation to generate expectancies. Under this view, the left hemisphere does not itself engage event knowledge, but rather selects activated event knowledge elements in the right hemisphere that also meet additional constraints on expectancy generation imposed by the linguistic context. Beeman et al. (2000) found that coherence inference is supported by left hemisphere selection of concepts activated in the right hemisphere, and such a mechanism might support expectancy generation as well.

These two accounts differ on whether event knowledge activation supported by the right hemisphere is required to generate expectancies with specificity at the level of events. Evidence that the right hemisphere itself is unnecessary for generating event-specific expectancies would indicate that the left hemisphere engages semantic memory along multiple dimensions (e.g., semantic features and events) during incremental comprehension, and would further support the notion of the left hemisphere as applying multiple constraints in top-down fashion to generate expectancies. On the other hand,

evidence that expectancy generation in the left hemisphere achieves specificity at the level of events only through communication with the right hemisphere would highlight an important role for the right hemisphere in engaging semantic memory in support of expectancy generation, and would imply event-specific expectancies are generated through inter-hemispheric coordination. Further research is necessary to address this issue.

This discussion presumes that the activation of contextually anomalous event knowledge elements, critically supported by the right hemisphere, does not itself reflect generation of expectancies. After all, a system geared toward expectancy should not generate expetations for upcoming input that would be anomalous in the unfolding linguistic context. Yet, Altmann and Mirković argue that "the 'grain size' of prediction is variable, with respect to both its temporal resolution and the level of representational abstraction at which predictions are made" (p. 586). At one grain size, expectancy may indeed be thought of as anticipating upcoming sentential input, and likely would preclude anticipating words or concepts that would be anomalous in context. The left hemisphere may be critically important to this form of expectancy generation. However, at a larger grain size, contextually anomalous event knowledge elements may indeed be expected, in a sense. Such concepts may become activated due to expectancy generation at a higher level of abstraction (i.e., above the message-level representation of the unfolding sentence). Constructing a representation of discourse-level meaning may involve anticipating concepts that will be necessary, for example, for maintaining coherence across multiple sentences. In this way, right hemisphere involvement in the activation of contextually anomalous event knowledge elements may indeed reflect expectancy

generation of a sort, albeit a different form than that attributed to left hemisphere processing. Ultimately, elaborative inference may itself be a form of expectancy generation.

Complementary Hemispheric Asymmetries In Language Processing

The present findings more generally inform theories of hemispheric asymmetries in language comprehension. Several attempts have been made to develop general theories of how comprehension is achieved through complementary right and left hemisphere processes. One proposal, termed *coarse semantic coding*, has been put forth by Beeman (Beeman, 1998; Jung-Beeman, 2005). Coarse semantic coding posits that the hemispheres differ primarily in the strength and breadth of semantic activation in response to meaningful inputs: The left hemisphere strongly activates narrow semantic fields, limiting activation only to those concepts that are closely linked to the inputs, while the right hemisphere weakly activates a broad semantic field that includes more distantly related concepts. These processes complement one another in that the left hemisphere quickly zeroes in on contextually appropriate meanings while the right hemisphere maintains activation of a wider range of information that might be relevant in the processing of complex and often unpredictable semantic relationships.

The findings presented here align in principle with coarse semantic coding. At a particular point in a sentence, the left hemisphere might activate only conceptual information that closely aligns with the message-level context at that point, thereby excluding activation of words that would constitute anomalous continuations of the sentence. With both Event-Related and Event-Unrelated targets being anomalous in

context, the left hemisphere may not activate either one in response to the discourse

context at the point at which they appear. This aligns with the finding that both

anomalous target types elicit N400 effects of similar amplitudes with RVF/LH

presentation. If the right hemisphere activates concepts more broadly related to the input

as coarse semantic coding suggests, it is reasonable to expect that with LVF/RH

presentation a word related to the general event would elicit a smaller N400 than one that

does not relate to the event, even when both violate the sentence context.

What remains unclear with respect to a coarse semantic coding account of these

results is the level at which semantic activation patterns are being driven. Activation of

concepts through coarse semantic coding is often explained at the lexical level (e.g.,

Beeman, 1998; Jung-Beeman & Chiarello, 1998). For example, the words *foot*, *glass*, and

pain may each individually be distantly related to the word *cut*. Right hemisphere

processing of each of these three words would weakly activate *cut*, and when all three are

processed, these weak activations would sum to yield strong activation of *cut* (Beeman,

1998). The present results could be driven by such a lexical-level mechanism (e.g.

blizzard, *kids*, and *outside* each weakly activating *jacket*), suggesting that event

knowledge activation in the right hemisphere is driven by directly word-to-word

associations, as opposed to higher-level meaning structures like mental or situation

models. However, Metusalem et al. attempted to address this issue in their original study

by analyzing a subset of items for which the average Latent Semantic Analysis (LSA;

Landauer, Foltz, & Laham, 1998) association score between the discourse context and the

Event-Related targets was equal to that between the context and the Event-Unrelated

targets. They found that even with LSA score controlled, N400 reduction for Event-

Related targets was still observed (although it is always possible that the brain encodes weak semantic associations not reflected in LSA). They also found that no N400 reduction is observed for Event-Related targets when the first two context sentences were removed, indicating that any effect of lexical association would have to be limited to the first two sentences and persist over a full sentence lag. Additionally, a recent unpublished study described by Huettig (in press) suggests that lexical associations cannot fully account for Metusalem et al.'s finding. Therefore, a lexical-level account may be insufficient here, and it is possible that coarse semantic coding at the message-level representation of meaning would provide a better explanation. Ultimately, with priming studies (Hare, Jones, et al., 2009; McRae et al., 2005) and corpus analysis (Willits, Amato, & MacDonald, 2015) suggesting that event knowledge may be encoded in lexical associations and language statistics, teasing apart the relationship between lexical and message-level meaning structures in activating event knowledge is a complex issue requiring further study.

Another general account of hemispheric asymmetries of semantic activation in language processing is that the right and left hemispheres differ in the top-down versus bottom-up use of context (Faust, 1998; Federmeier, 2007). Federmeier (2007) has argued that the left hemisphere exerts a great degree of top-down control on processing, potentially due to greater cortical feedback connections in the left hemisphere that support language production. The left hemisphere is proposed to quickly generalize away from the input to construct a message-level meaning representation, and then apply this meaning context in top-down fashion to predict upcoming input. Right hemisphere processing is argued to be more bottom-up and integrative, with the right hemisphere also

using message-level context during processing, but not in top-down fashion. Instead, right hemisphere processing is affected by the degree to which the incoming word aligns with the message-level meaning at that point. In this way, the two hemispheres complement one another by implementing a trade-off between processing speed in the left with processing flexibility in the right.

The present findings align with the notion of left hemisphere processing as supporting expectancy generation. Both Event-Related and Event-Unrelated targets in this study were not only zero-cloze but also semantically anomalous in sentence context, and therefore should not be expected to appear in the sentential position in which they were presented. Correspondingly, we did not find a difference in N400 amplitude between these target types with RVF/LH presentation. This finding contrasts with that of Federmeier and Kutas (1999b), in which unexpected words elicited a reduced N400 with RVF/LH presentation according to the degree of semantic feature overlap with the most expected word. In contrast to the within-category violations used by Federmeier and Kutas, the Event-Related targets here were not explicitly drawn from the same semantic category as the Expected targets. If, as Federmeier and Kutas propose, a left hemisphere mechanism pre-activates semantic features of likely upcoming input, then a concept that possesses relatively few or none of these semantic properties (e.g., the Event-Related targets here) should not be activated by this mechanism. Still, with respect to Federmeier and Kutas' (1999b) study, one may have reasonably hypothesized that relation to the described event is among the semantic features engaged by the left hemisphere as a component of expectancy generation. If this were the case, then one could reasonably predict that the Event-Related targets in this study should show N400 reduction with

RVF/LH presentation. Given that this was not found, the present study suggests that relation to the described event is not functionally equivalent to the semantic features investigated by Federmeier and Kutas and that the left hemisphere itself either engages only those event knowledge elements that would constitute expected (or at least non-anomalous) continuations of the sentence, or as discussed in the preceding section, draws upon event knowledge elements in the right hemisphere in order to generate expectancies with specificity at the level of events.

The present finding has interesting implications for the view of the right hemisphere as integrative. N400 reduction was found for Event-Related targets relative to Event-Unrelated targets in the right hemisphere, despite both being semantically anomalous in context. Federmeier and Kutas (1999b) found no evidence of N400 reduction in the right hemisphere for unexpected targets that overlapped with semantic features of the expected word, and this may reasonably reflect the fact that both unexpected target were equally easy or difficult to integrate into the context independent of feature overlap with the expected word. However, it is difficult to imagine that the Event-Related and -Unrelated targets here differed substantially in their ease of integration. Both were contextually anomalous and should be extremely difficult to integrate into a coherent representation of the sentence or discourse. This challenges the notion of the right hemisphere as engaging in purely integrative processing. Still, if integration is defined not only by how easily a coherently a new word fits into a message-level representation, but also by how easy it is to incorporate that word into a mental or situation model more generally, then perhaps the notion of the right hemisphere as integrative can account for the present findings. That is, while neither the Event-Related

nor -Unrelated targets are sensible in the sentence context in which they appear, the Event-Related targets are more easily integrated into an event-level representation that is abstracted away from the particular sentence being processed at the time. If this were true, it would imply a great degree of flexibility in how the right hemisphere integrates incoming words with the preceding context.

Late Positivities With Central But Not Lateralized Presentation

It is worth noting that the pattern of effects in the 500-900ms window observed in this study differs qualitatively from those observed in Metusalem et al.'s Experiment 1. In that experiment, a posterior positivity was observed for the two anomalous target types, with an earlier onset for the Event-Unrelated targets. No positivity was observed in this study for either anomalous target type in either visual field. Instead, both anomalous target types appeared to elicit negativities relative to the Expected targets in both visual fields, with strongest evidence of this effect for Event-Unrelated targets presented to the left visual field. The functional significance of the late window effects in this study is unclear, but it is striking to find no sign of the posterior positivity observed by Metusalem et al. in their Experiment 1. While the absence of a posterior positivity could be due to the slower presentation rate used here, it is possible that the positivity is elicited only when words are presented centrally, providing direct visual input to both hemispheres. Federmeier and colleagues (Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007; Wlotko & Federmeier, 2007) report a similar absence of a late positivity elicited with central presentation when the same stimuli were presented laterally. With central presentation, unexpected words in strongly constraining contexts elicited a frontal

positivity relative to unexpected words in weakly constraining contexts and expected words in both strongly and weakly constraining contexts (Federmeier et al., 2007). With lateralized presentation of the same stimuli (and at the same presentation rate), this positivity was not observed for either visual field of presentation (Wlotko & Federmeier, 2007). This is not to suggest functional links between the positivities observed by Metusalem et al. and Federmeier et al. (2007); after all, the two showed markedly different scalp distributions. Still, it is interesting that in both cases, unexpected words elicited late positivities relative to expected words with central but not lateralized presentation. It may be the case that certain late processes in response to unexpected words, observed at the scalp as positivities relative to expected words, are disrupted when initial visual processing is biased to one hemisphere.

Conclusion

Event knowledge activation is a central component of the real-time processes involved in incremental language comprehension. During comprehension, the brain activates event knowledge elements that are semantically anomalous in context. The present study found that this process appears to be supported crucially by the right cerebral hemisphere. This finding furthers our understanding of the neural basis of event knowledge activation and more generally advances our understanding of how event knowledge is activated during generation of expectancies and elaborative inferences during the course of incremental comprehension.

Acknowledgments

Thanks to members of the Kutas Cognitive Electrophysiology Lab, the Center for Research in Language, and the Institute for Neural Computation at UC San Diego, as well as to attendees of the 2014 Architectures and Mechanisms in Language Processing Conference, for helpful comments on this work. Thanks to Esmeralda De Ochoa and Alex Kuo for assistance with data collection. This study was funded by National Institutes of Health grants HD022614, HD053136, DC000041, and MH020002.

Chapter 3, in full, has been submitted for publication of the material as it may appear in Metusalem, R., Kutas, M., Urbach, T.P., & Elman, J.L. Hemispheric asymmetry in event knowledge activation during incremental language comprehension: A visual half-field ERP study. *Neuropsychologia*. The dissertation author was the primary investigator and author of this paper.

Appendix

The 72 experimental items. Target word position in the context is underscored. Target words are listed in the following order: Expected (top), Event-Related (middle), Event-Unrelated (bottom). The comprehension question answers are provided in parentheses.

Note: These are the same stimulus materials as in Chapter 2, with one difference: the Event-Related targets are reshuffled across items to obtain the Event-Unrelated targets, due to the reformation of stimulus rotation groups after crossing target type with visual field.

Item	Context	Targets	Comprehension Question
1	Elizabeth was standing at the intersection waiting for the light to change. All of a sudden she saw a car barrel through the red light. A moment later, she heard a terrible _____ come from down the street.	crash policeman priest	Was somebody driving recklessly? (Yes)
2	For several months, there had been burglaries in the neighborhood. Many people thought they knew who the crook was. Finally, he was caught when he set off somebody's _____ one night.	alarm police dealer	Was the crook eventually caught? (Yes)
3	I think it's important to start the day right. Every morning, I make sure to eat a hearty breakfast. Sometimes there's almost no room left on my _____ once I finish dishing up.	plate eggs ring	Do I usually eat a modest breakfast? (No)
4	The band was very popular, and Joe was sure the concert would be sold out. Amazingly, he was able to get a seat down in front. He couldn't believe how close he was when he saw the group walk out onto the _____ and start playing.	stage guitar poles	Did Joe get stuck with a bad seat? (No)
5	My Aunt Bettie was very popular in our family. When she died, lots of people gathered to pay their respects. Her three brothers and three sisters all gave very moving _____ during the service.	speeches coffins cages	Was Aunt Bettie liked by the rest of the family? (Yes)
6	Traveling these days is much less fun than it used to be. Now you have to deal with worries about terrorism. It can take several hours to make it through _____ and find your gate.	security luggage helmet	Has the threat of terrorism made travel more difficult? (Yes)
7	I'm very sluggish when I wake up. Sometimes it takes me an hour to get ready in the bathroom. I often end up staring blankly at myself in the _____ for a while.	mirror toothbrush book	Am I usually energetic in the morning? (No)
8	Debbie is more of a risk taker than she should be. She loves to gamble but really isn't very good at card games. Last night, she had a rough time playing _____ at the casino.	poker dealer receptionist	Is Debbie a good card player? (No)
9	Many people think living in the country is easy. But I grew up on a farm and I know there are some downsides. What I hated most was being woken up early each morning by the _____ outside my window.	rooster barn grills	Did I grow up on a farm? (Yes)

10	My friend Julie spends all her time exercising. The machine she likes the most is the treadmill. By the time she's done, she's drenched in _____ and breathing very heavily.	sweat towel brush	Does Julie exercise frequently? (Yes)
11	Going to the movies is great fun. Before the show starts, I like to get a snack. There's nothing like watching the show while eating a big box of _____ covered with butter.	popcorn soda toothbrush	Is chocolate my favorite snack? (No)
12	Bob and Linda celebrated their 25th anniversary recently. Their kids wanted to do something nice for them. So they all got together and threw a big _____ at the beach.	party family parachute	Did Bob and Linda get married last year? (No)
13	Michelle had a toothache for several months. She knew she should do something about it, but held off. She finally got checked out when she was told she could get some anesthetic to reduce the _____ and ease her discomfort.	pain dentist runners	Did Michelle eventually see somebody about her toothache? (Yes)
14	The parents were very excited about their new baby girl. One of the first things they did was to get her baptized in their church. The baby liked baths, so she smiled when she was sprinkled with _____ on her forehead.	water priest conductor	Did the baby enjoy getting baptized? (Yes)
15	During the summer, many people like to cook outdoors. Everybody has different preferences for what to make. My father likes both hot dogs and _____ but his favorite is bratwurst.	hamburgers grills dress	Do people like to cook indoors during the summer? (No)
16	Getting divorced is always difficult. Even when people get along, there are many details to work out. If there are children, the hardest part is the question of who gets _____ of them.	custody lawyer teacher	Is getting divorced a simple matter? (No)
17	The summer is a great time to go the beach. It's true you have to bring a lot of things with you, but that's OK. The only thing I don't really like is that your food gets full of _____ and attracts lots of ants.	sand towel puck	Do you need to bring a lot of things with you when you s pend the day at the beach? (Yes)
18	If you live in a city, the best way to see unusual animals is to go to the zoo. There are all kinds of exotic animals that children don't normally see. Sometimes, however, the kids are scared by the roar of the _____ and scream in terror.	lion cages license	Do kids sometimes get scared at the zoo? (Yes)
19	A favorite American pastime during the summer is going to a ballgame. Of course, people occasionally get rowdy. My sister gets really upset when people drink too many _____ and start acting crazy.	beers hotdogs luggage	Does my sister like it when people drink a lot at the ballgame? (No)
20	After a day of off-roading, my truck was covered in mud. I parked it out on the driveway to give it a wash. When I started, I realized that I had forgotten to turn on the _____ on the side of the house.	hose soap hammer	Did I take my truck to the car wash? (No)
21	The case of Bill the Butcher was the largest that this court had ever tried. The entire town came out to hear the opening statements. Once they were finished, the	witness lawyer actors	Did the opening statements draw a large crowd?

	prosecution called its first _____ to the stand.		(Yes)
22	This spring, I decided to start growing my own vegetables. I bought a variety of seeds and planted them in my backyard. I made sure to choose a spot that got plenty of _____ during the day.	sun dirt money	Did I start a vegetable garden? (Yes)
23	My parents were very happy when my sister finally got married. At the ceremony, my father looked so proud. My mother started crying when the couple recited their _____ and proclaimed their love.	vows ring water	Were my parents worried about my sister getting married? (No)
24	I usually take the bus to work in the morning. It was over twenty minutes late on Friday. To top it off, when it finally came I realized that I didn't have any _____ to pay the fare.	money driver salesman	Did the bus arrive on time on Friday? (No)
25	The restaurant down the street is known for its lousy service. One time, I actually caught a waiter taking a bite of someone's dinner. I immediately asked to speak with the _____ about the waiter's conduct.	manager food barn	Is it common to have bad service at the restaurant? (Yes)
26	A huge blizzard swept through town last night. My kids ended up getting the day off from school. They spent the whole day outside building a big _____ in the front yard.	snowman jacket couch	Did my kids play outside on their day off from school? (Yes)
27	My dad had a lot of trouble when I took him skiing for the first time. It took him forever just to figure out how to stand up. Then he fell when he tried to get onto the _____ with his skis crossed.	lift poles guitar	Is my dad a good skier? (No)
28	Jackie is a very methodical poker player. During the high-stakes tournament, she was even more careful than usual. Every few hands, she made sure to count her _____ silently to herself.	chips table jacket	Was Jackie playing carelessly during the poker tournament? (No)
29	My friend Mike went mountain biking recently. He lost control for a moment and ran right into a tree. It's a good thing he was wearing his _____ or he could have been seriously hurt.	helmet dirt coral	Did Mike crash on his bike? (Yes)
30	It's generally a good idea to drive slowly and obey traffic laws. If you don't, you're likely to get pulled over. It's always a terrible feeling when the officer issues you a _____ and sends you on your way.	ticket license box	Is it a good idea to obey traffic laws? (Yes)
31	I used to love taking field trips with my elementary school. We got out of class for the day, and we usually went someplace fun. I would always get excited when we were about to board the _____ and head off.	bus teacher lawyer	Were my field trips usually boring? (No)
32	We're lucky to live in a town with such a great art museum. Last week I went to see a special exhibit. I finally got in after waiting in a long _____ and paying an entrance fee.	line painting surfboard	Did I see a special exhibit at the aquarium? (No)
33	I took my friends to the desert for a few days of camping. After a couple hours of hiking, we found a good spot to spend the night. The weather was so nice that we didn't even pitch a _____ or use our sleeping bags.	tent fire family	Did we have nice weather on our camping trip? (Yes)

34	Jenny had a really difficult math exam earlier this week. She was so worried about being late that she arrived twenty minutes early. As soon as she arrived, she made sure to sharpen her _____ and find a seat.	pencil calculator vegetables	Did Jenny arrive early to the test? (Yes)
35	My friends and I played a game of pond hockey over the weekend. It was clear from the beginning that one of my friends had never played before. The poor guy couldn't even lace up his _____ or hold his stick properly.	skates puck hotdogs	Are all my friends experienced hockey players? (No)
36	Filming for the new movie was getting underway, and the crew was ready to shoot the first scene. One of the cameramen mentioned that she was getting some really bad glare in the shot. Somebody quickly dimmed the _____ and the director called action.	lights actors police	Did the cameraman complain about the lights being too dim? (No)
37	A high profile bank was robbed yesterday afternoon. The robbers entered through the back and made their way to the lobby. All the customers froze when they saw several masked men pointing _____ and threatening to shoot.	guns money dirt	Were there customers present during the bank robbery? (Yes)
38	It's a good idea to get some reading material before going on a long trip. I tend to go to the library the day before I leave. Last time I went, I was shocked to find out that I owed a huge _____ for something I had already returned.	fine book soda	Do I usually go to the library before going on a trip? (Yes)
39	Shopping at the used car lot can be a stressful ordeal. Even if you find a car you like, you never know if it has any problems. Just make sure to have a good look under the _____ before buying anything.	hood salesman clowns	Can you be certain whether or not a used car has problems? (No)
40	My little brother doesn't know how to swim, but we still bring him along when we go to the pool. One time, he fell into the deep end while no one was looking. He was quickly brought to safety by the _____ and given to our mother.	lifeguard water fire	Is my brother a good swimmer? (No)
41	Last Saturday I laid around watching television into the middle of the night. I eventually found myself watching an infomercial for some new cleaning product. I wanted to change the channel, but I couldn't find the _____ anywhere.	remote couch car	Was I watching TV late at night? (Yes)
42	Even the laziest people clean up around the house every once in a while. The worst part is always the bathroom. When you tackle the toilet, it's good to wear some _____ to guard against bacteria.	gloves bleach booths	Is the bathroom the worst part of cleaning the house? (Yes)
43	The airlines are getting so stingy that they don't even provide free food anymore. A lot of people complain that they no longer get a complimentary meal on long flights. I'd be happy just to get a bag of _____ or some crackers.	peanuts drinks bleach	Do all the airlines still provide complementary meals? (No)
44	We had our entire family over to our house for Thanksgiving this year. My mother set the table as if the President were coming for dinner. She laid out a	candles turkeys boots	Did we set the table for an ordinary dinner? (No)

	nice tablecloth and even lit a couple _____ for effect.		
45	The last presidential election drew an incredible number of voters. My polling place had a line out the door when I arrived on election day. I waited three hours before I was finally able to cast my _____ and head to work.	vote booths coffins	Did a lot of people vote in the election? (Yes)
46	My sister was only twenty when she won a Grammy for her first album. She seemed so nervous as she gave her acceptance speech. Her voice was shaky as she spoke into the _____ and thanked everyone.	microphone dress painting	Was my sister young when she won her Grammy? (Yes)
47	Jeremy is a great athlete despite being prone to injury. During his last high school football game, he was knocked unconscious twice. That still didn't stop him from scoring the winning _____ with only seconds remaining.	touchdown helmet glass	Did Jeremy sprain his ankle during the football game? (No)
48	Living in San Diego is great if you love to surf. The downside is that the water can be freezing during the winter. You'll be sorry if you go out without wearing your _____ or at least a shirt.	wetsuit surfboard food	Is the winter water warm enough to surf in just your bathing suit? (No)
49	Raja likes to go to the supermarket early in the morning to avoid the crowds. He usually brings his daughter along. She always insists on riding in the _____ while Raja pushes.	cart vegetables bed	Does Raja try to do his shopping when the store isn't crowded? (Yes)
50	My husband and I had some nice red wine with dinner last night. He's so clumsy that he ended up spilling some all over me. At least my shirt was dark enough to partially hide the _____ for the rest of the evening.	stain glass medal	Was I wearing a dark shirt? (Yes)
51	Andy was excited to get his driver's license, but he was afraid he wouldn't pass the parallel parking section of the test. He tried to remain calm as he checked his mirrors and began. Unfortunately, he ended up failing for knocking over too many _____ and had to retake the test.	cones instructors doctors	Did Andy pass his driver's test? (No)
52	Having major surgery is never a pleasant experience. You lie in a sterile room next to an operating table full of scary tools and devices. As if the anxiety isn't enough, you usually have to deal with a cold draft up your _____ while you wait to begin.	gown doctor instructors	Can major surgery be a pleasant experience? (No)
53	I used to love getting my hair cut when I was a kid. I got so excited every time I walked into barbershop. I would giggle with joy as I hopped into the _____ and greeted the barber.	chair scissors turkeys	Did I enjoy haircuts as a child? (Yes)
54	Tanya was totally pumped to be skydiving for the first time. When it was her turn to jump, she got a huge smile on her face. She didn't hesitate at all before leaping out of the _____ head first.	plane parachute eggs	Was Tanya excited to be skydiving? (Yes)
55	When Maya's laptop was stolen, she went to the Apple store to buy a replacement. She wanted to make sure to get one with a fast processor. She also had tons of files to store, so she wanted a lot of _____ as well.	memory salesman driver	Did Maya do her computer shopping online? (No)

56	My friends and I took a cross-country road trip after graduating from college. We ended up getting lost somewhere in the middle of Nevada. We eventually decided to stop and ask for some _____ at a gas station.	directions car table	Did we stop because we were out of gas? (No)
57	I helped my neighbor build a shed recently, and we managed to run into a few problems. First, we realized that we didn't make the doorway the right size. Then we didn't have enough shingles to finish the _____ so we returned to the store.	roof hammer drinks	Did we run out of shingles? (Yes)
58	The doctor was running very late, which was not uncommon. Mary couldn't wait any longer and decided to reschedule her check-up. So she asked if she could make another _____ for the following week.	appointment receptionist lawyer	Did Mary try to reschedule her appointment? (Yes)
59	Marathons take a lot out of you, and it's important not to get dehydrated. Ralph had been doing OK up until mile twenty-six. As he rounded the final bend, someone gave him some _____ and cheered him on.	water runners dentist	Did Ralph compete in a triathlon? (No)
60	Having serious car trouble is the worst. Aside from being unable to drive, it's hard to find a mechanic you can trust. You never know if you're being charged a fair _____ or not.	price tire towel	Is it easy to find a trustworthy mechanic? (No)
61	Little kids love to go to the circus. There are always exotic animals, and children find the acts very exciting. The scariest act is of course when the lion tamer puts his head inside the lion's _____ while the crowd gasps in horror.	mouth clowns salesman	Are there any scary acts at the circus? (Yes)
62	The Olympic ice skating competition is always well attended. Last year, the winner was the favorite, who was extremely popular. The crowd roared with delight as she took her place on the _____ and waved to her fans.	podium medal blood	Was the winner of the competition popular? (Yes)
63	The boxing match had gone on for seven rounds, and both contestants were exhausted. One of them had sustained serious injuries and finally fell to the mat. Worried about his condition, the referee declared the other fighter the _____ and ended the match.	winner blood rod	Did the referee end the match because one of the fighters cheated? (No)
64	I started taking an introductory painting course a few weeks ago. During the first class, the instructor had a very hard time giving even a simple demonstration. It was clear that he didn't have much teaching _____ and wouldn't be a good instructor.	experience brush towel	Did my painting class start out well? (No)
65	Nadia went snorkeling in the Great Barrier Reef while on vacation in Australia. She found it to be more beautiful than she had ever imagined. After several hours of swimming around, she still couldn't bring herself to climb back in the _____ and head to shore.	boat coral dirt	Did Nadia enjoy her time at the Great Barrier Reef? (Yes)
66	Music fans have a lot of different tastes when it comes to live performances. A lot of people like to go to rock concerts, but I prefer a symphony. My favorite part is	quartet conductor policeman	Do I prefer a symphony over a rock concert? (Yes)

	the string _____ because I love the violin.		
67	Moving to a new house is always a huge hassle. If you do it yourself, the whole ordeal can last several days. Things go much faster if you hire a moving _____ to help you.	company box gun	Is moving to a new house an easy job to do alone? (No)
68	The climb up Mount Whitney is beautiful but very challenging. Manny and Julia were tired but looking forward to what they knew awaited them at the top. Finally, they rounded the last bend and were awed by the magnificent _____ of Owens Valley below.	view boots scissors	Did Manny and Julia go hiking down by the river? (No)
69	The last time Tommy went hunting, he was nearly shot by another hunter. He was creeping quietly through the woods when the other hunter almost mistook him for a deer. It's a good thing he was wearing his orange _____ over his camouflage.	vest gun soap	Was Tommy almost shot by another hunter? (Yes)
70	I used to spend a lot of Saturday mornings fishing with my dad. We would wake up early and load the car with all of the equipment. We always brought a bucket of worms to use as the _____ even though worms grossed me out.	bait rod tire	Did I used to go fishing with my dad? (Yes)
71	I usually fall asleep pretty quickly. Sometimes, though, if I've had a busy day I find it hard to wind down. Then I find the best thing is to read a good _____ or magazine.	book bed car	Do I like to watch TV when I can't fall asleep? (No)
72	It can be difficult to find a decent parking spot downtown. A lot of the time you have to park on the street. That's why it's always good to have some change to feed the _____ or you might get a ticket.	meter car calculator	Is it easy to find good parking downtown? (No)

References

Altmann, G.T.M. & Mirković, J. (2009). Incrementality and prediction in human sentence processing. *Cognitive Science, 33*, 583-609.

Amsel, B.D., Delong, K.A., & Kutas, M. (2015). Close, but no garlic: Perceptuomotor and event knowledge activation during language comprehension. *Journal of Memory and Language, 82*, 118-132.

Atchley, R.A., Keeney, M., & Burgess, C. (1999). Cerebral hemispheric mechanisms linking ambiguous word meaning retrieval and creativity. *Brain and Cognition, 40*, 479-499.

Banich, M.T. (2003). The divided visual field technique in laterality and interhemispheric integration. In K. Hugdahl (Ed.), *Experimental Methods in Neuropsychology* (47-64). Boston: Kluwer Academic Publishers.

Beeman, M. (1993). Semantic processing in the right hemisphere may contribute to drawing inferences from discourse. *Brain and Language, 44*, 80-120.

Beeman, M. (1998). Coarse semantic coding and discourse comprehension. In M. Beeman & C. Chiarello (Eds.), *Right Hemisphere Language Comprehension: Perspectives From Cognitive Neuroscience* (255-284). Mahwah, NJ: Erlbaum.

Beeman, M., Bowden, E.M., & Gernsbacher, M.A. (2000). Right and left hemisphere cooperation for drawing predictive and coherence inferences during normal story comprehension. *Brain and Language, 71*, 310-336.

Benjamini, Y., Krieger, A.M., & Yuketieli, D. (2006). Adaptive linear step-up procedures that control the false discovery rate. *Biometrika, 93*(3), 491-507.

Bicknell, K., Elman, J.L., Hare, M., McRae, K., & Kutas, M. (2010). Effects of event knowledge in processing verbal arguments. *Journal of Memory and Language, 63*, 489-505.

Borovsky, A., Elman, J.L., & Fernald, A. (2012). Knowing a lot for one's age: Vocabulary skill and not age is associated with anticipatory incremental sentence interpretation in children and adults. *Journal of Experimental Child Psychology, 112*(4), 417-436.

Bouma, H. (1978). Visual search and reading: Eye movements and functional visual field: A tutorial review. In J. Requin (Ed.), *Attention and Performance VII* (115-147). Hillsdale, N.J.: Erlbaum.

Broca, P. (1861). Remarques sur le siége de la faculté du langage articulé, suivies d'une observation d'aphémie (perte de la parole). *Bulletin de la Société Anatomique, 6*, 330-357.

Brownell, H.H., Michel, D., Powelson, J., & Gardner, H. (1983). Surprise but not coherence: Sensitivity to verbal humor in right-hemisphere patients. *Brain and Language, 18*, 20-27.

Brownell, H.H., Potter, H.H., & Bihrle, A.M. (1986). Inference deficits in right brain-damaged patients. *Brain and Language, 27*, 310-321.

Brysbaert, M. & New, B. (2009). Moving beyond Kucera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior Research Methods, 41*, 977-990.

Burgess, C. & Simpson, G.B. (1988). Cerebral hemispheric mechanisms in the retrieval of ambiguous word meanings. *Brain and Language, 33*, 86-103.

Cardillo, E.R., Watson, C.E., Schmidt, G.L., Kranjec, A., & Chatterjee, A. (2012). From novel to familiar: Tuning the brain for metaphors. *NeuroImage, 59*, 3212-3221.

Chiarello, C. (1988). Lateralization of lexical processes in the normal brain: A review of visual half-field research. In H.A. Whitaker (Ed.), *Contemporary Reviews in Neuropsychology* (36-76). New York: Springer.

Chiarello, C., Liu, S., & Faust, M. (2001). Bihemispheric sensitivity to sentence anomaly. *Neuropsychologia, 39*, 1451-1463.

Chwilla, D.J. & Kolk, H.H.J. (2005). Accessing world knowledge: Evidence from N400 and reaction time priming. *Cognitive Brain Research, 25*, 589-606.

Coulson, S., Federmeier, K.D., Van Petten, C., & Kutas, M. (2005). Right hemisphere sensitivity to word- and sentence-level context: Evidence from event-related brain potentials. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*(1), 129-147.

Coulson, S. & Williams, R.F. (2005). Hemispheric asymmetries and joke comprehension. *Neuropsychologia, 43*, 128-141.

Coulson, S. & Wu, Y.C. (2005). Right hemisphere activation of joke-related information: An event-related brain potential study. *Journal of Cognitive Neuroscience, 17*(3), 494-506.

Cunningham, A.E. & Stanovich, K.E. (1990). Assessing print exposure and orthographic processing skill in children: A quick measure of reading experience. *Journal of Educational Psychology, 82*, 733-740.

DeLong, K.A., Troyer, M., & Kutas, M. (2014). Pre-processing in sentence comprehension: Sensitivity to likely upcoming meaning and structure. *Language and Linguistics Compass, 8*(12), 631-645.

Elman, J.L. (2009). On the meaning of words and dinosaur bones: Lexical knowledge without a lexicon. *Cognitive Science, 33*(4), 547-582.

Eviatar, Z. & Just, M.A. (2006). Brain correlates of discourse processing: An fMRI investigation of irony and conventional metaphor comprehension. *Neuropsychologia, 44*, 2348-2359.

Faust, M. (1998). Obtaining evidence of language comprehension from sentence priming. In M. Beeman & C. Chiarello (Eds.), *Right Hemisphere Language Comprehension: Perspectives From Cognitive Neuroscience* (161-185). Mahwah, NJ: Erlbaum.

Faust, M. & Chiarello, C. (1998). Sentence context and lexical ambiguity resolution by the two hemispheres. *Neuropsychologia, 36*(9), 827-835.

Faust, M., Kravetz, S., & Babkoff, H. (1993). Hemisphericity and top-down processing of language. *Brain and Language, 44*, 1-18

Federmeier, K.D. (2007). Thinking ahead: The role and roots of prediction in language comprehension. *Psychophysiology, 44*(4), 491-505.

Federmeier, K.D. & Kutas, M. (1999a). A rose by any other name: Long-term memory structure and sentence processing. *Journal of Memory and Language, 41*(4), 469-495.

Federmeier, K.D. & Kutas, M. (1999b). Right words and left words: Electrophysiological evidence for hemispheric differences in meaning processing. *Cognitive Brain Research, 8*(3), 373-392.

Federmeier, K.D., Mai, H., & Kutas, M. (2005). Both sides get the point: Hemispheric sensitivities to sentential constraint. *Memory & Cognition, 33*(5), 871-886.

Federmeier, K.D., Wlotko, E.W., De Ochoa-Dewald, E., & Kutas, M. (2007). Multiple effects of sentential constraint on word processing. *Brain Research, 1146*, 75-84.

Federmeier, K.D., Wlotko, E.W., & Meyer, A.M. (2008). What's 'right' in language comprehension: Event-related potentials reveal right hemisphere language capabilities. *Language and Linguistics Compass, 2*(1), 1-17.

Ferretti, T.R., Kutas, M., & McRae, K. (2007). Verb aspect and the activation of event knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*(3), 182-196.

Foldi, N.S. (1987). Appreciation of pragmatic interpretations of indirect commands: Comparison of right and left hemisphere brain-damaged patients. *Brain and Language, 31*, 88-108.

Gardner, H., Ling, P.K., Flamm, L., & Silverman, J. (1975). Comprehension and appreciation of humorous material following brain damage. *Brain, 98*, 399-412.

Gernsbacher, M.A. & Kaschak, M.P. (2003). Neuroimaging studies of language production and comprehension. *Annual Review of Psychology, 54*, 91-114.

Giora, R., Zaidel, E. Soroker, N., Batori, G., & Kasher, A. (2000). Differential effects of right- and left-hemisphere damage on understanding sarcasm and metaphor. *Metaphor and Symbol, 15*(1&2), 63-83.

Greenhouse, S.W. & Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika, 24*, 95-112.

Grodzinsky, Y. & Friederici, A.D. (2006). Neuroimaging of syntax and syntactic processing. *Current Opinion in Neurobiology, 16*, 240-246.

Groppe, D.M., Urbach, T.P., & Kutas, M. (2011a). Mass univariate analysis of event-related brain potentials/fields I: A critical tutorial review. *Psychophysiology, 48*, 1711-1725.

Groppe, D.M., Urbach, T.P., & Kutas, M. (2011b). Mass univariate analysis of event-related brain potentials/fields II: Simulation studies. *Psychophyisiology, 48*, 1726-1737.

Hare, M., Elman, J.L., Tabaczynski, T., & McRae, K. (2009). The wind chilled the spectators but the wine just chilled: Sense, structure, and sentence comprehension. *Cognitive Science, 33*, 610-628.

Hare, M., Jones, M., Thomson, C., Kelly, S., & McRae, K. (2009). Activating event knowledge. *Cognition, 111*, 151-167.

Hickok, G. & Poeppel, D. (2007). The cortical organization of speech processing. *Nature Reviews Neuroscience, 8*, 393-402.

Hough, M.S. (1990). Narrative comprehension in adults with right and left hemisphere brain damage: Theme organization. *Brain and Language, 38*, 253-277.

Huettig, F. (in press). Four central questions about prediction in language processing. *Brain Research.* DOI:10.1016/j.brainres.2015.02.014.

Johns, C.L., Tooley, K.M., & Traxler, M.J. (2008). Discourse impairments following right hemisphere brain damage: A critical review. *Language and Linguistics Compass, 2*(6), 1038-1062.

Johnson-Laird, P.N. (1983). *Mental models: Towards a cognitive science of language, inference, and consciousness*. Cambridge, MA: Harvard University Press.

Jung-Beeman, M. (2005). Bilateral brain processes for comprehending natural language. *TRENDS in Cognitive Sciences, 9*(11), 512-518.

Jung-Beeman, M & Chiarello, C. (1998). Complementary right- and left-hemisphere language comprehension. *Current Directions in Psychological Science, 7*(1), 2-8.

Kamide, Y., Altmann, G.T.M., & Haywood, S.L. (2003). The time-course of prediction in incremental sentence processing: Evidence from anticipatory eye movements. *Journal of Memory and Language, 49*, 133-156.

Kukona, A., Fang, S.-Y., Aicher, K.A., Chen, H., & Magnuson, J.S. (2011). The time course of anticipatory constraint integration. *Cognition, 119*, 23-42.

Kutas, M. & Federmeier, K.D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Sciences, 4*(12), 463-470.

Kutas, M. & Federmeier, K.D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology, 62*, 621-647.

Kutas, M. & Hillyard, S.A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207*, 203-205.

Kutas, M. & Hillyard, S.A. (1984). Brain potentials during reading reflect word expectancy and semantic association. *Nature, 307*, 161-163.

Landauer, T.K., Foltz, P.W., & Laham, D. (1998). Introduction to latent semantic analysis. *Discourse Processes, 25*, 259-284.

Mashal, N. & Faust, M. (2009). Conventionalisation of novel metaphors: A shift in hemispheric asymmetry. *Laterality: Asymmetries of Body, Brain, and Cognition, 14*(6), 573-589.

Mashal, N., Faust, M., Hendler, T., & Jung-Beeman, M. (2007). An fMRI investigation of the nueral correlates underlying processing of novel metaphoric expressions. *Brain and Language, 100*, 115-126.

Mashal, N., Faust, M., Hendler, T., & Jung-Beeman, M. (2008). Hemispheric differences in processing the literal interpretation of idioms: Converging evidence from behavioral and fMRI studies. *Cortex, 44*, 848-860.

Mason, R.A. & Just, M.A. (2004). How the brain processes causal inferences in text. *Psychological Science, 15*(1), 1-7.

Matsuki, K., Chow, T., Hare, M., Elman, J.L., Scheepers, C., & McRae, K. (2011). Event-based plausibility immediately influences online language comprehension. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*, 913-934.

McRae, K., Hare, M., Elman, J.L., & Ferretti, T.R. (2005). A basis for generating expectancies for verbs form nouns. *Memory & Cognition, 33*, 1174-1184.

McRae, K. & Matsuki, K. (2009). People use their knowledge of common events to understand language, and do so as quickly as possible. *Language and Linguistics Compass, 3*(6), 1417-1429.

McRae, K. Spivey-Knowlton, M.J., & Tanenhaus, M.K. (1998). Modeling the influence of thematic fit (and other constraints) in on-line sentence comprehension. *Journal of Memory and Language, 38*, 283-312.

Metusalem, R., Kutas, M., Urbach, T.P., Hare, M., McRae, K., & Elman, J.L. (2012). Generalized event knowledge activation during online sentence comprehension. *Journal of Memory and Language, 66*(4), 545-567.

Price, C.J. (2012). A review and synthesis of the first 20 years of PET and fMRI studies on heard speech, spoken language, and reading. *NeuroImage, 62*, 816-847.

Rayner, K. & Morrison, R.E. (1981). Eye movements and identifying words in parafoveal vision. *Bulletin of the Psychonomic Society, 17*(3), 135-138.

Robertson, D.A., Gernsbacher, M.A., Guidotti, S.J., Robertson, R.R.W., Irwin, W., Mock, B.J., & Campana, M.E. (2000). Functional neuroanatomy of the cognitive process of mapping during discourse comprehension. *Psychological Science, 11*(3), 255-260.

Schiepers, C. (1980). Response latency and accuracy in visual word recognition. *Perception & Psychophysics, 27*(1), 71-81.

Schneiderman, E.I, Murasugi, K.G., & Saddy, J.D. (1992). Story arrangement ability in right brain-damaged patients. *Brain and Language, 43*, 107-120.

Shamay-Tsoory, S.G., Tomer, R., & Aharon-Peretz, J. (2005). The neuroanatomical basis of understanding sarcasm and its relationship to social cognition. *Neuropsychology, 19*(3). 288-300.

St. George, M., Kutas, M., Martinez, A., & Sereno, M.I. (1999). Semantic integration in reading: Engagement of the right hemisphere during discouse processing. *Brain, 122*, 1317-1325.

St. George, M., Mannes, S., & Hoffman, J.E. (1997). Individual differences in inference generation: An ERP analysis. *Journal of Cognitive Neuroscience, 9*(6), 776-787.

Stanovich, K.E. & Cunningham, A.E. (1992). Studying the consequences of literacy within a literate society: The cognitive correlates of print exposure. *Memory & Cognition, 20*, 51-68.

Van Dijk, T.A. & Kintsch, W. (1983). *Strategies in discourse comprehension*. New York: Academic Press.

Virtue, S., Haberman, J., Clancy, Z., Parrish, T., & Jung-Beeman, M. (2006). Neural activity of inferences during story comprehension. *Brain Research, 1084*, 104-114.

Wapner, W., Hamby, S., & Gardner, H. (1981). The role of the right hemisphere in the apprehension of complex linguistic materials. *Brain and Language, 14*, 15-33.

Wernicke, C. (1874). *Der aphasische Syptomenkomplex: Eine psychologische Studie auf anatomischer Basis*. Breslau: Cohn & Weigert.

Willits, J.A., Amato, M.S., & MacDonald, M.C. (2015). Language knowledge and event knowledge in language use. *Cognitive Psychology, 78*, 1-27.

Wlotko, E.W. & Federmeier, K.D. (2007). Finding the right word: Hemispheric asymmetries in the use of sentence context information. *Neuropsychologia, 45*, 3001-3014.

Wlotko, E.W. & Federmeier, K.D. (2013). Two sides of meaning: The scalp-recorded N400 reflects distinct contributions from the cerebral hemispheres. *Frontiers in Psychology, 4*, 1-15.

Zwaan, R.A. & Radvansky, G.A. (1998). Situation models in language comprehension and memory. *Psychological Bulletin, 123*(2), 162-185.

CHAPTER 4:

Dynamic Modulation of Event Knowledge Activation in the Visual World Paradigm

Introduction

Real-world events dynamically unfold across time, as does the language speakers use to describe them. When comprehending linguistic event descriptions, comprehenders construct a mental representation of the described event (Johnson-Laird, 1983; van Dijk & Kintsch, 1982; Zwaan & Radvansky, 1998). These representations are not static, but are updated according to various cues as the discourse unfolds across time (Zwaan, Langston, & Graesser, 1995; Zwaan & Radvansky, 1998). Additionally, constructing event representations involves the activation of unstated information by mapping the linguistic input onto general knowledge of the type of event described (Graesser, Singer, Trabasso, 1994; Zwaan & Radvansky, 1998). Research suggests that this process occurs online, as language is comprehended word-by-word (Metusalem et al., 2012; O'Brien, Shank, Myers, & Rayner, 1988). Yet, research has not investigated the processes through which the activation of unstated event knowledge elements is modulated as an event description unfolds across time. The present study examines this issue in the context of the visual world paradigm.

Event Representation and the Visual World Paradigm

In the visual world paradigm (VWP), researchers measure eye movements over visual arrays as comprehenders listen to language relating to the arrays in some fashion (Cooper, 1974). Eye movements over the visual array are taken as an index of the real-time mapping between linguistic input and visually depicted conceptual information, with fixations being drawn at a particular point in time to depicted concepts that are saliently related to the unfolding language in some way. VWP research has proven fruitful in

investigating numerous aspects of linguistic processing (see reviews by Henderson & Ferreira, 2004, and Huettig, Rommers, & Meyer, 2011).

Altmann and Kamide (1999) demonstrated that linguistic and visual information can be integrated to generate predictions for upcoming mention of depicted concepts. Participants viewed an array containing, among other things, a ball and a slice of cake while listening to sentences such as "The boy will move the cake" or "The boy will eat the cake". Participants launched eye movements to the cake after the verb "move" but during the verb "eat", appearing to integrate linguistic information (selectional restrictions of the verb) with visual information (number of objects on the screen that satisfied those restrictions) to launch anticipatory eye movements to the depicted entity most likely to be mentioned. Kamide, Altmann, and Haywood (2003) expanded on this finding by demonstrating that anticipatory eye movements triggered by a given verb are directed to different depicted concepts depending on the agent of the verb. "The man will [ride/taste]…" triggers anticipatory fixations to a motorcycle or beer, respectively, while "The girl will [ride/taste]…" triggers anticipatory fixations to a carousel or sweets. Anticipatory eye movements thus are driven not solely by information provided by the verb, but by information integrated across the agent and verb. This suggests that anticipatory eye movements are mediated by knowledge of the event implied by the unfolding sentence. This interpretation aligns with views of language comprehension positing a central role for event knowledge in incremental processing, including linguistic expectancy generation (Altmann & Mirković, 2009; Elman, 2009; McRae & Matsuki, 2009).

Eye movements are not directed solely to entities that are mentioned or predicted to be mentioned, indicating that VWP eye movements do not simply index activation of concepts that are (predicted to be) mentioned in the unfolding language. The eyes are drawn also to depicted concepts that are semantically related to (Huettig & Altmann, 2005; Yee & Sedivy, 2006), have a similar shape as (Dahan & Tanenhaus, 2005), or serve a similar functional role to (Kalenine, Mirman, Middleton, & Buxbaum, 2012; Kukona, Altmann, & Kamide, 2014) a mentioned entity, and can even be directed to a stereotypical agent of a verb when the agent role has already been filled by another entity (Kukona, Fang, Aicher, Chen, & Magnuson, 2011). Fixations in the VWP thus do not solely reflect recognition (or prediction) of mention of depicted entities.

Altmann and Kamide (2009) report findings of eye movements to unmentioned objects that suggest VWP eye movements reflect the dynamic mapping of visual and linguistic inputs onto mental representations of described events. They monitored eye movements as participants viewed image arrays depicting, for example, a bottle of wine, an empty wine glass situated on the floor, and an empty table. They simultaneously listened to sentences such as "The woman will pick up the bottle and carefully pour the wine into the glass." Crucially, this sentence was preceded by a sentence stating either that the woman had moved the glass to the table or that the glass was left on the floor. Eye movements at "pour" and at "glass" in the second sentence reflected the implied location of the wine glass; participants were more likely to fixate the table when the glass had been described as having moved to the table versus remaining on the floor, despite the fact that the static visual scene depicted the glass on the floor in both conditions. This finding suggests that linguistic information served to update the event depicted in the

visual array and that this modified event representation influenced eye movements. The authors argue that VWP eye movements are driven by mental event representations constructed from the integration of the visual scene and the event description. Additional research has demonstrated that visually depicted events and stereotypical event knowledge each exert an influence on VWP eye movements, with visual event depictions taking precedence over stereotypical event knowledge when the two conflict (Knoeferle & Crocker, 2006). It therefore appears that comprehending event descriptions in the VWP involves integrating linguistic information, visual information, and event knowledge into mental event representations that guide eye movements over depicted concepts.

Dynamic Activation of Unstated Event Knowledge

As mentioned at the outset, constructing mental representations of described events involves activating unstated elements of event knowledge. While the circumstances under which comprehenders do so are complex (Graesser, Singer, & Trabasso, 1994; McKoon & Ratcliff, 1992), research using multiple methodologies has suggested that comprehenders engage event knowledge to infer unstated information during incremental comprehension (Cook, Limber, & O'Brien, 2001; Keefe & McDaniel, 1993; Metusalem et al., 2012; O'Brien et al., 1988). With unstated event knowledge elements being activated incrementally during language comprehension, and with VWP eye movements reflecting the integration of linguistic and visual information into mental event representations, it is likely that eye movements in the VWP should be directed to entities that are not mentioned in the discourse but are related to the described event. The

present study confirms that this is the case and utilizes this aspect of the VWP to examine the dynamics of activation of unstated event knowledge elements (described further below).

The present study utilizes a design similar to that of Kamide et al. (2003), in which participants listened to agent-verb-patient sentences while viewing a display that depicted two possible agents and two possible patients, with one of the two patients aligning with the event denoted by the combination of agent and verb and the other aligning with the verb only. This design allowed for examination of the dynamic activation of depicted event knowledge elements that were predicted to be mentioned next in the unfolding sentence. The present study utilizes a similar design to examine the dynamic activation of depicted event knowledge elements that are not mentioned but nevertheless are related to the described event.

In the present study, participants viewed arrays of four images while listening to three-sentence discourses describing real-world events. The first sentence established an event context, and the third sentence cued an update to the event representation likely to modulate the mapping between depicted concepts and the unfolding discourse. Consider the example in Figure 4.1, which contains a sample visual array and accompanying linguistic stimulus from the experiment. The discourse begins by establishing the event of baking an apple pie. It proceeds to update the discourse by mentioning that the protagonist is nervous about cutting himself. In the visual array are four images. The sugar is strongly related to the general event of baking an apple pie (as established through norming; see *Methods*). The saw is related to the act of cutting, but is an inappropriate cutting implement in the event context of baking an apple pie. The knife is

related to the act of cutting and is an appropriate cutting implement given the event

context. The sink is unrelated to the discourse.

Daniel decided one afternoon to <u>bake</u> an apple pie from scratch. He began working on the kitchen counter. He was always nervous about <u>cutting</u> himself, so he worked very carefully.
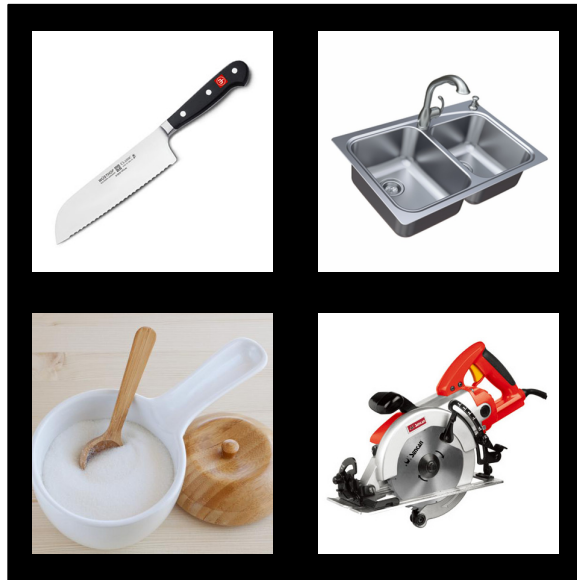
Figure 4.1: An example array and discourse. The event tag and update cue are underlined in the first and third sentences, respectively. The sugar is the Event-Related image, the knife is Update-Related image, the saw is the Update-Distractor, and the sink is Unrelated. This array was also paired with a discourse that began "Daniel was excited to start remodeling his kitchen" and continued verbatim to the second and third sentences in the example above. For this discourse, the sink was the Event-Related image, the saw was the Update-Related image, the knife was the Update-Distractor, and the sugar was Unrelated.

As past research suggests (Altmann & Kamide, 2009), participants should integrate the unfolding event description with the concepts depicted in the images and with their event knowledge in order to construct of a mental representation of the described event. An individual image should attract visual attention to the degree that it is saliently related to the event description at a particular point in time, despite not being explicitly mentioned. As the event description unfolds, an increase in the probability of fixating a particular image can be interpreted as indicating that the depicted concept has become activated through the construction of the mental event representation, possibly indicating consideration on the part of the comprehender that the depicted concept is a participant in the event.[12]

When a discourse first establishes the event context (e.g., at "bake an apple pie"), comprehenders should activate generalized knowledge of this type of event. At this point, the probability of fixating an image should increase to the degree to which the concept depicted in the image is a salient component of the activated event knowledge. (For baking an apple pie, the sugar and knife should attract visual attention.) When the discourse presents an update cue ("cutting") that can be mapped specifically to one of the depicted event knowledge elements (the knife), the probability of fixating this image should increase relative to the probability of fixating the other images.

Of particular interest here is if, at the update cue, there will be an increase in the probability of fixating the image that aligns locally with the update cue but not with the

---

[12] In context of the present study, we take an increase in looks to a particular image to index the cognitive processes involved in constructing mental event representations, but this is not to say that eye movements in the visual world paradigm cannot index other cognitive processes. See the Discussion for further comment on this issue.

general event context (the saw). Assuming this image does not show an increase in fixation probability before the update cue, the depicted concept presumably has not been activated as a component of the comprehender's general knowledge of the described event. As the event description progresses, activation of concepts through the construction of a mental event representation may be limited to only those concepts that were initially activated when the event context was first established. This would preclude activation of a depicted concept that aligns locally with the update cue but not with the general event context. This can be thought of similarly to the cohort model of word recognition (Marslen-Wilson & Tyler, 1980), in which the first phoneme of a word activates a cohort of candidates for recognition in which each candidate begins with that phoneme. As the word unfolds and subsequent phonemes are processed, this cohort is winnowed down until one candidate for recognition remains. Words that do not begin with the initial phoneme but do align with later phonemes (e.g., rhyming words) are never activated as candidates for recognition. Activation of event knowledge could proceed along similar lines, with an initial cohort of event-related concepts activated and subsequently winnowed down as the event description progresses.

However, the update cue could trigger an increased probability of fixating a depicted concept that aligns locally with the update cue but does not align with the event context. Such a finding would suggest that comprehenders do not activate and subsequently winnow down a cohort of event-related concepts, but rather continuously map the event description to the depicted concepts at each point in time. Even concepts that are not first activated as components of general knowledge of the described event are considered as potentially related to the described event as the discourse unfolds and

presents new information. With respect to the cohort model analogy, this would be akin to continuous mapping models of word recognition (e.g., TRACE; McClelland & Elman, 1986), in which phonemes are mapped to candidates for recognition at each point in time, with no special status given to the word-initial phoneme. Dynamic activation of event knowledge may also exhibit such continuous mapping between depicted concepts and event descriptions.

In summary, the present study investigates the dynamic construction of event representations in the visual world paradigm, specifically with respect to depicted but unmentioned elements of event knowledge. It establishes that unmentioned event knowledge elements draw visual attention and investigates the dynamic modulation of this attention allocation with respect to the winnowing down of an initial cohort of event-related concepts versus the continuous consideration of alternatives. In doing so, this study more generally provides a window into the dynamic processes involved in constructing event representations as a discourse unfolds across time.

Methods

Participants

Thirty-three UC San Diego undergraduates (22 females, 11 males) between 18 and 30 years of age (M=20.5) participated in the experiment for course credit. All participants had normal or corrected-to-normal hearing and vision, and all were native English speakers. Due to a coding error, incorrect images were displayed to one participant. This participant's data were excluded from analysis.

Stimuli

Stimuli consisted of arrays of four images accompanied by three-sentence discourses. Each discourse began with a sentence introducing one or two protagonists participating in a common event. The second sentence provided additional detail regarding the event, with the purpose of setting up a specific update to the described event in the final sentence. The final sentence then presented this update cue. Image arrays depicted four concepts that related to the unfolding discourse in various ways, as determined by norming procedures described below. None of the four images was mentioned in the discourse. An *Event-Related* image was strongly related to the event context established in the first sentence but was generally unrelated to the update cue. An *Update-Related* image was more weakly related to the general event context established in the first sentence (according to stimulus norming), but was closely related to the update cue. An *Update-Distractor* image was also related to the update cue, but was unrelated to the event context. An *Unrelated* image was unrelated to the discourse throughout.

Each image array was associated with a pair of three-sentence discourses that differed in the event established in the first sentence. In all but three discourse pairs, the second sentences were verbatim across the two discourses. (These three exceptions involved changing a single word across the second sentences to avoid breaks in discourse coherence. These are indicated in the Appendix.) The third sentence always was verbatim across the discourses. For example, the array in Figure 4.1 was paired with another discourse in which the protagonist is established in the first sentence as baking an apple pie. The discourse then continued verbatim to the second and third sentences in the

example in the figure. Across the two discourses in each pair, the same image served either as both Event-Related and Unrelated or as Update-Related and Update-Distractor.

With respect to looking behavior at the update cue, this design crucially allowed for monitoring of eye movements over the same pair of unmentioned images (e.g., knife and saw) triggered by the same linguistic event (the word "cutting"), but in different event contexts established two sentences prior. Differences in visual properties of the Update-Related and Update-Distractor images, as well as those images' semantic associations with the specific words presented, were thus controlled.

Twenty-four sets of arrays and associated discourse pairs were generated as follows. First, a group of 214 brief phrases describing common events (*event tags*; e.g., "baking an apple pie", "remodeling the kitchen") were generated. These were broken into two lists of 107 event tags each. Each list was presented through an online survey to a group of 45 UC San Diego undergraduates, who participated for course credit. For each event tag, participants were asked to form a "mental picture" of the named event and list up to five people, places, or objects that they imagined as being part of the event. Responses were scored based on order of mention (five points for the first response, four points for the second, etc.), and scores for each unique response were summed across participants to obtain a single score for that response. (This is the same "paint-a-mental-picture" task and scoring procedure used by Metusalem et al., 2012.) Scores for an individual response therefore could range from 0 to 225. The results of this "paint-a-mental-picture" norming task are summarized in Table 4.1. These norms were used to identify pairs of events that satisfied two criteria: 1) Each event had a highest-scoring response that was not provided (or provided only once) as a response for the other event

in the pair; 2) Each event had a low-scoring response that was not provided as a response to the other event and that could serve a similar real-world function to a low-scoring response provided for the other event. For example, "sugar" was the highest scoring response for *baking an apple pie* and was not provided as a response to *remodeling the kitchen*. "Sink" scored highest for *remodeling the kitchen* and was not provided as a response for *baking an apple pie.* "Knife" was a low-scoring cutting implement for *baking an apple pie* and was not provided as a response to *remodeling the kitchen.* "Saw" was a low-scoring cutting implement for *remodeling the kitchen* and was not provided as a response to *baking an apple pie*.

Table 4.1: Means and standard deviations of scores from the two norming tasks for the items included in the analysis of eye tracking data. The *Paint-A-Mental-Picture* norming scores are on a scale from 0 to 225, with higher values corresponding to greater association with the event. The *Fit* and *Fit: No Event Context* scores are on a scale form 1 to 7, with higher scores corresponding to greater association with the discourse update in the third sentence. Note that the mean *Paint-A-Mental-Picture* score for Unrelated concepts is slightly above zero due to two items that had low non-zero scores (see Appendix).

	Event-Related	Update-Related	Update-Distractor	Unrelated
Paint-A-Mental-Picture	88.20 (40.64)	4.83 (3.00)	0.00 (0.00)	0.15 (0.65)
Fit	3.59 (2.16)	6.35 (1.22)	3.85 (2.32)	1.40 (2.16)
Fit: No Context	1.77 (1.36)	5.24 (1.93)	5.62 (1.80)	1.76 (1.45)

Discourses were constructed after identifying 24 suitable event pairs. Each discourse began by introducing one or two protagonists and establishing one of the two events in the pair by embedding the event tag in a sentence context. The second sentence

then further described the event with the purpose of setting up the update cue in the third

sentence. Aside from the three exceptions indicated in the Appendix, second sentences

were verbatim across the two discourses in each pair. The third sentence always was

verbatim across the paired discourses and was designed such that a particular word

should trigger an update to the event representation. After discourse pairs were generated,

images for the individual four visual array entities were obtained from various Internet

sources. Whenever multiple depictions of an entity were possible, the depiction most

appropriate for the described event was chosen. For example, many depictions of a knife

are possible, but with the knife specifically being related to *baking an apple pie*, an image

of a chef's knife was chosen.

After obtaining all images, additional norming was conducted to confirm that the

Update-Related images were more closely associated with the update cue in the third

sentence than were the Update-Distractor images. Thirty-one participants on Amazon

Mechanical Turk participated for $5 each. Participants read the experimental discourses

and judged the relationship between the four images and the discourse, specifically

attending to the update cue. They were told to rate the "fit" of each picture with the final

sentence of the story, and that they should "think of the 'fit' of a picture as how likely,

plausible, or possible it is that the final sentence of the story describes a situation that

prominently involves or relates to the depicted object." Three lists of experimental items

were created, with each visual array appearing once in each list. Across the three lists,

each image array appeared once with one of the two associated discourses, once with the

other associated discourse, and once with only the second and third sentences of the

associated discourse pair. The latter was included to assess the effect of the first

sentence's event context on judgments, with the expectation that with the event context removed, both Update-Related and Update-Distractor items should be rated equally on average. Each participant completed one of the three lists. (One participant's responses strongly suggested that they had completely ignored the first two sentences when making their judgments, and their data was not included in analysis.) All four images in the array were presented for ratings simultaneously, with the discourse written immediately above the images. "Fit" ratings were made on a seven-point Likert scale. Participants also wrote out a simple label for each image, to ensure that they were interpreting the images as intended. Any response clearly demonstrating misunderstanding of the image (e.g., "body wash" for a bottle of sunscreen; "tea" for apple cider) was excluded when calculating mean norming scores for that image. This "fit" norming task revealed that for three of the 48 unique items (where "item" refers to the combination of visual array and one associated discourse), an image was misunderstood on at least half of trials. It also revealed four items for which the Update-Distractor image was rated on average one point or more higher than the Update-Related image, providing strong evidence that the Update-Distractor item was strongly related to the update cue within the event context, thereby invalidating the Update-Distractor vs. Update-Related distinction for that item. These seven items were excluded from all analyses and are indicated in the Appendix.

The results from the fit norming task are summarized in Table 4.1. Results showed that the Update-Related images were rated highest on average, and the Unrelated images were rated lowest. The Update-Distractor and Event-Related images were rated between the Update-Related and Distractor images. With the first sentence removed, the Update-Related and Update-Distractor images were rated equally highly and were rated

higher than the Event-Related and Unrelated images, which were rated equally lowly[13].

This qualitative pattern suggests that the Update-Related images were on average more

closely associated with the update cue than were the Update-Distractor images, and that

this difference was due to the event context established in the first sentence.

In addition to the 48 experimental items, 48 filler items were generated. Fillers

described common events, and arrays included zero, one, or two images that were

explicitly named in the discourse. (12 fillers mentioned no images, 24 mentioned one

image, and 12 mentioned two images.) All unmentioned images were chosen to be

unrelated to the discourse. Filler discourses explicitly mentioned images so that the

experiment did not consist entirely of trials in which no images were mentioned, which

might discourage participants from integrating linguistic and visual information.

Audio-Visual Stimulus Preparation

The four images for each array were sized to 400x400 pixels and placed in a 2x2

grid on a black background. Discourses were recorded with a female speaker in a sound-

attenuated chamber. For each discourse pair, the first sentence of each discourse was

recorded separately. In all instances in which the second and third sentence were

verbatim across the two discourses in the pair, those sentences were recorded together,

and each discourse was then created by splicing the appropriate first sentence onto the

second and third sentences. This ensured that verbatim sentences in each pair were

---

[13] Note that the distinction between Update-Related and Update-Distractor images, and between
Event-Related and Unrelated images, is arbitrary for fit norms collected with the first sentence
removed. Groupings into these categories were based on the division of discourse pairs into
separate a/b experimental lists as indicated in the Appendix.

acoustically identical. For the three discourse pairs in which a minor wording change was made to the second sentence, the unique second sentences were recorded separately and spliced onto the single recording of the third sentence. Thus, the third sentences in each discourse pair always were acoustically identical. The three sentences in each discourse were separated by 600 ms of silence, and each discourse ended with an additional 600 ms of silence.

Procedure

The 48 experimental items were split into two groups of 24 items each. Each image array appeared exactly once in each group, and the two associated discourses for each array were split across groups. Within each group, four versions of each image array were made, with each image appearing exactly once in each grid position. This resulted in eight total experimental lists. Within each list, each possible configuration of the four image types into the 2x2 grid appeared exactly once. The 48 filler items were added to each list, resulting in 72 total trials per list. Each list was completed by four of the 32 participants included in the analysis. Experimental and filler trials were presented in unique pseudo-randomized order for each participant; no more than two experimental trials were presented in succession.

Participants were told that they would be presented with arrays of images as they listened to short stories. They were asked only to listen to the stories and freely view the images, following the "look and listen" task common in VWP research (see Huettig et al., 2011). To encourage attention, participants were told that they would be asked a few questions at the end of the experiment about what they saw and heard. They were not told

of any relationship or lack thereof between the images and the stories. They completed two practice trials to familiarize themselves with the procedure before beginning the experiment.

At the start of each trial, the image array was displayed for a 2000 ms preview period during which participants could familiarize themselves with the four images. The auditory stimulus began after this preview period, and the image array remained on the screen through the completion of the auditory stimulus (including the 600 ms of silence following the final sentence). A fixation point appeared at screen center, and participants fixated the point to begin the next trial. If fixation at this point indicated calibration drift, the eye tracker was recalibrated before the next trial. Participants were provided two planned breaks during the experiment. At the completion of the experiment, participants filled out a debriefing questionnaire asking what they found easy or difficult about the experiment and if they noticed any relationship between the images and stories. Most participants reported noticing that some images were related to the stories and some were not.

Eye Movement Recording and Data Processing

Eye movements were recorded using an SR Research Eyelink 1000 in remote configuration. The eye tracking camera was mounted to the bottom of a 17-inch LCD monitor, which itself was mounted on a moveable arm attached to the desk at which the participant sat. Participants wore a small target sticker on their forehead that allowed the eye-tracking camera to adjust for head movement. Monitor/eye tracker position was adjusted for each participant such that the forehead sticker was approximately 600 mm

from the screen, with the center of the monitor placed at eye level. Eye location was sampled at 500 Hz. Eye movement data were obtained through SR Research's Data Viewer software. Fixations shorter than 75 ms and within 0.5 degrees visual angle of another fixation were merged with that fixation, affecting approximately 3% of all fixations. Data were then exported in sample report format (i.e., each sample of eye location as an individual observation) and were further processed in R to obtain the eye movement measures for analysis.

Results

Fixation Proportions

Figures 4.2 and 4.3 presents the proportion of fixations in 20 ms bins at each of the four images across time, time locked to the event tag onset and to the update cue onset, respectively. Fixation proportions were analyzed to assess the relative allocation of visual attention across time to each of the four images. Analysis was conducted using by-subject and by-item paired-sample, two-tailed t-tests in consecutive 20 ms time bins, time locked to either the event tag onset or update cue onset. To minimize the chance of spurious significant results for any single test, only time windows consisting of five or more statistically significant test results ($p<0.05$) both by-subjects and by-items were taken to indicate a significant difference between the contrasted fixation proportion curves across the corresponding time window. Once a time window showing a significant difference in the probability of fixating two contrasted images was established, it was considered broken by the first single non-significant test result not immediately followed by five or more consecutive significant results.

Figure 4.2: Proportion of fixations across time to each of the four images, time locked to the onset of the event tag. Error bars represent the standard error of the mean. The dotted line labeled 'a' marks the time at which the Event-Related trace (blue) diverges from the other three traces. The dotted line labeled 'b' marks the time at which the Update-Related trace (green) diverges from the Update-Distractor and Unrelated.
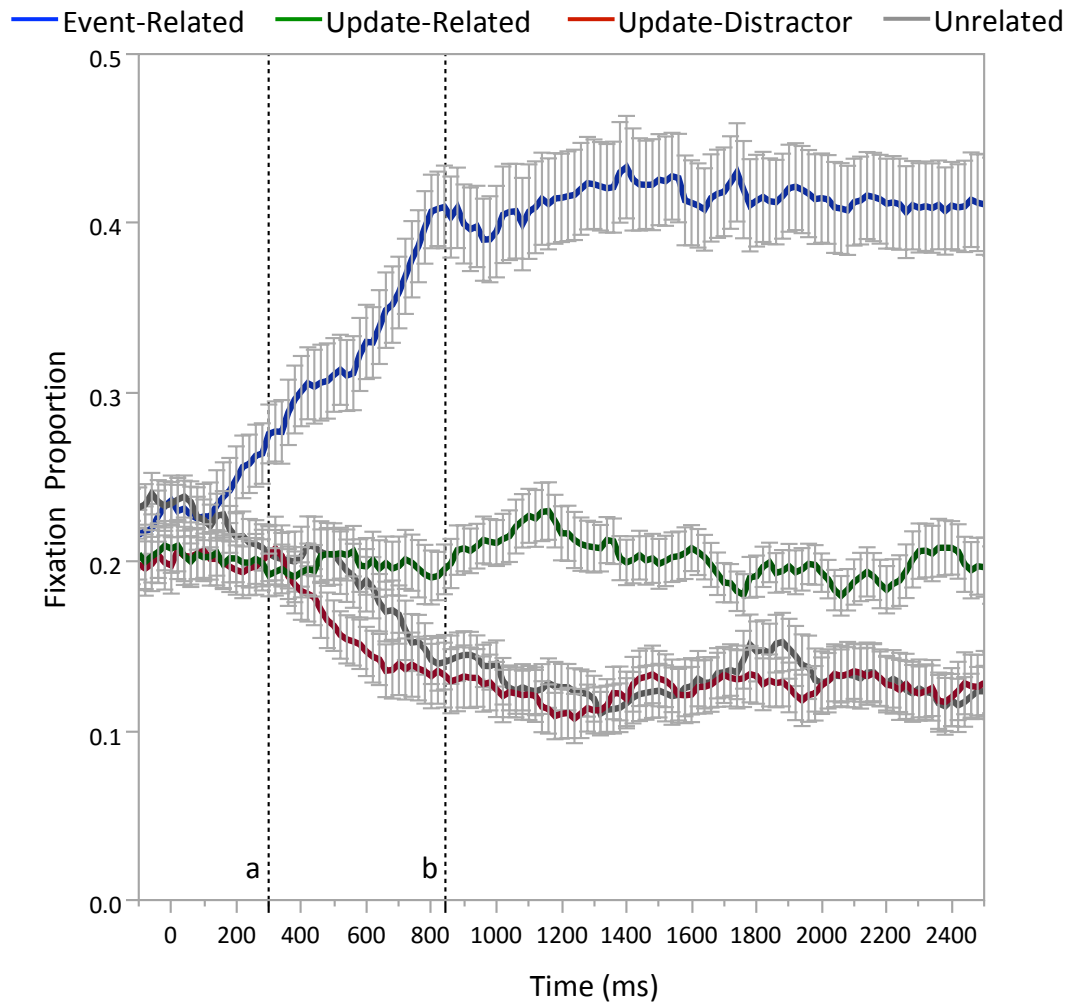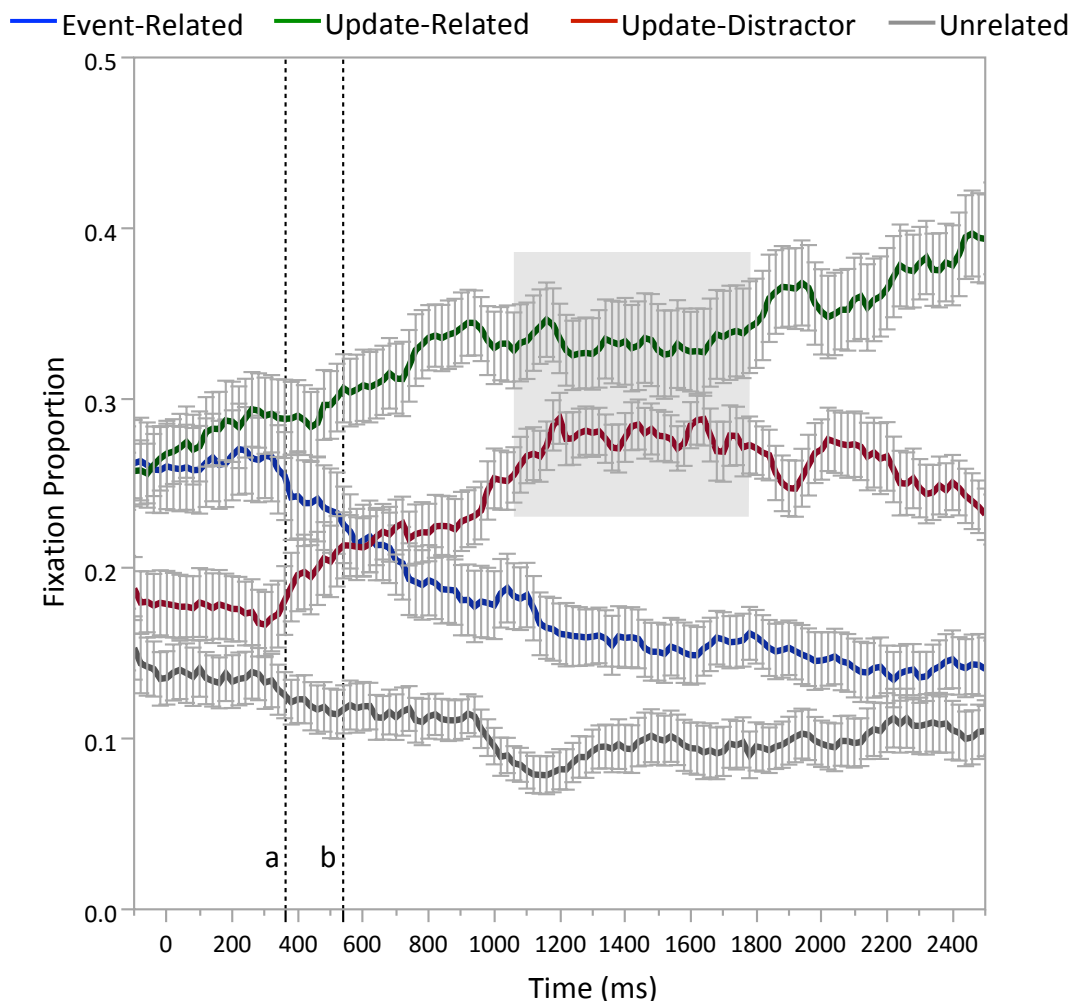
Figure 4.3: Proportion of fixations across time to each of the four images, time locked to the onset of the update cue. Error bars represent the standard error of the mean. The dotted line labeled 'a' marks the time at which the Update-Distractor trace (red) diverges from the Unrelated trace (gray). The dotted line labeled 'b' marks the time at which the Update-Related trace (green) diverges from the Event-Related trace (blue). The gray box indicates the time window in which fixation probability for Update-Related and Update-Distractor images are statistically indistinguishable.

Fixation proportion analysis time locked to the event tag onset was conducted from zero to 2500 ms post-onset. Analysis revealed that fixation proportions for the four images were statistically indistinguishable from 0 to 300 ms. Following this, the

proportion of fixations on the Event-Related image rose relative to the other three images, remaining statistically greater throughout the remainder of the plotted time window. Fixation proportions for the Update-Related image remained statistically indistinguishable from the Update-Distractor and Unrelated images until 840 ms, before becoming statistically greater for the remainder of the plotted time window. Fixation proportions for the Update-Distractor and Unrelated images remain statistically indistinguishable throughout the plotted time window. In summary, fixation proportions time locked to the event tag indicate that visual attention was rapidly attracted to the Event-Related image relative to the other images. Additionally, participants allotted greater visual attention to the Update-Related image than the Update-Distractor and Unrelated images, although this difference appeared later in time.

Analysis time locked to the update cue onset was conducted from 0 to 2500 ms post-onset. From update cue onset to 540 ms, fixation proportions for the Event-Related and Update-Related images were statistically indistinguishable. From 540 to 2500 ms, the fixation proportion for the Update-Related image was significantly greater than that for the Event-Related image. Fixation proportion for the Event-Related image dropped throughout the time window, being overtaken statistically by the Update-Distractor at 1,080 ms and becoming statistically indistinguishable from the Unrelated image beginning at 1,940 ms. Fixation proportion for the Update-Distractor rose throughout the time window, becoming statistically greater than the that for the Unrelated image beginning at 360 ms and statistically greater than that for the Event-Related image at 1,080 ms. While fixation proportion for the Update-Distractor never numerically exceeded that for the Update-Related, the two became statistically indistinguishable from

1,060 to 1,780 ms, before the fixation proportion for the Update-Related again became statistically greater than that for the Update-Distractor.

Analysis of fixation proportion measures time locked to the update cue onset thus reveals the following qualitative patterns. First, fixations to the Event-Related and Update-Related were equal at update cue onset. Shortly after, looks rose to the Update-Related and fell to the Event-Related. Second, fixations to the Update-Distractor and Unrelated were statistically indistinguishable at update cue onset. (There was a numerical trend for more looks to the Update-Distractor than Unrelated.) Crucially, looks to the Update-Distractor rose with a similar time course as those to the Update-Related. While numerically looks to the Update-Related were more probable than looks to the Update-Distractor throughout the time window, there was a time period (1,060 to 1,780 ms) in which they were statistically indistinguishable.

This last point is worth further consideration. If the probability of fixating the Update-Distractor approaches that of fixating the Update-Related, it might be the case that the event context was exerting no effect on looking behavior between the two following the update cue, despite the Update-Related being rated in the fit norms as more closely associated with the event description at that point. To address this issue, we conducted two additional analyses time locked to update cue onset, each testing the hypothesis that looking behavior immediately following the update cue would be affected by the event context. Specifically, if at the update cue the Update-Related images did attract visual attention more strongly than the Update-Distractor images, we should observe the following: First, when fixation was on the Update-Related or Update-Distractor images at update cue onset, the eyes should linger longer on the Update-

Related image before moving to a new image than they should on the Update-Distractor image. Second, when the eye was on either the Event-Related image or Unrelated image (allowing for either the Update-Related or Update-Distractor to be the next image fixated), participants should be more likely to next fixate the Update-Related than Update-Distractor image.

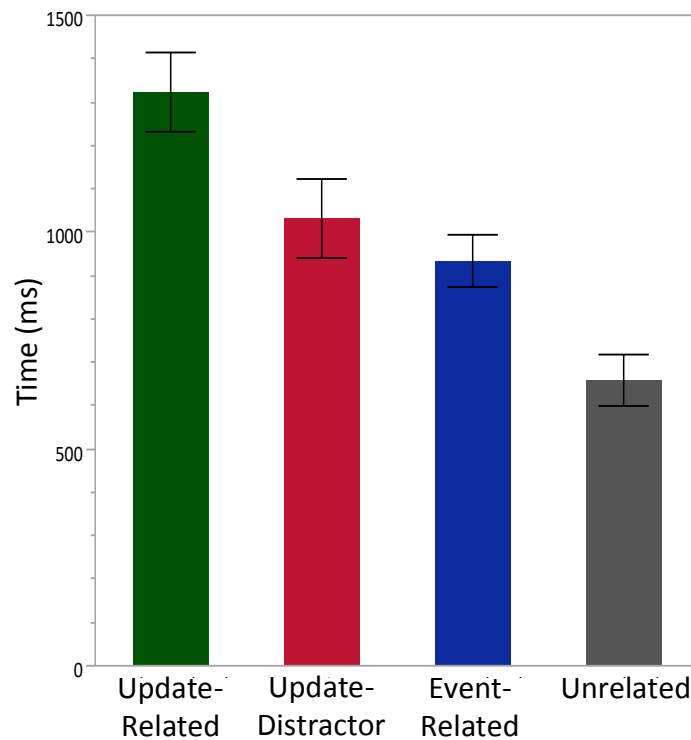Figure 4.4: Linger times for each image following the update cue onset. Error bars represent the standard error of the mean. Linger time is calculated as the time from update cue onset until the eye moved to a new image.

Linger Time

To test the prediction regarding linger time, we measured for each trial the time from update cue onset to the initiation of a saccade away from the currently fixated image.

This measure captures for each image type, how long the eye remained on that image (including refixations on the image) following the update cue onset before leaving to inspect a new image. To the degree that the update cue directs visual attention to one image over another, that image should show longer linger times than the other image.

Linger time analysis utilized linear mixed effects modeling implemented in the lme4 package in R (version 1.1-8; Bates, Maechler, Bolker, & Walker, 2015). Linger time in milliseconds was predicted as a function of image type, using successive-differences coding with the following pairwise comparisons: Update-Related vs. Update-Distractor, Update-Distractor vs. Unrelated, and Unrelated vs. Event-Related. The first comparison addressed the crucial prediction that linger times on Update-Related images should be longer than on Update-Distractor images. The second investigated if participants lingered longer on the Update-Distractor than on the Unrelated baseline. The final comparison investigated if participants lingered longer on Event-Related than Unrelated images. A maximal random effects structure was specified. Random by-subject intercepts and slopes were included. The item-level random effect in this analysis was specified as the unique image fixated in a given experimental item (e.g., fixating the knife while listening to the *baking an apple pie* discourse); therefore, image type did not vary within the item level of this analysis, and only random by-item intercepts were included. Nested model comparisons with likelihood ratio tests were used to assess statistical significance. Trials in which fixation was not at one of the four interest areas at update cue onset (e.g., fixation on the black space between images) were excluded, as were trials with linger times less than 100 ms. The latter were excluded because such short linger times suggest that the eye likely left the image fixated at update cue onset before the cue

could influence eye movement behavior, and because it has recently been suggested that linguistic input can influence eye movements within 100 ms through cancellation of saccades to images that mismatch the current linguistic input (Altmann, 2011). Finally, the analysis excluded trials on which the eye did not leave the image fixated at update cue onset before trial end, because linger times for those trials were necessarily truncated. This resulted in 528 trials entered into analysis.
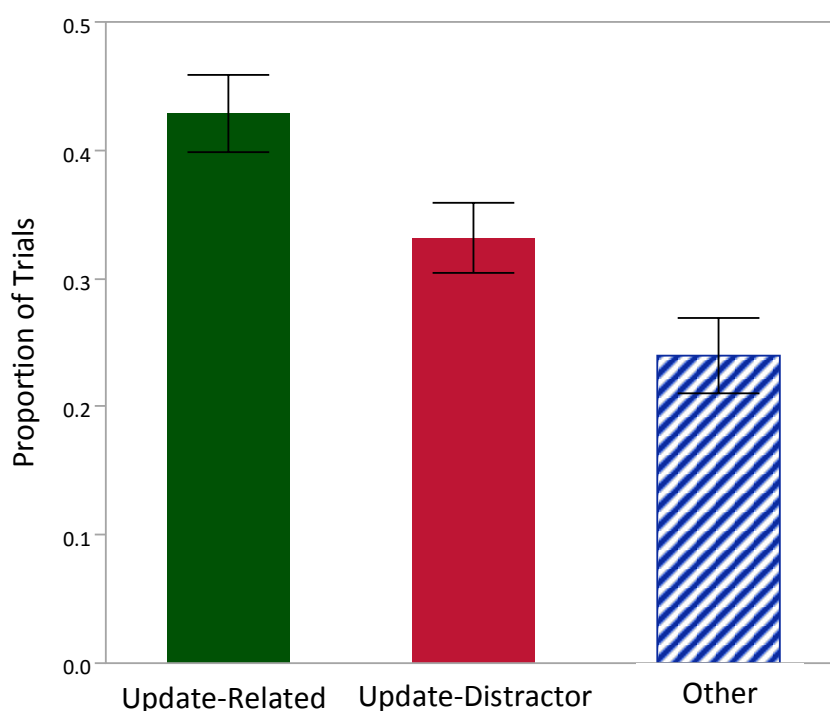
Figure 4.5: The proportion of trials in which, at update cue onset, fixation was at the Event-Related or Unrelated image and next moved to either the Update-Related, Update-Distractor, or Other image (i.e., Event-Related or Unrelated). Error bars represent standard error of the mean.

Figure 4.4 shows mean linger times for each of the four image types. The Update-Related images show the longest linger time, and the Unrelated the shortest. The Update-Distractor and Event-Related images appear intermediate to these two image types, with

only slightly longer linger times for the Update-Distractor relative to the Event-Related image. The linear mixed effects model analysis confirmed the prediction of longer linger times on Update-Related than Update-Distractor images (χ=4.32, p=0.038). Participants also lingered longer on Update-Distractor than Unrelated images (χ=4.84, p=0.028), indicating that the Update-Distractor images captured attention relative to baseline. The analysis also revealed marginally longer linger times on Event-Related than Unrelated images (χ=3.56, p=0.059).[14] The results therefore indicate that participants lingered longer on the Update-Related images than the Update-Distractor images following update cue onset, suggesting that the Update-Related images captured attention more strongly than the Update-Distractor images immediately following update cue onset.

Next Image Fixated

If the update cue more strongly directs visual attention to the Update-Related than the Update-Distractor image, then when fixation is on either the Event-Related or Unrelated image at update cue onset, the eyes should be more likely to move to the Update-Related than Update-Distractor image. This prediction was assessed by comparing the proportion of trials in which the eye began on the Event-Related or Unrelated image and moved to the Update-Related, Update-Distractor, or other image (i.e., the Event-Related when originally fixating the Unrelated, or the Unrelated when

---

[14] This analysis was also run with a control predictor of the normalized time preceding update cue onset that the eye was inspecting the current image. This model did not include an interaction between this control predictor and image type or random effects for the control predictor. The only qualitative difference between this analysis and that reported in the main text was that the difference between Event-Related and Unrelated images was no longer marginally significant (χ=2.27, p=0.132). The difference between Update-Related and Update-Distractor images was again statistically significant (χ=4.32, p=0.038).

originally fixating the Event-Related). As in the linger time analysis, trials in which the eye moved from the currently fixated image less than 100 ms following update cue onset were discarded, as were trials in which the eye did not move from its original location before trial end. A total of 247 trials were entered into analysis. Both by-subject and by-item proportions of trials were compared using paired one-tailed t-tests. The proportions (Figure 4.5) show a three-way split: Update-Related with the highest proportion, Update-Distractor with an intermediate proportion, and Other with the lowest proportion. Statistical tests confirmed this pattern. The proportion of trials in which the eye moved to the Update-Related image was significantly greater than that for the Update-Distractor image by subjects ($t(31)=1.96$, $p=0.030$) and marginal by items ($t(40)=1.67$, $p=0.052$). Additionally, the probability of next fixating the Update-Distractor image was significantly greater than for Other images by subjects ($t(31)=1.91$, $p=0.033$) and marginally greater by items ($t(40)=1.66$, $p=0.052$). These analyses reveal that when participants were fixating the Event-Related or Unrelated images at update cue onset, they were more likely to next move their eyes to the Update-Related than to the Update-Distractor image. They also were more likely to next move their eyes to the Update-Distractor image than to the other image (i.e., Event-Related or Unrelated) on the screen.

Discussion

Linguistic descriptions of events unfold over time, as do the mental representations of those described events. The present study examined the dynamic modulation of event representations in the visual world paradigm (VWP), specifically with respect to unmentioned event knowledge elements. As participants comprehended

event descriptions while viewing unmentioned images, increases in the probability of fixating an image at a particular point in comprehension was taken as indicating that the depicted concept was activated as a component of the dynamically constructed mental representation of the described event.

When a discourse describes an event, images depicting event knowledge elements attract visual attention even when they are not mentioned in the unfolding discourse, evidenced by an immediate increase in looks to the Event-Related image relative to the other images. That looks to the Update-Related image were greater than those to the Update-Distractor and Unrelated images suggests that even weakly associated event knowledge elements (as quantified through the paint-a-mental-picture norming task) attract visual attention to a greater degree than depicted concepts that are not associated with the described event.

By the update cue onset, participants were equally likely to fixate the Event-Related and Update-Related image, and both were more likely to be fixated than the Update-Distractor or Unrelated image. This indicates that by this point in the discourse, the participants had recognized two possible event participants depicted on the screen; in a sense, they recognized a cohort of two event-relevant concepts. Interestingly, when the update cue was presented, looks rose not only to the Update-Related image, but also to the Update-Distractor, despite the Update-Distractor not being a member of the initial cohort of event-relevant concepts. This rise in looks to the Update-Distractor did not appear delayed, as looks to the Update-Distractor diverged from looks to the Unrelated image approximately 360 ms after the update cue onset. This suggests that participants considered the Update-Distractor as a possible event participant immediately following

the update cue, despite the Update-Distractor not being recognized as related to the event before that point. This more generally suggests that as participants were constructing event representations online, they actively considered the alternatives presented to them at each point in time as the discourse unfolded. While the allocation of visual attention up to the update cue suggested that they identified a cohort of event-relevant concepts, they did not limit themselves to these concepts when considering the relevance of each image following the update cue. That is, participants did not establish a subset of event-relevant concepts and subsequently winnow down that subset to arrive at the most relevant concept; instead, they actively considered the relevance of each of the depicted concepts to the described event at each point in time.

It might seem strange to suggest that constructing an event representation involves considering something as unlikely as using a saw while baking an apple pie. Yet, events do not always play out in stereotypical fashion in the real world, nor do their descriptions proceed as one might expect. To function adaptively both as a language user and actor in the real world, flexibility and the constant consideration of alternative possibilities is required. It is likely that this consideration of alternatives is constrained by the comprehender's prior knowledge. Additional analyses conducted on eye movement behavior (i.e., the linger time and next-image-fixated analyses) did show that the Update-Related image attracted visual attention to a greater degree than the Update-Distractor image following the update cue, and the probability of fixating the Update-Related image was numerically greater than that of fixating the Update-Distractor throughout. If looks to the Update-Distractor do reflect the consideration of alternative possibilities within the event context, then the degree to which the Update-Distractor could be incorporated into

the event representation should affect the amount of visual attention allocated to it in this paradigm. Unfortunately, the present study was not designed to address this issue. This could be examined in future research that systematically varies the degree of fit between various images and the unfolding discourse at a particular point in time.

It must also be noted that it is possible that looks to the Update-Distractor do not reflect event representation construction, but instead reflect another cognitive process operating in parallel. Linguistic processing at a local level could drive looks to the Update-Distractor; "cutting" could cue looks to cutting implements without those looks reflecting processing at the level of the event context. Still, it is unlikely that local effects can completely explain looks to the Update-Distractor. The Update-Related image did attract visual attention to a greater degree than the Update-Distractor following the update cue, indicating that event knowledge was directing visual attention at that point in processing. It seems unlikely that event knowledge exert no effect on looks to the Update-Distractor image.

As looks to the Update-Distractor rose following the update cue, looks to the Event-Related image dropped, approaching the Unrelated baseline late in the 2500 ms time window of analysis. This might indicate that participants were no longer considering the Event-Related image as a possible component of the described event. However, such a conclusion should be made with caution. The probability of fixating the Event-Related image did not exhibit a precipitous drop following the update cue, remaining greater than the probability of fixating the Unrelated image for much of the analysis time window (and numerically greater throughout). Additionally, with participants appearing to actively consider both the Update-Related and Update-Distractor images, it may be that

they visually abandoned the Event-Related image while nevertheless continuing to entertain as related to the described event. Further study is necessary to clarify this issue.

Additional caution must be taken when generalizing these results to language comprehension in the absence of nonlinguistic conceptual cues. In the present study, participants were given a set of four concepts to map onto the unfolding discourse. While previous research indicates that comprehenders do activate unstated elements of event knowledge, it is possible, perhaps even likely, that the Update-Distractor would not be activated during comprehension if it were not otherwise cued. The present study nevertheless informs our understanding of the dynamics of event representation construction, specifically by demonstrating that comprehenders actively consider the alternatives provided to them at each point in time, as opposed to initially identifying a set of event-relevant concepts and proceeding to consider only those concepts as a discourse unfolds. More generally, it demonstrates flexibility in the activation of unstated event knowledge elements during the dynamic construction of mental representations of described events.

With respect specifically to the mapping of linguistic and visual information in the VWP, the present study demonstrates that event knowledge mediates the mapping between language input and visually depicted concepts that are never mentioned in the discourse. Much like event knowledge drives anticipatory eye movements, it also drives eye movements to unmentioned objects related to the described event. Altmann and Kamide (2007) put forth a mechanistic account of eye movements to unmentioned objects. They argue that fixating an entity results in formation of an episodic trace associated with that entity and its location in the visual field. The trace is a temporal

record of both the sensory experience of the entity, as well as the entity's conceptual

characteristics (e.g., its functional properties). When processing language, conceptual

information that overlaps with the information associated with the episodic trace may

become active, thereby boosting activation of the trace. As the activation of the trace

increases, so does the probability of launching an eye movement to the associated

location in the visual field. Crucially, knowledge of an entity's functional characteristics

and the types of events the entity takes part in are part of the conceptual information

associated with the episodic trace. This account seems to make the straightforward

prediction that when an event description highlights a depicted object with certain

functional properties (e.g., something that can be used to cut while remodeling a kitchen),

and a depicted entity's episodic trace is linked to this conceptual information, the eyes

should be drawn to that entity despite it not being mentioned.

This account may also predict the present finding that the Update-Distractor also

attracted visual attention to a certain degree. The Update-Distractor concepts overlapped

in functional characteristics with the Update-Related concepts; this was how potential

Update-Distractors were identified during stimulus generation. To the degree that the

update cues in the discourses activated information regarding an object with certain

functional characteristics, any depicted concepts that overlap in these functional

characteristics (even if not typically involved in that event) should draw visual attention

to some degree. Thus, Altmann and Kamide's (2007) account has the potential to explain

increased looks to the Update-Distractor images here, and possibly previous reports of an

increase in looks to potential patient nouns that align with the preceding verb but not

necessarily with the event denoted by the combination of agent and verb (Borovsky,

Elman, & Fernald, 2012; Kamide et al., 2003). This account would imply that looks to Update-Distractor images in this study were driven mainly by the Update-Distractor concepts' functional characteristics and that an Update-Distractor that is judged to be an improbable event participant, or even impossible to coerce into the event, should nevertheless draw visual attention so long as it possesses certain functional properties. As the degree of fit with the event context increases, so should the probability of attracting visual attention, with the most event-appropriate concept drawing greatest attention. This hypothesis can be tested in future research.

Finally, the present study provides general evidence that language-mediated eye movements over visually depicted concepts reflect the construction of mental representations of described events through the integration of sensory inputs with event knowledge. While this has been realized within a particular experimental paradigm here, it likely is a more general property of cognition, with cognitive agents integrating in real time the information from all available modalities onto their own knowledge in order to form unified mental representations that support reasoning about and acting within the world.

Chapter 4, in full, is currently being prepared for publication of the material. Metusalem, R. & Elman, J.L. Dynamic Modulation of Event Knowledge Activation in the Visual World Paradigm. The dissertation author was the primary investigator and author of this material.

Appendix

Summary of the experimental stimuli. Under *Item*, numbers indicate unique visual arrays and *a/b* specifies the two discourses associated with the array. Half of participants received the 24 'a' items, and half the 24 'b' items. *Sentence 1* is the first sentence for the discourse, with the word used to time lock to the event tag underlined. *Sentences 2 & 3* are the following sentences for both the 'a' and 'b' discourses, with the word used to time lock to the update cue underlined. *Concepts* are the four concepts represented in the visual array. The first listed is the Event-Related concept for the item (and Unrelated for the other item in the a/b pair), while the second is the Update-Related concept for the item (and Update-Disrtactor for the other item in the a/b pair). *Paint-Pic* and *Fit* provide the scores from the paint-a-mental-picture and fit norming tasks. In each pair of scores, the left score represents the score when the concept was related to the described event (i.e., Event-Related or Update-Related), and the right represents the score when the concept was not related to the described event (i.e., Unrelated or Update-Distractor).

An example: The discourse for Item 01a was "Kaitlin's mom took her in for a checkup with the doctor. Kaitlin was a little scared, but she ended up doing great. She knew she wouldn't go home empty handed after doing so well." The associated array depicted a stethoscope (Event-Related), a lollipop (Update-Related), a car (Update-Distractor), and stage lights (Unrelated). The paint-a-mental-picture norming score was 41 for the stethoscope, 5 for the lollipop, and zero for both the stage lights and car. The fit norm score was 4.3 for the stethoscope, 4.8 for the lollipop, 1.1 for the stage lights, and 2.8 for the car.

Items 03a, 03b, and 21a were excluded for having an image mislabeled by more than half of participants in the in the fit norms. Items 12a, 14b, 17a, and 23a were excluded for having an Update-Distractor image with a fit norm score of one or more points higher on average than the Update-Related.

Item	Sentence 1	Sentences 2 & 3	Concepts	Paint-Pic		Fit	
01a	Kaitlin's mom took her in for a <u>checkup</u> with the doctor.	[Kaitlin/She] was a little scared, but she ended up doing great. She knew she wouldn't go home <u>empty</u> handed after doing so well.	stethoscope lollipop	41 5	0 0	4.3 4.8	1 1.5
01b	Kaitlin was competing on a popular <u>game</u> show.		stage lights car	34 7	0 0	4.5 4.6	1.1 2.8
02a	Julie spent her Saturday night <u>out</u> at the bar.	The night started out quietly, but things quickly got really loud and crazy. Julie decided to <u>sit</u> down and rest for a few minutes so she could make it through the night.	beer stool	42 9	0 0	3.3 6.2	1.1 5.2
02b	Julie spent her Saturday night <u>babysitting</u>.		television couch	54 8	3 0	2.8 7	1.5 3
03a	Jenny went for a tour at an <u>apple</u> orchard.	She started down the long trail and managed to work up a good sweat. She was very <u>thirsty</u> by the end of the long trek.	trees cider	122 6	0 0	3.3 3.75	1.7 2.4
03b	Jenny competed in a desert <u>dirt</u> bike race.		helmet water	50 8	0 0	3.3 6.5	1 6.3
04a	Harry was outside when he got <u>bitten</u> by a rattlesnake.	The situation was looking pretty bad. Harry hoped that somebody would call <u>911</u> before things could get any worse.	poison ambulance	73 9	0 0	3.6 6.8	1.4 4.9
04b	Harry was out on the town when he crossed the wrong <u>guy</u> and got into a fight.		fists police	86 7	0 0	4.7 6.5	1.2 4.4
05a	Emily was up in the <u>mountains</u> going skiing.	It was rather chilly in there, and she was cold. During a break, she <u>drank</u> from a hot thermos to warm	snow hot chocolate	155 4	0 0	4.2 6.7	2.4 6.1

05b	Emily was in the classroom taking a difficult final exam.	up a bit.	pencil coffee	122 4	0 0	2.7 5.9	1.1 5.8
06a	Lynn spent the day hanging out at the beach.	The sun was very intense, and Lynn was beginning to overheat. She decided to sit in the shade for a little while to avoid getting heat exhaustion.	sand umbrella	114 17	0 0	3.9 6.6	1.9 4
06b	Lynn spent the day climbing a nearby mountain.		rope tree	82 6	0 0	1.8 6.7	1 3.9
07a	James attended a long and difficult math class.	After what seemed like forever, he became very tired. He checked the time to see how much longer it would be until he could go home.	calculator clock	64 4	0 0	2.8 6.6	1.1 4.4
07b	James worked a long and difficult day as a lumberjack.		ax watch	115 1	0 0	3.3 6.8	1 6.7
08a	Lauren joined some friends to play volleyball at the beach.	She was distracted as she [played/worked], but soon noticed searing heat on her exposed skin. She had accidentally burned herself and promised to be more careful in the future.	net sunscreen	106 7	0 0	4.1 6.3	1 1.5
08b	Lauren worked in her kitchen baking a cake.		oven mitt	64 3	0 0	6.7 5.5	2 1.8
09a	Robert laid back and watched some TV.	As he enjoyed the show, he felt a cold draft and got a little chilled. He bundled up as best he could and turned his attention back toward the show.	couch blanket	114 5	0 0	3.9 6.6	1 3.7
09b	Robert went to the symphony at the local concert hall.		instruments coat	58 4	0 0	4.1 6.2	1.1 4.8
10a	Damien went over to a friend's house for a summer barbecue.	The day was hot and humid, and Damien was uncomfortable. He hoped he might be able to take a swim to cool off, and asked his friend if that would be possible.	grill pool	80 11	3 0	2.8 6.6	1.7 3.3
10b	Damien's good friend took him camping during the summer.		tent lake	177 3	0 0	3.9 6.4	1.2 4.8
11a	Steve had to take his car in to the mechanic.	He wasn't sure what the problem was, other than it wouldn't turn on. He checked that there was electricity flowing before anything else.	oil battery	71 3	0 0	3.4 6.2	1 1.8
11b	Steve recently had some trouble setting up his home theater system.		speaker outlet	106 4	0 0	4.2 6.2	1.9 2.6

	Sentence	Story	Word				
12a	Suzy went out on Halloween to go trick-or-treating.	She soon found herself along in the shadows and was a little spooked. She heard a scuttling underfoot and jumped at a small shadow darting across the ground.	candy cat	148 6	0 0	3.3 5.2	1.2 4.3
12b	Suzy took a ride on the subway last night.		ticket rat	64 4	0 0	2.8 6	1 6.2
13a	Over the weekend, Sandra went out to a dance club.	The place looked absolutely amazing on the inside, and Sandra wanted to take a picture. She hadn't had enough room to pack a camera, though, because she had brought so much else with her.	alcohol purse	51 5	0 0	3.4 6.3	1.1 2.5
13b	Over the weekend, Sandra went cave diving.		flashlight backpack	52 4	0 0	3.9 6.4	1.5 3.7
14a	Luke explored the savannah on an African safari.	As he stood in the sun, he noticed a (mountain) lion peering at him over a nearby hill. He wondered how he might defend himself if the creature were to get any closer.	jeep gun	66 6	0 0	3.7 6.7	1.5 6.4
14b	Luke worked a long day outside on his farm.		tractor pitchfork	46 9	0 0	2.9 4.5	1.3 2.8
15a	Daniel decided one afternoon to bake an apple pie from scratch.	He began working on the kitchen counter. He was always nervous about cutting himself, so he worked very carefully.	sugar knife	54 3	0 0	2.8 6.8	1 2.6
15b	Daniel was excited to start remodeling his kitchen.		sink saw	42 7	0 0	3.6 6.1	2.3 2.8
16a	Amanda and Haley were working out at the gym.	Haley asked to borrow some money to go buy a drink from the nearby vending machine. Amanda's wallet was tucked away with her other things, so she took a moment to go grab it.	weights locker	104 3	0 0	3.7 5	1 1.5
16b	Amanda and Haley were hanging out at the beach.		sand bag	114 2	0 0	3.7 6.5	1.1 5
17a	Frank was nearly finished with yet another day of work on his farm.	He was exhausted and knew that he would sleep well that night. But he dreaded the loud wake-up call that awaited him early in the morning.	hay rooster	49 2	0 0	2.4 5.2	1.4 4.4
17b	Frank was nearly finished with the first day of a three-day interview for a new job.		suit alarm clock	123 3	0 0	2.5 6.7	1.2 6.3

18a	Rachel started teaching <u>art</u> class at the local kindergarten.	She knew the whole ordeal would be very messy. She covered the <u>table</u> to keep the wood from getting scratched up or stained.	paint newspaper	164 2	0 0	4.7 6.5	1.2 3.6
18b	Rachel had her entire family over for <u>Thanksgiving</u> dinner.		turkey table cloth	213 3	0 0	4.1 6.9	1 4.9
19a	Scott recently <u>dissected</u> a frog in biology class.	He was amazed at the beauty and complexity of nature. However, he wished he could somehow <u>zoom</u> in to get a closer look at a few things.	scalpel microscope	84 5	0 0	3.2 7	1.4 3.5
19b	Scott recently was led on a <u>jungle</u> expedition.		trees binoculars	70 7	0 0	3.8 6.6	1 2.6
20a	Brenda and a friend were making a <u>fruit</u> salad.	They planned to enjoy their labors for lunch a few hours later. They <u>chilled</u> their lunch so that it wouldn't spoil before they were ready to eat.	bowl refrigerator	68 4	0 0	3.4 6.5	1.5 2.7
20b	Brenda and a friend were <u>fishing</u> up in the mountains.		pole cooler	96 4	0 0	4 6.9	1 4.2
21a	Brooke was getting ready for <u>bed</u>.	As she sipped some water, she accidentally spilled a good amount down her chin and shirt. She <u>blotted</u> her chin dry, but there was little she could do to dry her shirt.	toothbrush towel	109 6	0 0	2.1 6.8	1.4 5.6
21b	Brooke was having a <u>picnic</u> at the park.		basket napkin	140 2	0 0	3.2 6.7	1.1 3.8
22a	Kelly and Logan spent several days on a <u>jungle</u> expedition.	It had been raining, and the mud was pretty deep. Soon their <u>feet</u> were soaked through and caked in nastiness, and they were both miserable.	trees boots	70 5	0 0	4.9 6.3	2 4.6
22b	Kelly and Logan were trying to push their <u>car</u> out of some mud.		tires shoes	40 1	0 0	2.8 5.9	1 4.5
23a	Justin performed a <u>halftime</u> show in his high school marching band.	As he walked along, he suddenly got very dizzy. He soon <u>collapsed</u> and smacked his head pretty hard, and a friend knelt down to help him.	uniform grass	84 2	0 0	4.3 4.3	1.4 2.5
23b	Justin spent the day sightseeing in <u>New</u> York City.		taxi concrete	49 2	0 0	2.3 6.5	1 5.4
24a	Jack was doing some <u>shopping</u> on the Internet.	He was quite happy with what he had bought. Randomly, he remembered that he had some news	credit card email	84 3	0 0	2 6.8	1.7 6

| 24b | Jack was out <u>mailing</u> a gift to a friend. | to <u>send</u> to a friend, so he took care of that too. | stamp letter | 110 2 | 0 0 | 5.1 5.8 | 3.2 3.5 |

References

Altmann, G.T.M. (2011). Language can mediate eye movement control within 100 milliseconds, regardless of whether there is anything to move the eyes to. *Acta Psychologica, 137*, 190-200.

Altmann, G.T.M. & Kamide, Y. (1999). Incremental interpretation at verbs: Restricting the domain of subsequent reference. *Cognition, 73*, 247-264.

Altmann, G.T.M. & Kamide, Y. (2007). The real-time mediation of visual attention by language and world knowledge: Linking anticipatory (and other) eye movements to linguistic processing. *Journal of Memory and Language, 57*, 502-518.

Altmann, G.T.M. & Kamide, Y. (2009). Discourse-mediation of the mapping between language and the visual world: Eye movements and mental representation. *Cognition, 111*, 55-71.

Altmann, G.T.M. & Mirković, J. (2009). Incrementality and prediction in human sentence processing. *Cognitive Science, 33*, 583-609.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*(1), 1-48.

Borovsky, A., Elman, J.L., & Fernald. A. (2012). Knowing a lot for one's age: Vocabulary skill and not age is associated with anticipatory incremental sentence interpretation in children and adults. *Journal of Experimental Child Psychology, 112*, 417-436.

Cook, A.E., Limber, J.E., & O'Brien, E.J. (2001). Situation-based context and the availability of predictive inferences. *Journal of Memory and Language, 44*(2), 220-234.

Cooper, R.M. (1974). The control of eye fixation by the meaning of spoken language. *Cognitive Psychology, 6*, 84-107.

Dahan, D. & Tanenhaus, M.K. (2005). Looking at the rope when looking for the snake: Conceptually mediated eye movements during spoken-word recognition. *Psychonomic Bulletin & Review, 12*(3), 453-459.

Elman, J.L. (2009). On the meaning of words and dinosaur bones: Lexical knowledge without a lexicon. *Cognitive Science, 33*, 547-582.

Graesser, A.C., Singer, M., & Trabasso, T. (1994). Constructing inferences during narrative text comprehension. *Psychological Review, 101*(3), 371-395.

Henderson, J.M. & Ferreira, F. (2004). Scene perception for psycholinguists. In J.M. Henderson & F. Ferreira (Eds.), *The Interface of Language, Vision, and Action: Eye Movements and the Visual World* (pp. 1-58). New York, NY: Psychology Press.

Huettig, F. & Altmann, G.T.M. (2005). Word meaning and the control of eye fixation: Semantic competitor effects and the visual world paradigm. *Cognition, 96*, B23-B32.

Huettig, F., Rommers, J., & Meyer, A.S. (2011). Using the visual world paradigm to study language processing: A review and critical evaluation. *Acta Psychologica, 137*(2), 151-171.

Johnson-Laird, P.N. (1983). *Mental Models*. Cambridge, England: Cambridge University Press.

Kalénine, S., Mirman, D., Middleton, E.L., & Buxbaum, L.J. (2012). Temporal dynamics of activation of thematic and functional knowledge during conceptual processing of manipulable artifacts. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 38*(5), 1274-1295.

Kamide, Y., Altmann, G.T.M., & Haywood, S.L. (2003). The time-course of prediction in incremental sentence processing: Evidence form anticipatory eye movements. *Journal of Memory and Language, 49*, 133-156.

Keefe, D.E. & McDaniel, M.A. (1993). The time course and durability of predictive inferences. *Journal of Memory and Language, 32*, 446-453.

Knoeferle, P. & Crocker, M.W. (2006). The coordinated interplay of scene, utterance, and world knowledge: Evidence from eye tracking. *Cognitive Science, 30*, 481-529.

Kukona, A., Altmann, G.T.M., Kamide, Y. (2014). Knowing *what*, *where*, *and when*: Event comprehension in language processing. *Cognition, 133*, 25-31.

Kukona, A., Fang, S.-Y., Aicher, K.A., Chen, H., & Magnuson, J.S. (2011). The time course of anticipatory constraint integration. *Cognition, 119*, 23-42.

Marslen-Wilson, W. & Tyler, L.K. (1980). The temporal structure of spoken language understanding. *Cognition, 8*, 1-71.

McClelland, J.L., & Elman, J.L. (1986). The TRACE model of speech perception. *Cognitive Psychology, 18*(1), 1-86.

McKoon, G. & Ratcliff, R. (1992). Inference during reading. *Psychological Review, 99*(3), 440-466.

McRae, K. & Matsuki, K. (2009). People use their knowledge of common events to understand language, and do so as quickly as possible. *Language and Linguistics Compass, 3*(6), 1417-1429.

Metusalem, R., Kutas, M., Urbach, T.P., Hare, M., McRae, K., & Elman, J.L. (2012). Generalized event knowledge activation during online sentence comprehension. *Journal of Memory and Language, 66*, 545-567.

O'Brien, E.J., Shank, D.M., Myers, J.L., & Rayner, K. (1988). Elaborative inferences during reading: Do they occur on-line? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14*(3), 410-420.

van Dijk, T.A. & Kintsch, W. (1983). *Strategies of Discourse Comprehension*. New York, NY: Academic Press.

Yee, E. & Sedivy, J.C. (2006). Eye movements to pictures reveal transient semantic activation during spoken word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*(1), 1-14.

Zwaan, R.A., Langston, M.C., & Graesser, A.C. (1995). The construction of situation models in narrative comprehension: An event-indexing model. *Psychological Science, 6*(5), 292-297.

Zwaan, R.A. & Radvansky, G.A. (1998). Situation models in language comprehension and memory. *Psychological Bulletin, 123*(2), 162-185.

CHAPTER 5:

GENERAL DISCUSSION

Event knowledge guides incremental language comprehension, including the generation of expectations for upcoming input (Altmann & Mirković, 2009; Elman, 2009; McRae & Matsuki, 2009). The research presented in this dissertation began by investigating the scope of event knowledge activation during comprehension, specifically testing the hypothesis that activation extends to knowledge elements beyond those expected to appear in the unfolding language. An event-related brain potential (ERP) study found that concepts that unexpected words elicit a reduced N400 when related to the general event described (Chapter 2). This finding indicates that event knowledge activation during real-time comprehension extends beyond those elements expected to appear in the unfolding sentence. A further ERP study utilizing the same stimuli examined cerebral hemispheric asymmetries in this activation, testing the hypothesis that right hemisphere processes drive activation of linguistically unexpected event knowledge elements. It was found that N400 reduction for unexpected but event-relevant words was obtained with left visual field/right hemisphere presentation but not right visual field/left hemisphere presentation, supporting the hypothesis (Chapter 3). With prior research demonstrating that the right hemisphere is critically involved in the generation of elaborative inferences (e.g., Beeman, Bowden, & Gernsbacher, 2000), it is possible that the activation of linguistically unexpected event knowledge elements reflects the generation of elaborative inferences (i.e., inferences that are not necessary for discourse coherence but that enrich the mental representation of the described event).

As detailed in their respective chapters, these studies expand our knowledge of the information activated during incremental language comprehension and the neurocognitive mechanisms underlying this activation. Nevertheless, they do leave open

numerous important questions. Future research should address the specific aspects of the discourse context that determine which elements of event knowledge are activated. This research could take as a starting point discourse comprehension theories that specify the conceptual dimensions along which situation models are constructed and updated, such as the Event Indexing Model (Zwaan, Langston, & Graesser, 1995). Research additionally should address the time course of activation. With the studies in Chapters 2 and 3 probing activation at single points in a sentence, it remains unknown when the activation first occurred, whether activation was gradual or all-at-once, and how long activation persisted. The time course of activation for any given knowledge element is likely to be highly context sensitive, requiring a fusion of research on the time course of activation with that on the role of various contextual cues.

Despite these unknowns, the present findings challenge the "minimalist" theory of inference generation (McKoon & Ratcliff, 1992), which argues that elaborative inference (and nearly all other forms of inference) rarely occurs in reading. With the stimuli in Chapters 2 and 3 not involving discourse coherence breaks (and therefore not likely to trigger bridging inferences), the Event-Related targets in those chapters can be thought of as probing elaborative inferences. It appears that elaborative inference is more common than the minimalist theory posits. While the "constructionist" theory of inference (Graesser, Singer, & Trabasso, 1994) posit a greater prevalence of elaborative inference than does the minimalist view, even the constructionist view argues that elaborative inference is relatively rare and occurs only under specific circumstances. It is possible that the stimuli from Chapters 2 and 3 embody the specific circumstances proposed by the constructionist view to support elaborative inference, although they were not

specifically designed to do so. Instead, it perhaps is more likely that the combination of electrophysiological measures with carefully normed stimuli allowed the research presented here to detect evidence suggesting routine generation of elaborative inferences, while the wide variety of behavioral methods paradigms employed at the height of text processing research yielded muddled results (see Keenan, Potts, Golding, & Jennings, 1990, for thorough discussion of this issue). Ultimately, the research presented in Chapters 2 and 3 was concerned with the scope of and the mechanisms supporting event knowledge activation, and was not designed to test specific theories of inference generation. Yet, with inference an undoubtedly crucial component of language comprehension, and with past inference research leading theorists at the time to argue that elaborative inference is relatively uncommon, this dissertation generally challenges sentence and discourse comprehension researchers to reconsider the prevalence of elaborative inference and its role in comprehension.

The study presented in Chapter 4 complements those in Chapters 2 and 3 by examining the dynamic activation of unstated event knowledge elements in the visual world paradigm. The continuous nature of eye movement measures allowed for observing how individual images related to an event description varied in the degree to which they attracted visual attention as the description unfolded over time. The results of that study showed that unmentioned event knowledge elements drew visual attention rapidly following the establishing of an event context early in the discourse. When the discourse further elaborated on the event, highlighting the relevance of one of the images first recognized as related to the event, visual attention was drawn not only to this image, but also to an image that locally related to the sentence but had not drawn visual attention

when the event context was first established. This suggests that comprehenders were entertaining the relevance of each image to the unfolding event description at each point in time, as opposed to limiting consideration to only those images first recognized as related to the event earlier in the discourse. Caution must be taken when generalizing these results to language comprehension processes in the absence of imagistic cues. Still, these results are compatible with a view of unexpected event knowledge activation as highly flexible as it occurs across time. When a discourse establishes an event context, a comprehender may engage a body of knowledge regarding how that event typically unfolds, but as a discourse progresses, activation is not limited to concepts in this body of knowledge. Comprehenders will flexibly consider alternatives to previously activated knowledge elements, at least when prompted by additional contextual cues.

While the studies in this dissertation address a rather specific set of issues related to event knowledge and language comprehension, they also highlight a more fundamental aspect of comprehension: the meaning of language extends beyond the words and sentences presented. Language comprehension is more than the computation of logical propositions entailed by a sentence, and event knowledge activation extends beyond those concepts necessary for computing such propositions. Results like those presented here suggest that comprehension is a process by which the comprehender uses their knowledge of the world, in combination with available contextual cues (both linguistic and nonlinguistic), to understand not the language presented to them, but the world described by that language. In this view, "understanding" language describing the world is akin to "understanding" the world nonlinguistically. This is not a radical idea; it aligns not only with the notion of the situation model, but also with ideas from cognitive

linguistics and embodied cognition suggesting that comprehension relies upon the cognitive and neural systems that support perceiving and acting in the world (Barsalou, 1999; Fauconnier, 1985; Jackendoff, 1987; Lakoff & Johnson, 1980; Langacker, 1986; Talmy, 1983). Additionally, this is not to dismiss the importance of the words in a sentence, the syntactic structures in which those words are situated, or the propositions that structured sequences of words entail; these are the foundation on which higher-level understanding is built. This is only to highlight that the research in this dissertation supports a views of language as the incremental transformation of linguistic input into event representations that facilitate reasoning about and acting within the world.

It must be admitted that the advocated interpretation of the research in this dissertation begs the question of whether the activation of linguistically unexpected event knowledge elements reflects the incorporation of those elements into the event representation itself. When the concept of a jacket is partially activated while reading a story about children playing in the snow, does this indicate that the mental representation under construction specifies the children as wearing jackets? When the eyes are drawn to an image of a saw when hearing the word "cut" in a story about remodeling a kitchen, does this indicate that the mental representation specifies the saw as the cutting implement? To the degree that language comprehension entails mental representation of described events, it seems parsimonious to assume the answers to these questions to be "yes". Yet, perhaps it is the case that the activation of event-relevant concepts observed here does not affect the ongoing construction of a mental representation of a described

event, but rather is a byproduct of this or some other process.[15] The answer to these questions even might differ between the studies in Chapters 2 and 3 and that in Chapter 4. It could be that comprehending language in the presence of visual images encourages incorporation of the depicted concepts into the event representation, but that the N400 reduction observed in Chapters 2 and 3 do not reflect such incorporation. The present findings reflect may indeed reflect incorporation of unexpected event knowledge elements into mental event representations, but this issue requires further research.

The studies presented here leave open additional questions regarding if and how various comprehension functions are affected by or depend on the activation of linguistically unexpected event knowledge. Numerous cognitive functions, linguistic and nonlinguistic, could depend on or otherwise be affected by such activation. For example, generation of coherence or bridging inferences prompted by breaks in discourse coherence might be facilitated when the concepts necessary for those inferences have been activated previously. Previous research already suggests that such a situation holds for anaphor resolution (O'Brien, Shank, Myers, & Rayner, 1988). Pragmatic communicative functions of language could rely crucially on such activation; after all, speakers often leave much unsaid, and the communicative efficiency of language would suffer if a comprehender could not fill in this unstated information in real time. Ability to learn about the world from language might rely on such activation. That is, when language describes an event for which the comprehender has general knowledge,

---

[15] Recall that the study in Chapter 2 attempted to rule out lexical associative priming as the mechanism through which N400 reduction for Event-Related targets occurred, and the design of the experiment in Chapter 4 controlled for lexical priming effects.

activating knowledge beyond that required to process the unfolding language might support formation of new associations between what is said and what is already known.

If these or other cognitive functions depend on activation of linguistically unexpected event knowledge, investigating individual differences in this activation could prove particularly fruitful. Past research already has demonstrated systematic individual differences in both children and adults in the generation of inferences and construction of situation models (e.g., Cain, Oakhill, Barnes, & Bryant, 2001; Whitney, Ritchie, & Clark, 1991; Zwaan & Brown, 1996), suggesting that individuals likely differ in the real-time activation of event knowledge beyond that necessary to process the unfolding sentence. If important comprehension or learning functions crucially rely on this activation, some individuals would be at a comprehension or learning disadvantage relative to others. While these issues remain largely theoretical, it may be that uncovering the particular consequences on comprehension and learning of real-time event knowledge activation, in combination with identification of sources of individual differences in this activation, could lead to a better understanding of why some individuals seem to comprehend and learn from language better than others. Leveraging this understanding to improve education and communication at the individual level would allow research in this area to enrich individuals' lives.

Conclusion

This dissertation provides evidence that event knowledge activation during real-time language comprehension extends beyond those elements expected to appear in the unfolding language. Evidence of crucial right hemisphere involvement in this activation

suggests certain neurocognitive mechanisms, particularly those involved in the generation of elaborative inferences, underlie this activation. Activation of linguistically unexpected event knowledge additionally mediates the dynamic mapping of visual and linguistic contexts onto mental representations of described events. This mapping involves the continuous consideration of each depicted concept's relevance to the unfolding event description. Taken together, these findings highlight and refine the view that comprehending language involves integrating contextual cues with event knowledge to go beyond the meaning of the words and sentences encountered while constructing of mental representations of described events. Future research not only should investigate in further detail the cognitive mechanisms supporting real-time activation of linguistically unexpected event knowledge, but also should investigate the cognitive repercussions of such activation, including a at the level of individual differences, so that we may better understand how the conceptual operations of moment-to-moment language comprehension ultimately affect communication, understanding, and learning.

References

Altmann, G.T.M. & Kamide, Y. (2009). Discourse-mediation of the mapping between language and the visual world: Eye movements and mental representation. *Cognition, 111*, 55-71.

Altmann, G.T.M. & Mirković, J. (2009). Incrementality and prediction in human sentence processing. *Cognitive Science, 33*, 583-609.

Barsalou, L.W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences, 22*, 577-660.

Beeman, M.J., Bowden, E.M., & Gernsbacher, M.A. (2000). Right and left hemisphere cooperation for drawing predictive and coherence inferences during normal story comprehension. *Brain and Language, 71*, 310-336.

Cain, K., Oakhill, J.V., Barnes, M.A., & Bryant, P.E. (2001). Comprehension skill, inference-making ability, and their relation to knowledge. *Memory & Cognition, 29*(6), 850-859.

Elman, J.L. (2009). On the meaning of words and dinosaur bones: Lexical knowledge without a lexicon. *Cognitive Science, 33*, 547-582.

Fauconnier, G. (1985). *Mental spaces: Aspects of meaning construction in natural language*. Cambridge, MA: MIT Press.

Graesser, A.C., Singer, M., & Trabasso, T. (1994). Constructing inferences during narrative text comprehension. *Psychological Review, 101*(3), 371-395.

Jackendoff, R. (1987). On beyond zebra: The relation of linguistic and visual information. *Cognition, 26*, 89-114.

Kamide, Y., Altmann, G.T.M., & Haywood, S.L. (2003). The time-course of prediction in incremental sentence processing: Evidence from anticipatory eye movements. *Journal of Memory and Language, 49*, 133-156.

Keenan, J.M., Potts, G.R., Golding, J.M., & Jennings, T.M. (1990). Which elaborative inferences are drawn during reading? In D.A. Balota, G.B. Flores d'Arcais, & K. Rayner (Eds.), *Comprehension processes in reading* (pp. 377-402). Hillsdale, NJ: Lawrence Erlbaum Associates.

Lakoff, G. & Johnson, M. (1980). *Metaphors we live by*. Chicago, IL: University of Chicago Press.

Langacker, R.W. (1986). An introduction to cognitive grammar. *Cognitive Science, 10*, 1-40.

McKoon, G. & Ratcliff, R. (1992). Inference during reading. *Psychological Review, 99*(3), 440-466.

McRae, K. & Matsuki, K. (2009). People use their knowledge of common events to understand language, and do so as quickly as possible. *Language and Linguistics Compass, 3*(6), 1417-1429.

O'Brien, E.J., Shank, D.M., Myers, J.L., & Rayner, K. (1988). Elaborative inferences during reading: Do they occur on-line? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14*(3), 410-420.

Talmy, L. (1983). How language structures space. In H. Pick & L. Acredelo (Eds.), *Spatial orientation: Theory, research, and application* (pp. 225-282). New York, NY: Plenum.

Whitney, P., Ritchie, B.G., Clark, M.B. (1991). Working-memory capacity and the use of elaborative inferences in text comprehension. *Discourse Processes, 14*(2), 133-145.

Zwaan, R.A. & Brown, C.M. (1996). The influence of language proficiency and comprehension skill on situation-model construction. *Discourse Processes, 21*(3), 289-327.

Zwaan, R.A., Langston, M.C., & Graesser, A.C. (1995). The construction of situation models in narrative comprehension: An event-indexing model. *Psychological Science, 6*(5), 292-297.