

THE TIME COURSE OF MEANING CONSTRUCTION WITH VARYING EXPECTATIONS

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To my loving parents.

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by

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The human brain is an amazing information processor that derives meaning from our environment quickly and effortlessly, but not passively. Instead, it does so interactively by pre-adapting to changes, recognizing and learning patterns, and forming expectations about the future. How does the brain combine influences from our external and internal milieu to construct meaning? Electrophysiological studies of semantic memory have identified the N400 event related potential—a neural correlate indexing semantic processing in the brain—sensitive to a variety of top-down and bottom-up influences; however, the mechanisms that explain volitional aspects of semantic meaning construction are not fully understood. To explore this, participants were visually shown sentences, with words presented one at a time, and evaluated whether the final words of sentences formed sensible (SC) or unconnected completions (UCs). Top-down expectancies were modulated using colored boxes that surrounded the words of each sentence cueing the participants to either expect a SC (green) or UC (orange). A neutral cue (purple) that did not indicate the completion type served as a baseline condition. Top-down expectancies were factorially crossed with completion type forming valid, invalid, and neutral conditions. Participants were more accurate when evaluating validly than invalidly cued sentences and

selectively faster when solving validly cued sentences that were semantically congruent. The N400, as measured following the presentation of the final word, was modulated mainly by semantic congruency but not expectancy. These results suggest that top-down mediated expectancies do not affect neural signatures of semantic access, but ultimately affect processing responsible for resolving discrepancies between semantic congruency and expectancy.

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CHAPTER 1

MEMORY IN THE CORTEX

We live in a dynamic and complex environment. The information we perceive from our environment through our senses (i.e., sight, smell, hearing, touch, taste) allows us to make sense of our surroundings. Likewise, we have the ability to change our environment. Our thoughts, either in reaction to external stimuli or internally driven, lead to action (or inaction) capable of altering the present environment. The changes we make then get perceived and may lead to additional behavior. This interplay between our external and internal environments is the perception-action (PA) cycle (Fuster, 1995, 2003, 2013). Understanding the relationship between our environment, cognition, and behavior through the PA cycle is a fundamental interest within the various cognitive sciences, including cognitive and affective neuroscience, cognitive science, cognitive psychology, and their sub-fields such as neuroeconomics, reasoning, thinking, and judgment and decision making. This complex and dynamic relationship between the brain and its environment underlies important daily functions such completing goals (e.g., providing for loved ones, exercising daily, having a successful career, etc.), making decisions (e.g., whether to quit your current job, purchasing a new car, etc.), and planning/pre-adapting for the future (e.g., choosing to stay at home and cook dinner instead of ordering out, becoming more alert driving due to slippery conditions, etc.). Each of these important cognitive functions relies on our ability to perceive, understand, and act (or react) in our external environment, while under simultaneous consideration of our internal milieu consisting of long-term memories, goals, plans, and emotions. Therefore, investigating the cognitive mechanisms underlying how humans

understand their environment under different contexts, both external and internal, will provide understanding across a breadth of fundamental abilities important for daily life functioning.

Nearly all cognitive abilities rely on memory to interface between our internal thoughts and external environment, hereafter referred to as the perception-action (PA) cycle. For example, consider the process of language production during discourse. Engaging in conversation requires the activation of knowledge representations (e.g., semantic memory), previous autobiographical memories (e.g., episodic memory), motoric memories to guide speech production and hand gestures, and schemas that guide appropriate responses given the dialogue's context and content. Although these above listed memory types¹ are seemingly distinct, they importantly share the same neural substrate and mechanisms that govern their acquisition and self-organization: Hebbian associative learning. "In static as well as dynamic terms, all memory is essentially associative, in its formation, in its structure, and in its activation. Associative integration is essential to acquisition, storage, and recall, especially if the memory or item of knowledge is complex" (Fuster, 2009, p. 2049). It is through life experience, which results in temporal synchrony and association of related memory networks, that memories become intertwined at various hierarchical levels of complexity. The pervasiveness of memory and its interaction with other cognitive faculties speaks to its importance in understanding how the brain creates, stores, modifies, and accesses memories.

Firmly rooted in the PA cycle is Joaquín Fuster's model of memory in the cerebral cortex (i.e., neocortex) that organizes memory representations into perceptual and executive cortical

¹ In Fuster's framework, the notion of separable systems of memory is replaced, instead, with *memory for systems*. Due to the dense interconnections from associative-based memories, distinct memory systems no longer apply (Fuster, 2003).

networks according to four main tenets (Fuster, 2003). First, long-term memory networks are topographically separated by the central sulcus (i.e., Rolandic fissure) with perceptual memory mainly organized across parietal, temporal, and occipital lobes (PTO cortex) and executive memory mainly organized in the frontal lobe. In Fuster's theory, a "cognit" represents a unit of information or memory in the brain. Cognits are comprised of networks of associatively related neurons with diffuse and continuous boundaries. Due to their associative nature, cognits are enmeshed with other cognits and are hierarchically organized (see below). Cognits, especially complex and conceptual ones, are widely distributed across the cortex with reciprocal interconnections across the central sulcus at various hierarchical levels (Fuster & Bressler, 2012). Studies of resting state functional connectivity (rsFC) using magnetic resonance imaging (MRI) have identified a series of networks similarly distributed across the cortex (for reviews see Fox & Raichle, 2007; Wig, Schlaggar, & Petersen, 2011). Although some networks are more localized in topography, like the visual network(s) in occipital cortex, other networks are more distributed across the central sulcus and communicate flexibly with other brain networks to achieve cognitive control, like the fronto-parietal network (Cole et al., 2013). These more functionally parcellated networks obtained from rsfMRI are not in opposition to an anterior-posterior distinction between executive and perceptual cognits, but likely reflect differences in how cognits of various complexities are implemented in lower- to higher-order cognition. For instance, Spreng, Stevens, Chamberlain, Gilmore, and Schacter (2010) demonstrated a differential modulation of resting-state networks during planning tasks. The default mode network had greater blood-oxygen-level dependent (BOLD) percent signal change for autobiographical versus visuospatial planning, while these results reversed for the dorsal

attention network; however, the fronto-parietal control network was involved in both types of planning, suggesting these networks work synergistically during higher order cognitive tasks. These differences in resting-state network activations is likely the result of differences in cognitive activation and implementation in task states (Fuster & Bressler, 2012).

Second, representations within each network are hierarchically organized, such that conceptual memories (e.g., temporal integration of information, conceptual understanding of reasoning) are comprised of increasingly rote memories (e.g., motoric reflex, visual perception of color). Third, the hierarchical structure of perceptual and executive memories is densely interconnected by reciprocal intra- and inter-hemisphere connections. Fourth, a heterarchical organization emerges through these reciprocal connections, as well as from feed-forward and feed-back connections, within and across each representational network. From this model emerges a synergistic framework of cognitive abilities, such as perception, attention, language, reasoning, and intelligence, that is supported by decades of research on monkey electrophysiology and human neuropsychology, cognitive psychology, and cognitive neuroscience.

An important element emphasized in Fuster's model is the reciprocal nature of connections that exist between posterior and anterior association cortex. Not only do neural signals from perceptually-based memories feedforward to anterior cortex, but also signals originating in anterior cortex innervate and influence processing in PTO cortex. In other words, frontally- and posteriorly-mediated cognitive processes are anatomically connected and simultaneously influence each other to enable complex behaviors. The factors that mediate the relative strength of these influences, either more anterior or posterior influence, are embedded in

the PA cycle and emerge from our external and internal environments. This dual-systems view between anterior and posterior influence is a major component of several cognitive models across related fields, including cognitive psychology (e.g., top-down vs. bottom-up; Matlin & Farmer, 2016), judgment and decision making (e.g., system 2 vs. system 1; Kahneman, 2011), social cognitive neuroscience (e.g., reflective vs. reflexive; Satpute & Lieberman, 2006), and semantic memory (e.g., controlled vs. automatic; McNamara, 2012; Neely & Kahan, 2001). However, little is understood about the neuro-cognitive mechanisms that underlie these converging influences, especially when executive and perceptual representations are in conflict.

Given the hierarchical organization within both networks and the reciprocal connections across each level of the hierarchy between both networks, converging influences occur at all levels of the hierarchy. Rather than examining influence at all hierarchical levels, this project takes a focused examination of the highest level that enables sophisticated behaviors in humans, such as reasoning, decision making, and goal-driven behaviors. Likewise, accessing semantic memories—our neural representations of object and concept meaning—is a fundamental cognitive process for making sense of our environment. The current study investigates the neuro-cognitive mechanisms that underlie converging influences from these two highest levels in the hierarchy; specifically, how executive-based prospective functions of the prefrontal cortex influence perceptual-based semantic memory activations, as well as the relative time course of this influence. Prospective memory functions, such as working memory and planning, allow humans to prepare and preadapt for impending events or actions in their environment. Cues in the environment induce “attentional set”, which is the ability to modulate attention to anticipate or bias a future sensory percept or motor action, by impacting neural firing patterns and behavior

prior to a stimulus or motor action (Fuster & Bressler, 2015). The central question in the current investigation is to what extent does attentional set impact humans' ability to construct meaning from the environment. In other words, this study examines how expectancy of predictable and unpredictable semantically rich stimuli (e.g., words) impacts their processing, especially in cases when expectancy of a future stimulus is in conflict with its ground truth.

There are several robust behaviorally-based semantic memory phenomena, such as priming, that have provided insight into how semantic representations are accessed and organized in the brain. Furthermore, neural correlates of semantic access derived from scalp electroencephalogram (EEG), such as the N400 event-related potential (ERP), have provided additional temporal specificity to semantic access. However, little is known about how executive top-down influences impact the neuro-cognitive time course of semantic access. Chapter 2 will review current research on the N400 ERP in semantic memory access and how executive-based processes influence the neuro-cognitive processing underlying meaning construction. Following this review in Chapter 3, I will explain my hypothesis about how executive-based processes generated in the frontal lobe may influence posterior processes of semantic knowledge access and integration.

CHAPTER 2

ELECTROPHYSIOLOGY OF SEMANTIC ACCESS

A fundamental question is how semantic representations are accessed and interface with each other to guide behavior. The advent of localizing semantic networks to modular areas on the cortex began with early neuropsychological findings and later reinforced with MRI-based imaging. Expressive and semantic aphasia present prominent anterior-posterior distinctions that closely align with Fuster's (2003) executive motor and perceptual semantic cognits, respectively. Broca's aphasia is characterized by difficulties in language production following damage to the inferior frontal gyrus despite intact understanding. In contrast, Wernicke's aphasia is characterized by difficulties in understanding the semantic content of language following damage to posterior superior temporal gyrus despite articulate, fluent, nonsensical speech. A double dissociation was found between these aphasia and understanding verbs and nouns, such that Broca's aphasia demonstrated difficulties with verbs and not nouns, while Wernicke's aphasia were impaired on nouns and not verbs (e.g., Caramazza & Hillis, 1991). Lesion and imaging studies suggest that the temporal lobe (e.g., left inferior temporal cortex) figures prominently in representations of object knowledge, while prefrontal areas support representations of executive actions and knowledge. However, these anterior and posterior areas supporting differing knowledge representations seem to share processes of integration, suggesting neural inseparability between action and object (reviewed by Vigliocco, Vinson, Druks, Barber, & Cappa, 2011). This shared system of integration is likely due to associative nature of anterior executive and posterior perceptual cognits and their parallel interconnected development through interactions with the environment (Fuster, 2003).

The phenomenon of semantic priming—where the presentation of a stimulus (e.g., doctor) facilitates access to a related stimulus (e.g., nurse), but not an unrelated stimulus (e.g., wrench)—provides further insight to how semantic representations are organized in the cerebral cortex (see McNamara, 2012, for a review of semantic priming theories). For instance, consider automatic spreading of activation (ASA) models (e.g., Collins & Loftus, 1975; Quillian, 1967) that conceptualize semantic representations as separable nodes connected through associated links in a network. ASA theory postulates that semantic access to a node (e.g., doctor) primes other semantically related nodes (e.g., nurse) through spreading of activation. This activation decreases in strength proportional to its relatedness, such that semantically unrelated nodes are not activated (e.g., wrench). Increased facilitation (e.g., faster word recognition) for semantically related concepts is the result of accessing semantic concepts that were previously activated. Importantly, ASA and similar semantic priming models organize semantic representations in a non-random fashion, such that concepts are activated/related due to temporal co-occurrences from our experience in navigating our external or internal environments.

2.1 The N400 ERP

Evidence from electroencephalography (EEG) analyzed with event-related potentials (ERPs) suggest a neural signature for semantic priming. Kutas and Hillyard (1980) discovered a negative-going deflection in voltage occurring 400 milliseconds following violations in semantic context when presenting participants with sentences that ended with an unexpected word (e.g., He took a sip from the *transmitter*) compared to an expected word (e.g., It was his first day at *work*). This voltage difference is named the N400 effect and is observed across a variety of stimulus presentation methods (e.g., words, images, faces, objects) and modalities (e.g., visual

and auditory; see Kutas & Federmeier, 2011, for a review). The N400 provides a temporally sensitive measure sensitive to semantic information and facilitates the exploration of memory-related questions.

What cognitive process does the N400 index? Decades of N400 research following the momentous discovery by Kutas and Hillyard (1980) has demonstrated that simply classifying the N400 as an index of semantic priming is a gross oversimplification. Although there are several lines of inquiry into components of cognition that cause modulations in N400 deflections, a long-standing debate is the extent to which top-down and bottom-up processing is responsible for N400 morphology. Many have coined this distinction as reflecting either facilitated lexical integration or lexical access. Proponents of the lexical access view posit that semantic context, whether in the form of a word or sentential frame, serves to pre-activate semantic representations in long term memory prior to their presentation (Federmeier, 2007; Kutas & Federmeier, 2000, 2011); however, whether prediction occurs in a bottom-up or top-down fashion is not always theoretically clear (Mantegna, Hintz, Ostarek, Alday, & Huettig, 2019). The pre-activation of these semantic representations is proposed to facilitate the lexical access of words when presented, thus resulting in more negative N400 amplitudes for less predicted words/concepts. I will use the word “prediction” to refer to this process of pre-activating semantic representations, noting my hesitancy for attributing this process entirely to either top-down or bottom-up processing, for the remainder of this document. In contrast, proponents of the semantic integration view posit that word recognition proceeds in a bottom-up fashion and only after word recognition can semantic representations, which are derived from prior lexical access, be integrated into the broader semantic context held in working memory (e.g., Brown & Hagoort,

1993). In this view, more negative N400 amplitudes are the result of increased effort to integrate the current stimulus with the broader semantic context; a process that is proposed to occur via controlled top-down control. To date, myriad studies have investigated the automatic bottom-up versus controlled top-down distinction in the N400. Given the several previous reviews that comment on this distinction (see Deacon & Shelly-Tremblay, 2000; Federmeier, 2007; Federmeier & Laszlo, 2009; Holcomb, 1988; Kutas & Federmeier, 2000, 2011; Lau, Phillips, & Poeppel, 2008; Van Petten & Luka, 2012), the following will briefly highlight contrasting results and illustrate more recent work pertinent to the current investigation.

One method of investigating whether the N400 is driven by unconscious bottom-up processing is masked priming (i.e., forward/backward masking). Similar to traditional priming studies, participants are presented with prime-target word pairs (e.g., doctor-NURSE) and facilitated semantic access to the target word is measured via faster lexical decisions or modulations in N400 amplitudes; however, the prime word is instead presented extremely fast (e.g., 30-50ms) with a visual mask (e.g., GNLDPIRFS, #####) following the prime word to eliminate iconic memory effects and render the prime imperceptible to participants (Holender, 1986). Facilitated access to target words from masked primes generates subliminal priming effects and suggests that semantic access is possible without attentional awareness. Despite several investigations, evidence from behavioral studies remain equivocal due to limitations in methodology, such as ensuring that primes are not perceptible to participants (see McNamara, 2012). Electrophysiological studies, however, provide online measures of cortical activity that are well-suited to capture masked priming effects and have shown support for subliminal semantic priming. Several studies have demonstrated classic N400 effects following the

presentation of target words when the prime was masked (e.g., Deacon, Hewitt, Yang, & Nagata, 2000; Kiefer, 2002). Additionally, the influence of masked primes on target processing decays rapidly at long stimulus onset asynchronies (SOA; Kiefer & Spitzer, 2000) and is sensitive to orthographic similarities (e.g., teble-TABLE) albeit at a lesser extent than identical repetition effects (e.g., table-TABLE; Holcomb & Grainger, 2006). Together, these electrophysiological studies argue that the N400 effect reflects an automatic bottom-up process to semantic access, mainly due to modulations in N400 amplitude even when participants are unaware of primes.

Additional evidence supporting the N400 as an index of bottom-up semantic access emerges from the attentional blink paradigm that presents participants with a rapid stream of stimuli (e.g., words, letters, or numbers) and requires participants to identify probes following presented targets. It was found that participants were inaccurate in identifying probes that lagged between 2-8 items post-target, but were accurate at immediate (i.e., 1 lag) and longer lags post-target (Raymond, Shapiro, & Arnell, 1992). Behavioral studies inferred that visual attention mechanisms were suppressed following the perception of the target—analogous to how visual information is suppressed during an eye blink—thus interfering with perception or recognition processes. However, electrophysiological recordings determined that perceptual processing is intact during the attentional blink with unmodulated P1 and N1 components at all lags (Luck, Woodman, & Vogel, 2000). During the attentional blink, the N400 effect was obtained between related and unrelated words while P3 amplitude was reduced (Luck, Vogel, & Shapiro, 1996). These results suggested that attention interfered not with perceptual process and subsequent semantic analysis, but rather with post-perceptual processes that update working memory (i.e., the P3 ERP). This is particularly emphasized with classic N400 effects during the attentional

blink—indicating successful semantic access—despite participants’ inability to accurately report probes. In other words, the N400 effect was obtained despite reduced attentional awareness, providing evidence against post-lexical integration views.

In contrast, several studies argue that the N400 reflects a more conscious process susceptible to top-down attentional focus or task set. Brown and Hagoort (1993) failed to observe an N400 effect during masked priming but demonstrated differences reaction times, suggesting that the N400 requires conscious awareness of context (e.g., primes), thus supporting the process of semantic integration. Holcomb and Grainger (2009) demonstrated that masked primes eliminated the N400 effect during semantic/associative priming (e.g., table-CHAIR) but not repetition priming (e.g., chair-CHAIR), suggesting that N400-indexed semantic priming may reflect more conscious processing, while repetition priming may reflect more automatic processing. Kiefer and Brendel (2006) investigated whether attention to the presentation of a masked prime, as well as the duration of masked priming effects via manipulating the SOA (see Kiefer & Spitzer, 2000) resulted in semantic access differences. The N400 to target words was modulated at short SOAs *and* when the participants’ attention was directed to processing the subliminally presented masked prime, suggesting that top-down attentional control can influence unconscious processing. Kiefer and Martens (2010) later extended these results and demonstrated that manipulating task set by instructing participants to pay attention to semantic or orthographic (i.e., perceptual) features of the stimuli similarly modulated the N400 ERP to targets under masked priming.

Furthermore, manipulations of attention and task set impact N400 amplitudes (reviewed by Deacon & Shelly-Tremblay, 2000). McCarthy and Nobre (1993) presented participants with

semantically related and unrelated word pairs either to the left or right visual field. Although participants maintained a central fixation, their attention was directed to either the left or right visual field. The N400 effect was observed between related and unrelated word pairs, but only when the words were presented to the attended location. This result suggested that directed and focused attention was required to elicit the N400 effect, arguing that N400 modulations of semantic access did not propagate automatically. Chwilla, Brown, and Hagoort (1995) similarly demonstrated that even directing attention to specific components of word forms modulate N400 amplitudes. Using a levels of processing approach, participants performed either a lexical decision task (i.e., word or non-word determination) or a lower or uppercase discrimination. An N400 effect was obtained for the lexical decision task, but not during the letter-case discrimination, suggesting semantic access was obtained through deeper semantic analysis and not simply from observing shallow aspects of stimuli (i.e., case of letters). In an extreme example of task demands influencing priming, Norris, Kinoshita, Hall, and Henson (2018) measured ERPs following primed or unprimed words and non-words across two tasks: 1) judging whether the target was the same or a different word than the prime and 2) lexical decisions (i.e., word or non-word discriminations). Norris et al. (2018) hypothesized that priming is task driven such that the nature of the decision—either lexical or same/different—would influence priming and not the nature of the stimulus (i.e., word vs. non-word). The results demonstrated that ERP priming effects were a function of task set such that lexical decision tasks only primed words, while the same-different task primed only same judgments regardless words and non-words. Therefore, task demands, such spatial attention and depth of processing, modulate N400 amplitudes and further suggest its reliance on top-down mediated processing.

A popular and long-standing interpretation is that N400 modulations are the result of lexico-semantic pre-activations emanating from predictive processing (Federmeier, 2007). In this view, the brain processes and utilizes streams of information in parallel to anticipate future stimuli. Federmeier and Kutas (1999) presented participants with sentences that were either strongly or weakly constrained to manipulate the predictability of final word completions (i.e., strongly constrained sentences have highly predictable sentence endings). Sentence endings in both conditions were also manipulated such that participants were presented with endings that violated predictions both within- and between-category violations, as well as expected endings. In the weakly constrained sentences, a classic N400 was observed that separated expected endings from violations; however, the N400 in strongly constrained sentences was modulated by the *degree* of violation, such that within-category violations increased in positivity compared to weakly constrained sentences. This result suggested that increasing the predictability of future stimuli pre-activated the expected lexico-semantic representations as well as semantically associated representations to a greater extent than in less predictable contexts (i.e., within-category violations; see also Federmeier, McLennan, De Ochoa, & Kutas, 2002).

N400 prediction effects are also observed in cleverly constructed word-pair paradigms. Lau, Holcomb, and Kuperberg (2013) presented participants with related and unrelated prime-TARGET word pairs across two blocks. In the high-relatedness proportion block, participants received a higher proportion of related to unrelated targets than in the low-relatedness proportion block. Manipulating the relatedness proportion of each block influenced the participants' expectations of upcoming targets, such that related targets were more expected in the high- than low-relatedness blocks. This was evidenced by an interaction between block and relatedness in

N400 mean amplitudes with a larger N400 effect in high-relatedness blocks. Additionally, the related targets in the high-relatedness block elicited more positive N400 mean amplitudes than in the low-relatedness blocks. In a similar study, Steinhauer, Royle, Drury, and Fromont (2017) showed modulations in the N400 in response to semantic relationships shared between prime-target word pairs. Blocks that contained a higher proportion of word pairs with the same semantic relationship (e.g., member-category: hammer-tool) facilitated relational priming such that targets of high proportion relations elicited more positive N400s than lower proportion relations and unrelated word pairs. Together, these results suggest that manipulating the task demands, such as facilitating predictions of upcoming stimuli, result in top-down modulations to the N400 and thus may influence the way meaning is constructed.

2.2 Summary

It is clear from decades research that the N400 captures the complexity of semantic processing that the brain does so quickly and effortlessly. What is not clear is how our internal milieu and external world interact while we derive meaning in different situations and states of mind. A helpful, but perhaps ill-defined (see Kutas & Federmeier, 2011), dichotomy is the distinction between cognitive processes that occur from the top-down (i.e., controlled and conscious) and bottom-up (i.e., automatic and unconscious) and how they might impact the N400, ergo semantic processing. As briefly reviewed above, there is evidence supporting both sides of the debate; the N400 is affected by both pre-lexical prediction-based effects as well as post-lexical integration-based efforts. Recent work has attempted to disentangle prediction from integration at the N400. Mantegna et al. (2019) demonstrated N400 effects to incongruency, while holding integration effort constant via rhyme scheme, thus supporting the role of prediction in N400 signals as well

as showing that it is not trivial to distinguish top-down and bottom-up influences from semantic processing. As surmised by Kutas and Federmeier (2011), there is evidence that refutes both cases and a unifying N400 semantic access theory must account for these interactions. What seems important to consider is the current state of one's semantic memory (i.e., network), the adaptive ability of the brain, as well as the brain's ability to process information at face value.

It is more likely that the brain processes top-down and bottom-up semantic information in parallel. In contrast to the anterior-posterior dichotomy presented in Chapter 1, Federmeier and colleagues have demonstrated that hemispheric differences may provide insight to these differences in semantic processing. More specifically, the left hemisphere demonstrates sensitivity to top-down predictive processing while the right hemisphere operates in a more bottom-up approach (reviewed in Federmeier, 2007). In either case, it seems the brain is able to process and derive meaning in multiple ways that depend on feed-forward activations in the visual processing stream as well as reciprocal anterior-posterior connections from cortical memory theory (see Chapter 1). Understanding these interactions, and how meaning is processed under different situations, is paramount to understanding how humans can efficiently and quickly process meaning in our environment. In the following chapter, I will outline my hypothesis and predictions about how our internal and external milieu may interact to affect semantic access via the N400 ERP.

CHAPTER 3

STUDY HYPOTHESES AND PREDICTIONS

Given supporting evidence that the N400 is sensitive to both automatic bottom-up and controlled top-down processing, it is likely that our ability to understand the meaning of external stimuli is affected by a mixture between task demands and basic priming through associative links.

Therefore, the N400 may not reflect the activation of meaning per se, but rather the “activity in a multimodal long-term memory system...as meaning is dynamically constructed” (Kutas & Federmeier, 2011, p. 640). Conceptualizing semantic access as a dichotomy between bottom-up and top-down processing, especially in terms of identifying the underlying neural process of the N400, is problematic in the face of empirical evidence and neural anatomy. Instead, semantic access is more likely a dynamic process that operates along a continuum between bottom- and top-down influences as a function of our internal and external environments. Framing semantic access as a continuous, rather than dichotomous, process is in agreement with Fuster’s model of cortical memory (see Chapter 1) that establishes reciprocal connections between frontal-lobe executive and posterior perceptual memory. In other words, these areas of cortex influence each other and provide a framework to further understand their reciprocal influence. The comprehensiveness and neurobiological plausibility of Fuster’s cortical memory model allows testable hypotheses regarding how executive and perceptual processes interact to construct meaning of words. Exploring the mechanisms that underlie this dynamic construction of meaning and how context, whether internally or externally generated, affects this process has implications for understanding how humans access meaning in an ever-changing world.

The purpose of the proposed project was to examine executive aspects of expectation and how they affect online constructions of meaning. The N400 effect (see section 2.1) is observed in a variety of stimulus presentation methods, including single word contexts (i.e., prime-TARGET; Holcomb, 1988; Lau et al., 2013; Steinhauer et al., 2017) and even pairwise presentations, such as target word-pairs in verbal analogies (Kmieciak, Brisson, & Morrison, 2019); however, Kutas (1993) demonstrated a larger and earlier N400 when participants processed the final words of a sentence compared to prime-target word pairs. Additionally, the waveforms differed only quantitatively, not qualitatively, suggesting the underlying cognitive processing of the target word did not differ with respect to the context in which it was presented. Furthermore, the degree to which a sentential frame predicted the final word in a sentence (i.e., cloze probability) was highly correlated ($r = .9$) with N400 mean amplitude (Kutas & Federmeier, 2011). Together, this evidence suggested that sentential frames may more strongly constrain the predictions generated, either consciously through executive control or unconsciously via association, for final target words compared to other presentation methods. Therefore, sentential context frames are well suited for studying prediction effects on dynamic constructions of semantic meaning and were chosen for the design of the current investigation.

To explore the process of expectation on semantic access, participants were shown sentences presented one word at a time while recording their EEG from scalp electrodes. Sentences ended with either a sensible completion (i.e., plausible ending) or an unconnected completion (i.e., implausible ending). To the extent that the N400 indexed prediction-based mechanisms from sentence semantics, I predicted an N400 effect between sensible and unconnected sentence completions such that unconnected completions (UCs) would evoke more

negative potentials compared to sensible completions (SCs). It is important to clarify that I define prediction-based mechanisms to mean a pre-activation of lexico-semantic representations prior to their presentation, which are in the form of words, and that this mechanism likely proceeds in a mixture of bottom-up and top-down processing. My reasoning behind this mixed mechanism is that it is difficult to dissociate semantic activations that result from ASA-based priming from top-down pre-activations during sentence reading (Mantegna et al., 2019). To the extent that meaning construction is influenced by top-down effects, such as task demands, I predict the N400 effect will interact with expectancy.

To test this, I presented participants with a colored rectangular box surrounding each word cuing three particular contexts. A green box signaled an approaching SC, an orange box signaled an UC, and a purple box did not signal whether the sentence ended with a SC or UC. Trial numbers were weighted such that 2/3 of trials with green and orange cues aligned with their cues (i.e., valid trials), while 1/3 of trials did not align with their cues (i.e., invalid trials). When considering all trials, only 20% of trials contained invalid cues. This design fully crossed prediction mechanisms (i.e., SCs vs. UCs) and top-down expectancy (i.e., valid vs. invalid vs. neutral) to study N400 effects during meaning construction; a dynamic process that likely falls on a continuum across bottom-up and top-down processes that depend on the state of the semantic network and feed-forward mechanisms from visual processing. It is important to clarify that I dissociate *prediction* (i.e., lexico-semantic pre-activations from sentence reading) from *expectancy* (i.e., top-down influence from cues). I define the latter as more of a pure top-down influence due to its non-semantic features (i.e., using colors that are not naturally

semantically charged, unlike traffic light colors: red, green, yellow) and its dependence on using volition to incorporate cues into the context.

The proposed project explored the neural correlates of online meaning construction and how this process was affected by prediction and expectancy. Participants were presented with a series of sentences and tasked with determining whether the final word of those sentences completed each sentence sensibly. These sentences were presented with cues to create expectations about the connectiveness of the approaching final word. The connectiveness of the sentences and context cues are factorially crossed such that both SCs and UCs contain cues that are valid, invalid, or neutral with the final word. The interface between feed-forward semantic activations and the current state of the semantic network, as measured via the N400, is affected by both top-down and bottom-up processes (see Chapter 2). This sensitivity of the N400 to task demands and subliminal priming is likely a result of the reciprocal connections between the frontal lobe and posterior areas of association (Fuster, 2003; Fuster & Bressler, 2015). Therefore, I hypothesize that mechanisms of semantic priming (i.e., sentence reading) and top-down expectancy (i.e., utilizing context cues) will interact by modulating mean amplitudes of the N400 ERP following the presentation of the final word. When comparing SC and UC trials, I predict (see Figure 3.1):

Prediction 1 (P1). an N400 effect such that UC neutral trials will elicit more negative mean amplitudes than SC neutral trials—the classic N400 effect

Prediction 2 (P2). an N400 effect such that UC invalid trials with a green cue are more negative than SC valid trials with a green cue. I also predict this N400 effect to be larger than the N400 effect in prediction #1.

A prediction that is not easily generated from the N400 literature is the influence of orange cues that indicate the sentence will end illogically. On valid trials, where participants are made aware of the upcoming UC, top-down generated expectations are in conflict with predictions from sentence reading (see Figure 3.1). This is the opposite on invalid trials; prediction mechanisms are now in conflict with top-down expectations. This comparison is interesting because it allows insight into which mechanism may influence online meaning constructions to a greater degree. Given that the N400 is susceptible to top-down attentional mechanisms (e.g., Lau et al., 2013), my third prediction is that:

Prediction 3 (P3). SC sentences with invalid orange cues will elicit more negative N400 mean amplitudes than valid UC trials, despite agreement in sentence semantics.

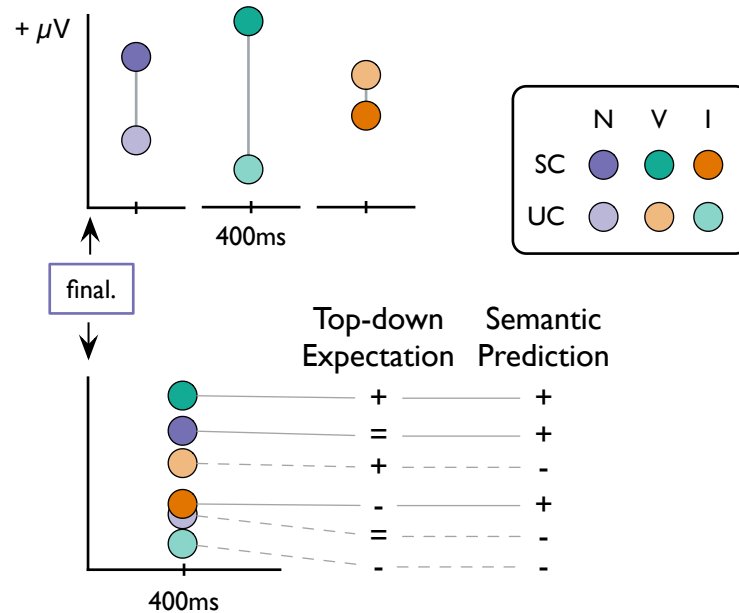


Figure 3.1. Mean N400 amplitude predictions following the presentation of the sentences' final word. The plus (+) signs denote facilitated processing of the final word, while minus (-) signs denote hinderances in information processing of the final word. N = Neutral, V = Valid, I = Invalid, SC = Sensible Completion, UC = Unconnected Completion.

Considering predictions 1 through 3, I am ultimately interested in the interaction of expectancy and prediction effects, some of which may be bottom-up. Therefore, I predict:

Prediction 4 (P4). The factors of completion (SC vs. UC) and condition (valid vs. invalid), will interact by affecting semantic access at the level of N400 mean amplitudes.

Chapter 4 includes descriptions that detail the experimental design, materials, statistical analysis methods, and power analysis that determined benchmarks for recruitment efforts.

CHAPTER 4

METHOD

4.1 Power Analysis

A power analysis was conducted to estimate sample size for participant recruitment. The effect sizes and parameters of this power analysis were obtained from an ERP study (Lau et al., 2013) that presented participants with related and unrelated prime-target word pairs across high and low proportion blocks (see section 2.1 for a full description of the task). The experimental task presented in Lau et al. (2013) did not exactly match the proposed study's complexity, namely due to presenting word pairs instead of sentence stems and not including a neutral condition; however, it was a close approximation given the following factors. Similar to the proposed investigation, Lau et al. (2013) compared semantically related and unrelated trials to achieve an N400 effect. Furthermore, to induce prediction effects, Lau et al. (2013) administered blocks with either high or low proportions of related trials. This was analogous to the current investigation's implementation of valid and invalid trials that also differed in respect to high and low proportions, respectively. In addition, the current investigation and Lau et al. (2013) were equated in the number of matched trials entered into mean N400 amplitude measurements (i.e., 40). Thus, despite the increased complexity of the current investigation, Lau et al. (2013) provided approximate effect size estimates for how factors of semantic relatedness and prediction interacted to modulate N400 mean amplitudes.

Lau et al. (2013) demonstrated a significant interaction between these factors, $F(1, 31) = 12.3, p < .01, n = 32$. An effective Cohen's d value (d_e) was calculated from this F -value using the following equation:

$$d_e = \sqrt{F_{1,v} \cdot 4/n}$$

where $F_{1,v}$ was equal to the obtained F -value and n was equal to the sample size from Lau et al. (2013). To account for between-subject variability in N400 amplitudes, a Cohen's d value was obtained by multiplying d_e by the square root of $1 - \text{an intraclass correlation coefficient (ICC)}$:

$$d = d_e \cdot \sqrt{1 - \frac{\sigma_b^2}{\sigma_b^2 + \sigma_w^2}}$$

where σ_b^2 and σ_w^2 represented the between- and within-subject variability, respectively.

However, Lau et al. (2013) did not report the between- and within-subject variability statistics for their N400 effect. Therefore, the ICC was estimated from P1 amplitude data ($\text{ICC} = .5$) obtained via Tillman et al. (2018). Although the P1 occurs much earlier in the neural time course and represents a more exogenous component compared to the N400, its ICC value of .5 likely represents a more conservative estimate, especially given N400 ICC values between .5 - .7 were obtained when Kiang, Patriciu, Roy, Christensen, and Zipursky (2013) examined N400 priming effects across testing sessions separated by one week.

Given the F -value ($F = 12.3$) and sample size ($n = 32$) from estimated from Lau et al. (2013), as well as the ICC value ($\text{ICC} = .5$) estimated from Tillman et al. (2018), the Cohen's d value calculated to estimate power and sample size for the proposed study was $d = .88$. A power analysis conducted with this effect size estimated that 22 participants were required to reliably detect an effect with 80% power ($\beta = .8$; see left panel of Figure 4.1). Additionally, the minimum Cohen's d value for reliably detecting this effect given a power of 80% ranges

between a medium to large effect (i.e., .5 - .8) given a proposed sample size of 30 participants, a 15% attrition rate ($n = 25$), and a range of ICCs (see right panel of Figure 4.1).

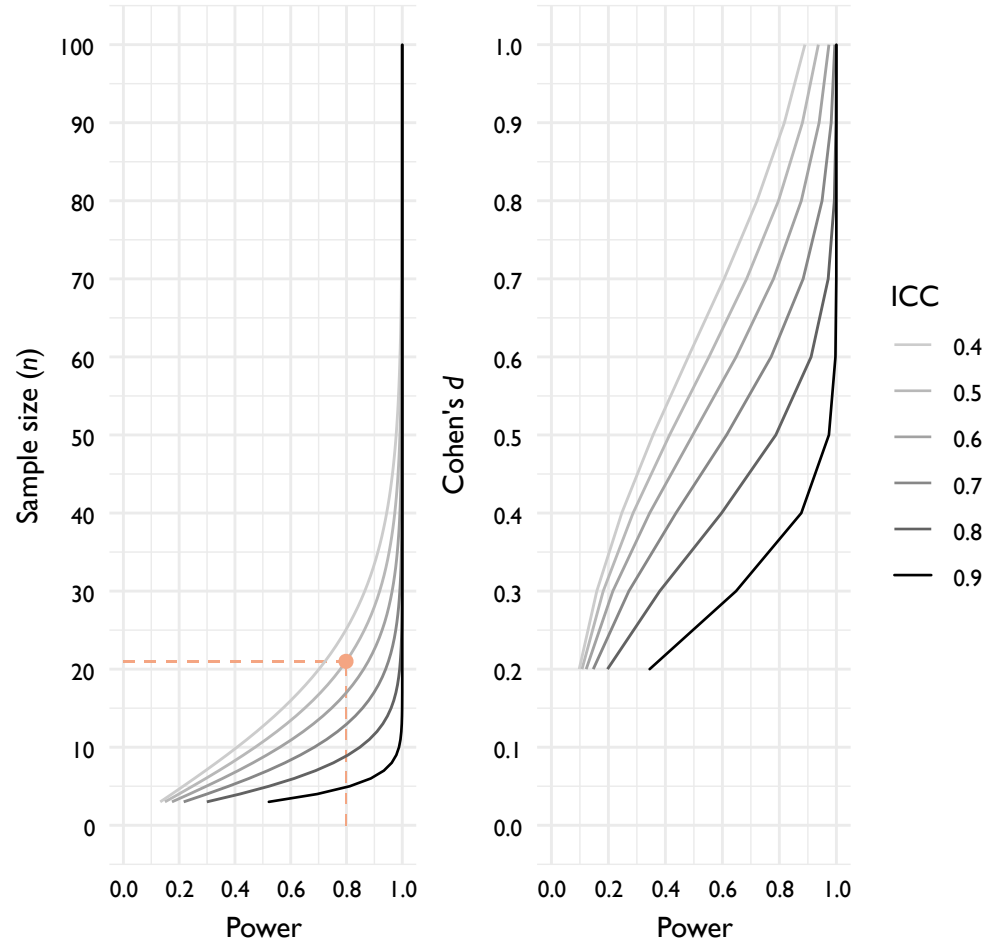


Figure 4.1. Power analysis. Line-graphs depicting estimated sample sizes and minimum Cohen's d values for detecting an experimental effect based on Lau, Holcomb, and Kuperberg (2013). Left panel: An estimated 22 participants are necessary to reliably detect an effect with a given intraclass correlation coefficient (ICC) of .5. Right panel: The minimum Cohen's d value to detect an effect with the proposed 30 participants, given an attrition rate of 15%, is between a medium and large effect across several different ICC levels.

Given the power analysis results for this effect size, as well as taking into account attrition due to excessive EEG artifacts in some participants, I initially proposed to recruit 30 participants for this investigation; however, a total of 37 individuals were recruited. These

additional seven participants were necessarily recruited due to the exclusion of five participants due to a task malfunction and excessive EEG artifacts that disproportionately affected the counterbalancing of the task versions.

4.2 Participant Eligibility Criteria

Although age-related effects on the N400 are unclear, Wlotko, Federmeier, and Kutas (2012) found N400 differences between younger adults ($M = 20$, range = 18-28 years; Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007) and older adults ($M = 72.4$, range = 59-88 years) during sentence comprehension, suggesting that older adults use sentential context to guide prediction to a lesser extent than younger adults. Given potential age-related effects on the N400 (see Federmeier, 2007), a relatively conservative age window—between 18-40 years—was selected.

Additional eligibility criteria include: 1) native English speaking, 2) abstinence from alcohol and drug use for 24 hours prior to the testing session (e.g., cannabis, cocaine, amphetamine type stimulants, inhalants, sedatives or sleeping pills, hallucinogens, opioids), 3) not diagnosed with any of the following mental health disorders: bipolar disorder, mental retardation, pervasive developmental disorders, schizophrenia, schizoid disorder, psychosis, active behavioral disorder (ADHD or ADD), personality disorder, and 4) not diagnosed with the following neurological disorders: ALS, Alzheimer's disease, brain tumor, cerebral palsy, dementia, epilepsy, neuropathy, spinal cord injury or deformity, stroke, brain aneurysm, multiple sclerosis, muscular dystrophy, Bell's palsy, mild cognitive impairment, or Parkinson's disease.

4.3 Participants

A total of 37 individuals participated in this study. One participant was excluded due to a task malfunction that resulted the loss of behavioral data and four participants were excluded due to excessive amounts of EEG artifacts ($> 25\%$ of total trials that exceeded $\pm 100 \mu\text{V}$ on epoched trials between -200 and 1100ms). Therefore, the remaining 32 participants (age in years $M = 24.1$, $SD = 5.17$; years of education $M = 15.50$, $SD = 2.23$; 19 females; all right-handed) were included in all behavioral and EEG/ERP analyses presented below. The participants' racial identification included White ($n = 15$), Asian ($n = 6$), Not Reported ($n = 4$), Black or African-American ($n = 2$), Black or African-American/White ($n = 2$), Asian/Not Reported ($n = 1$), Asian/White ($n = 1$), and American Indian or Alaska Native/White ($n = 1$)². The participants ethnic identification included Not Hispanic or Latino ($n = 20$), Hispanic or Latino ($n = 10$), Not Reported ($n = 1$), and Unknown ($n = 1$). The highest degree or level of schooling completed³ by the participants included Some College, No Degree ($n = 9$), High School Graduate, Diploma or the Equivalent ($n = 7$), Associate Degree ($n = 7$), Bachelor's Degree ($n = 6$), Master's Degree ($n = 2$), and Trade/Technical/Vocational Training ($n = 1$). The sample was near 1 SD above the population mean on the Test of Premorbid Functioning (TOPF; age-adjusted standard scores or IQ $M = 114.88$, $SD = 9.03$; raw scores or number of words pronounced correctly $M = 52.81$, $SD = 7.99$). All participants gave informed consent and received either course credit or monetary compensation for their participation. All study procedures implemented in accordance with the

² Slashes (/) indicate participants that identified with more than one race.

³ Participants selected the highest degree received if they were currently enrolled.

Declaration of Helsinki and approved by the Institutional Review Board (IRB) of The University of Texas at Dallas (UTD IRB #19-08).

4.4 Materials

The stimuli were constructed from a published database of sentences that were normed for cloze probabilities (i.e., predictability of the final word given the sentence context) and demonstrated the N400 effect (Block & Baldwin, 2010). The top 400 sentences with the highest cloze probabilities were selected to increase the predictive context and facilitate stronger N400 effects. These 400 sentences were sorted into two conditions: sentences in which the final word completed the sentence logically (sensible completions; SC) and sentences that were completed illogically (unconnected completions; UC). In version one, the final words of the SCs were recycled and randomly assigned to UC sentences to form the UCs in version one. This process was the opposite in version two; UC sentences were assigned as SC and the SCs were assigned as UCs. The final words of the UCs (that were not used in version one) were also recycled and used as the final words in both SCs and UCs in version two. This counterbalancing procedure ensured that each sentence and final word appeared as both a SC and an UC when ERPs were averaged across participants when versions one and two were administered in equal proportions.

Both SCs and UCs were then further subdivided into the three cueing conditions: neutral, valid, and invalid. Valid trials have sentence endings that align with the prediction generated by the cue, while invalid trials' sentence endings do not align with the predictions generated by the cue. During sentence reading, green cues signal an approaching SC final word, orange cues signal an approaching UC final word, and purple cues do not signal the connectiveness of the final word. Thus, valid trials are SCs that have a green cue and UCs that have an orange cue,

while invalid trials are SCs that have an orange cue and UCs that have a green cue. Neutral trials are SCs and UCs that have a purple cue (see Figure 4.2 for example sentences and counterbalancing scheme).

The deceptive nature of invalid trials introduced a risk that incentivized participants to not utilize the cues to generate predictions. To reduce this effect the conditions were weighted such that, out of 400 total trials, valid trials appeared 240 times (60%), neutral trials appeared 80 times (20%), and invalid trials appeared 80 times (20%) split evenly among completion type. See Appendix A for a table of stimuli across both versions.

To facilitate ERP intra-cue comparisons (effect of green, orange, and purple cues), sentences and final words were paired together and counterbalanced across versions (i.e., between-subjects). This counterbalancing procedure ensured that intra-cue comparisons (e.g., N400 mean amplitude, proportion correct, and reaction time for correct solutions) when collapsed across versions were comparisons that did not differ in: 1) cue color, 2) sentence context, 3) final word (see Figure 4.2). Due to the heavily weighted nature of the valid vs. neutral/invalid trials, only 40 trials are completely matched within valid and invalid trials (maximum possible). As a consequence, this produced a completely counterbalanced/matched subset of valid trials across green and orange cues, thus allowing a strong secondary comparison of whether cue color impacted processing between valid SC and valid UC trials. Additionally, each version contained two subversions that counterbalanced the hand used when selecting the response, such that subversion A and B required participants to identify SCs with the left- and right-hand index finger, respectively. Thus, the dependent variables of interest were not influenced by ipsilateral influences of motor preparation/response.

Version	Completion	Condition		Neutral Example	
				Word SC/UC	Sentence SC UC
Version #1	Sensible Completion 200	Neutral 40	Jesse ran the race at a slower → pace.	●	●
		Valid 120	Vic asked her to repeat what she had → said.		
		Invalid 40	The kids fed the ducks some stale → bread.		
	Unconnected Completion 200	Invalid 40	The baby bird was ready to learn to → said.		
		Valid 120	The athlete enjoyed lifting weights at the → bread.		
		Neutral 40	He had a long day and was in a bad → pace.	●	●
Version #2	Sensible Completion 200	Neutral 40	He had a long day and was in a bad → mood.	●	●
		Valid 120	The baby bird was ready to learn to → fly.		
		Invalid 40	The athlete enjoyed lifting weights at the → gym.		
	Unconnected Completion 200	Invalid 40	Vic asked her to repeat was she had → fly.		
		Valid 120	The kids fed the ducks some stale → gym.		
		Neutral 40	Jesse ran the race at a slower → mood.	●	●

Figure 4.2. Trial counts and example sentences for each version, completion, and condition. The counterbalancing procedure is illustrated for purple cues, but also applies to 40 green and 40 orange cues.

To ensure that UCs were completed illogically, the semantic similarity between the sentence stem and the final word was measured using latent semantic analysis (LSA; Landauer, Foltz, & Laham, 1998) via the *LSAfin* package (Gunther, Dudschig, & Kaup, 2015) in R (version 3.5.1; R Core Team, 2015) and RStudio (version 1.1.456). LSA is a method that measures the similarity between two entities of text (e.g., paragraph-paragraph, sentence-word, word-word, etc.) given a “semantic space” or context. LSA simultaneously considers several relationships between textual inputs across the semantic space, thus providing a rich index of meaning that closely mirrors human performance (Landauer et al., 1998). LSA estimates were derived using the *EN_100k* semantic space (downloaded from <http://www.lingexp.uni-tuebingen.de/z2/LSAspace/>) that was created from a ~2 billion word corpus. Following the derivation of LSA estimates between the sentence stem and the final word, the sentences were visually inspected to ensure they were connected illogically. Occasionally, UCs that were randomly assigned a recycled SC ending completed sentences logically. In these cases, the affected sentences were exchanged with other sentences within the chosen stimulus set to generate new UCs. LSA values were re-computed for these newly recombined sentences.

Sentences and final word endings were recycled across version and completion, but only within subgroups of condition (i.e., neutral, valid, invalid). To ensure these subgroups did not differ in lexical and orthographic characteristics, word frequency ratings derived from a corpus of television and film subtitles (*SUBTLEX_{US}*; Brysbaert & New, 2009), sentence length (*SLEN*), and final word length (*WLEN*) estimates were calculated. Word frequency was estimated using a standard word frequency per million words estimate (*SUBTL_{WF}*; abbreviated hereafter as *WF*) and a contextual diversity (*SUBTL_{CD}*; abbreviated hereafter as *CD*) measure that estimates the

percentage of television shows/films that words appear within the *SUBTLEX_{US}* corpus (Brysbaert & New, 2009). Together, these two lexical estimates provide well-rounded measures of natural word usage.

The balance of the stimuli across semantic, lexical, and orthographic estimates was assessed via five separate 2 (version: 1 vs. 2) x 2 (completion: SC vs. UC) x 3 (condition: neutral vs. valid vs. invalid) between-subjects analyses of variance (ANOVAs). One ANOVA was computed for each measure serving as the dependent variable: LSA, WF, CD, WLEN, SLEN. No significant main effects nor interactions were observed, except for the intended main effect of completion for LSA values (see Figure 4.3). This result suggested that within each version, SCs had higher LSA semantic similarity ratings than UCs and this difference did not interact with version, demonstrating that UCs were objectively more unconnected between sentence stem and final word compared to SCs. Although these stimuli were specifically counterbalanced to increase inferential power within cue color (i.e., same sentences and same words appear for comparison), comparisons of completion x condition were balanced across these semantic-lexical properties, despite not having the same words and sentences (see Appendix B for descriptive stimuli statistics). This balanced aspect of the stimulus set increased the inferential power when investigating N400 mean amplitude interactions between completion and condition.

4.5 EEG Acquisition

EEG data were recorded from each participant using an ANT Neuro eego™ mylab 24-bit high impedance system from 64 Ag/AgCl scalp electrodes embedded in a shielded waveguard™ cap arranged in the International 10/20 System. Bipolar electrodes were placed above and below the right eye and laterally from both eyes to measure vertical and horizontal eye movements,

respectively. EEG data were collected raw and unfiltered at a sampling rate of 1000Hz using CPz as the reference and AFz as the ground. Vertical and horizontal bipolar channels were self-referential (i.e., a subtraction between both electrodes), thus they did not share the same reference as the scalp electrodes.

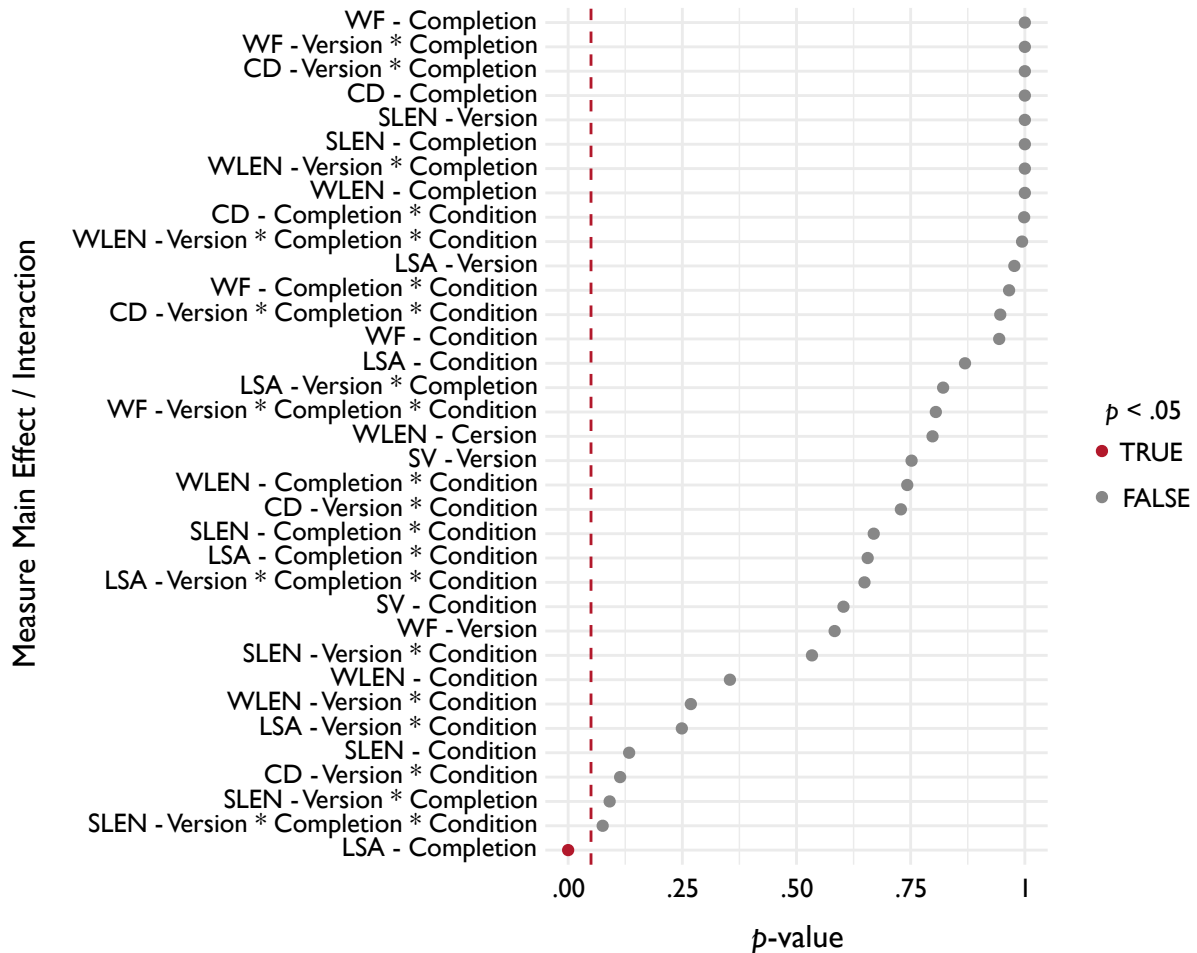


Figure 4.3. Stimulus counterbalancing statistical results. A main effect of latent semantic analysis (LSA) estimates between sensible and unconnected completions was the only significant effect observed, indicating this manipulation was successful between completion types and controlled across condition and version. SLEN = sentence length, WLEN = final word length, CD = contextual diversity, WF = word frequency. Interactions are indicated with * separating between-subjects factors.

4.6 EEG Preprocessing

EEG preprocessing was performed in MATLAB (R2017a) using the EEGLAB toolbox (Delorme & Makeig, 2004). EEG data were first re-referenced to an averaged left and right mastoid reference prior to the application of a .05 Hz Hamming windowed sinc finite impulse response (FIR) highpass filter (-6dB half-amplitude cutoff, .1 Hz transition band-width, 3300 filter order). Line noise (i.e., 60 and 120 Hz) was removed using the Cleanline EEGLAB plugin. Continuous EEG, excluding break periods and bipolar channels, was then submitted to an infomax independent components analysis (ICA) using the “runica” algorithm in EEGLAB. Components were visually inspected for each participant and removed if the component was identified as either an eye blink, a lateral eye movement, or high-frequency electromyographic (EMG) noise. Following ICA-based artifact correction, spherical spline interpolation was applied, if necessary, to channels that maintained uncharacteristic signals throughout the duration of the recording (e.g., disconnected channels, channels particularly susceptible to EMG noise such as T7 and T8, etc.). Trials were separated into epochs between -200ms and 1500ms of the final word and baseline corrected. Trials were rejected if EEG signals exceeded $\pm 100 \mu\text{V}$ criterion threshold. All participants included had $\leq 17\%$ (68) of total trials (400) rejected.

4.7 Procedure

Participants first completed an online demographic survey administered via Qualtrics that gathered information such as age, education, race and ethnicity, language fluency, and prescribed medications. Participants then completed the Test of Premorbid Functioning (TOPF; Wechsler,

2011). The TOPF is a pronunciation test of short phonetically irregular words (e.g., knead, lieu, ceilidh) that assessed the participants' reading ability and verbal intelligence.

Next, the participants were seated in a comfortable chair 100cm away from a computer monitor (Dell S2417DG, 2560 x 1440 resolution, 144Hz refresh rate) and prepared for EEG recording. Following EEG preparation, the cued Sentence Verification Task (cSVT) was administered using E-Prime 2.0 Standard (Schneider, Eschman, & Zuccolotto, 2012) on a machine running Windows 10 (64-bit Intel® Core™ i7-7700K CPU @ 4.20GHz, 16 GB RAM). The cSVT presented participants with 400 sentences, one word at a time using the rapid serial visual presentation (RSVP) method, that ended either logically (SC) or illogically (UC; see Figure 4.4).

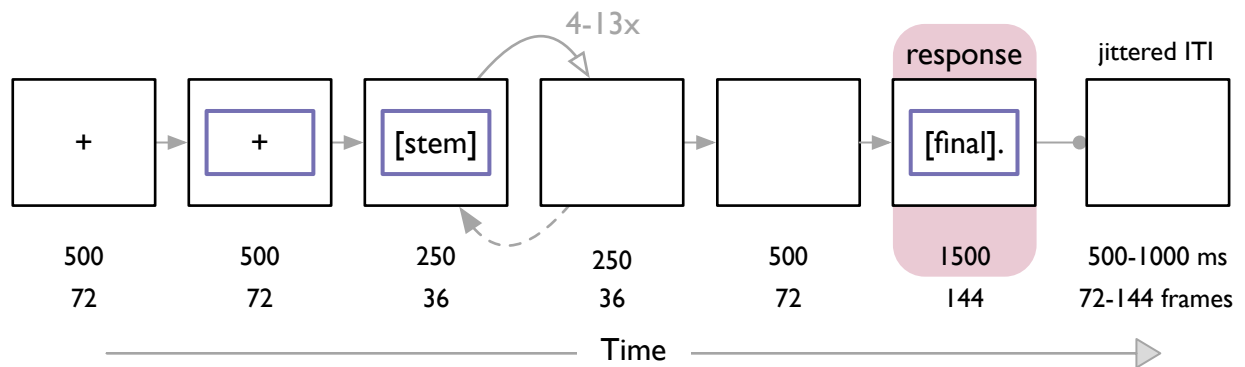


Figure 4.4. Trial procedure for the cued Sentence Verification Task. The refresh rate of the presentation monitor was 144 Hz.

The participants were instructed to determine whether the final word of the sentence completed the sentence logically by using the left or right bumper on an Xbox One controller. Left and right bumper presses were counterbalanced within each version. Furthermore, each word in the sentence stem was surrounded by a colored box that cued whether the approaching final word would complete the sentence logically or illogically. Green cues signaled an

approaching SC final word, orange cues signaled an approaching UC final word, and purple cues did not signal the connectiveness of the final word. Participants were instructed to utilize the cues to facilitate predictions about the approaching sentence endings. Participants were forewarned that the cues were occasionally incorrect (i.e., invalid trials), that this was normal, and that this is done to ensure they were paying attention to the task. Prior to starting the task, the participants received two blocks of 12 practice sentences, which were presented with the same timing as the experimental task, except that the first block did not introduce cues (i.e., black colored cues), the second block introduced the colored cues, and both blocks provided feedback after each trial. Also, the practice block that contained the colored cues presented only neutral and valid trials. The cSVT was presented across 8 blocks with 50 trials per block split evenly across completion and condition (see Table 4.1). Participants received a self-timed break at the end of each block.

Table 4.1. Sentence Verification Task Trial Counts Per Block.

Completion	Condition	Block								Total
		1	2	3	4	5	6	7	8	
Sensible	Valid	15	15	15	15	15	15	15	15	120
Sensible	Invalid	5	5	5	5	5	5	5	5	40
Sensible	Neutral	5	5	5	5	5	5	5	5	40
Unconnected	Valid	15	15	15	15	15	15	15	15	120
Unconnected	Invalid	5	5	5	5	5	5	5	5	40
Unconnected	Neutral	5	5	5	5	5	5	5	5	40
	Total	50	50	50	50	50	50	50	50	400

4.8 Statistical Analyses

Statistical analyses were performed in R (R Core Team, 2015) and R Studio using the *dplyr* (Wickham, Francois, Henry, & Müller, 2018), *broom* (Robinson & Hayes, 2018), *lmSupport* (Curtin, 2018), and *effsize* (Torchiano, 2017) packages, while figures were prepared using the *ggplot2* package (Wickham, 2016). Participant performance was modeled using multilevel modeling within a model comparison framework (Judd, McClelland, & Ryan, 2017) for both behavioral and EEG/ERP data. Orthogonally coded contrasts using effect coding were implemented for the following main effects: main effect of completion (Sensible = +1/2, Unconnected = -1/2), neutral versus valid and invalid condition (neutral = +2/3, valid = -1/3, invalid = -1/3), and valid versus invalid condition (valid = +1/2, invalid = -1/2). Interactions of both condition contrasts with the completion contrast were also modeled. In level one, performance was modeled individually for each participant according to the contrast codes defined above such that regression estimates reflected mean differences across contrasted factors and interactions. In level two, regressions were performed on regression estimates derived from level 1 for each of the contrasts specified, resulting in five regression models estimating the effect of completion, condition (both Neutral vs. Valid + Invalid and Valid vs. Invalid), and their interactions. Level two model intercepts therefore represent the grand mean of each contrast, while estimates represent the average mean difference across participants for each contrast.

Behavioral task performance was measured via proportion correct and reaction time (RT) for only correct solutions—referred to hereafter as correct RT. Given the unbalanced presentation of valid versus invalid trials, a subset of the valid trials (40) were completely matched for sentence stems and final words within each cue color (see section 4.4). Therefore,

behavioral results were separately analyzed for both matched trials (80 trials per cue color for a total of 240 trials) and all trials (80 neutral, 240 valid, and 80 invalid for a total of 400 trials) for optimal comparison with ERP results. Occasionally, participants failed to respond within the 1.5 second response period following the presentation of the final word. Therefore, proportion correct was calculated for trials that participants recorded a response. This criterion resulted in only 1.42% of trials excluded from analyses of all trials, while only 1.52% of trials were excluded from analyses of matched trials. Correct RT was calculated from trials in which participants correctly responded.

In an effort to boost the signal to noise ratio and power (Luck, 2014), a cluster of nine electrodes surrounding and including Cz, where the N400 is usually maximal (Kutas & Federmeier, 2011), were averaged together for each subject: FC1, FCz, FC2, C1, Cz, C2, CP1, CPz, and CP2. The N400 is characterized as a negative-going deflection in signal that can begin as early as 200ms and last up to 400ms post-stimulus for visually presented words (Kutas & Federmeier, 2011); however, a precise time window for measuring N400 mean amplitudes is ill-defined in the literature and often varies in starting time and duration across studies. For instance, Kutas and Hillyard (1980) in their seminal study that discovered the N400 measured mean amplitudes between 300-600ms. The investigation that provided cloze probability and N400 norms for the base stimulus set in the current investigation measured N400 mean amplitudes between 250-500ms (Block & Baldwin, 2010), while Steinhauer et al. (2017) proposed three separate time windows/phases to the N400: prediction (200-450ms), ASA (300-500ms), and post-lexical integration (> 400ms).

However, several studies have utilized the 300-500ms time window that has shown flexibility across sentence reading paradigms (e.g., Dambacher & Kliegl, 2007; Ito, Martin, & Nieuwland, 2016; Lewis, Schoffelen, Hoffmann, Bastiaansen, & Schriefers, 2016) and word pair presentations investigating analogical reasoning (Kmieciak et al., 2019) and N400 prediction effects (Lau et al., 2013). Given the precedent of using the 300-500ms time window across presentation methods, the peaking of the N400 around 400ms, and the use of Lau and colleagues' (2013) results to inform effect size measurements for the current investigation's power analysis, I chose *a priori* to measure N400 mean amplitudes between 300-500ms following the presentation of the final word of only matched trials. N400 mean amplitudes for were analyzed using the multilevel modeling procedure describe above and were derived from only matched trials (i.e., the 160 valid trials that were unmatched with invalids were excluded). Predictions 1 through 3 (see Chapter 3) were simpler models that only included the factor of completion for each cue color separately, while prediction 4 was modeled using the full multilevel modeling procedure. Analyzing only matched trials controlled for sentence stem and final word differences within each color cue and ensured that ERPs were compared between equivalent base trial amounts (i.e., 40). Including unmatched valid trials within ERP averaging would have disproportionately increased the number of trials in the valid than invalid conditions and altered ERP waveforms for reasons other than cognitive differences (e.g., smoother and reduced amplitudes with more trials).

CHAPTER 5

RESULTS

5.1 Behavioral Results

5.1.1 All Trials

When considering all possible task trials administered (i.e., when including the 160 unmatched valid trials), participants were very accurate on the task correctly answering on average 96.09% ($SD = 2.69\%$) of task trials and answering these trials with an average RT of 615ms ($SD = 118$ ms; see Table 5.1 for descriptive statistics and left panel of Figure 5.1).

Table 5.1. Behavioral Descriptive Statistics for All Trials.

		Condition					
		Neutral		Valid		Invalid	
Measure	Completion	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Proportion Correct	Sensible	0.97	0.04	0.97	0.03	0.93	0.06
	Unconnected	0.97	0.05	0.97	0.02	0.95	0.06
Correct RT (ms)	Sensible	580.94	136.38	562.29	128.32	613.65	136.80
	Unconnected	644.64	116.01	632.00	114.49	657.53	118.74

Multilevel modeling of participants' proportion of correctly solved trials (see Table 5.2) demonstrated improved performance when evaluating neutral trials compared to valid and invalid trials collapsed across completion type. Furthermore, participants correctly evaluated a higher proportion of valid than invalid trials; however, this factor of condition interacted with completion type such that participants performed equally on valid trials, while performance suffered more for invalid sensible than unconnected completions (see left panel of Figure 5.2).

Table 5.2. Proportion Correct Multilevel Modeling Results for All Trials.

Source	<i>b</i>	<i>SS</i>	<i>MSE</i>	<i>F</i>	<i>p</i>	<i>PRE</i>
Between-Subjects	96.09	2954.45	0.11	27586.05	< .001	.999
Completion	-0.70	0.16	0.08	2.05	.162	.062
Neutral vs. Valid + Invalid	2.38	1.81	0.31	13.55	.001	.304
Valid vs. Invalid	1.31	0.55	0.23	16.19	< .001	.343
Completion x (N vs. V+I)	1.41	0.64	0.05	2.36	.135	.071
Completion x (V vs. I)	3.09	3.05	0.19	5.91	.021	.160

Note. Degrees of freedom for the numerator and denominator were 1 and 31, respectively; values for *b*, *SS*, and *MSE* were multiplied by 100 for visual purposes and are therefore in units of accuracy, not proportion correct; *PRE* = proportional reduction in error also known as R^2 ; N= Neutral; V = Valid; I = Invalid.

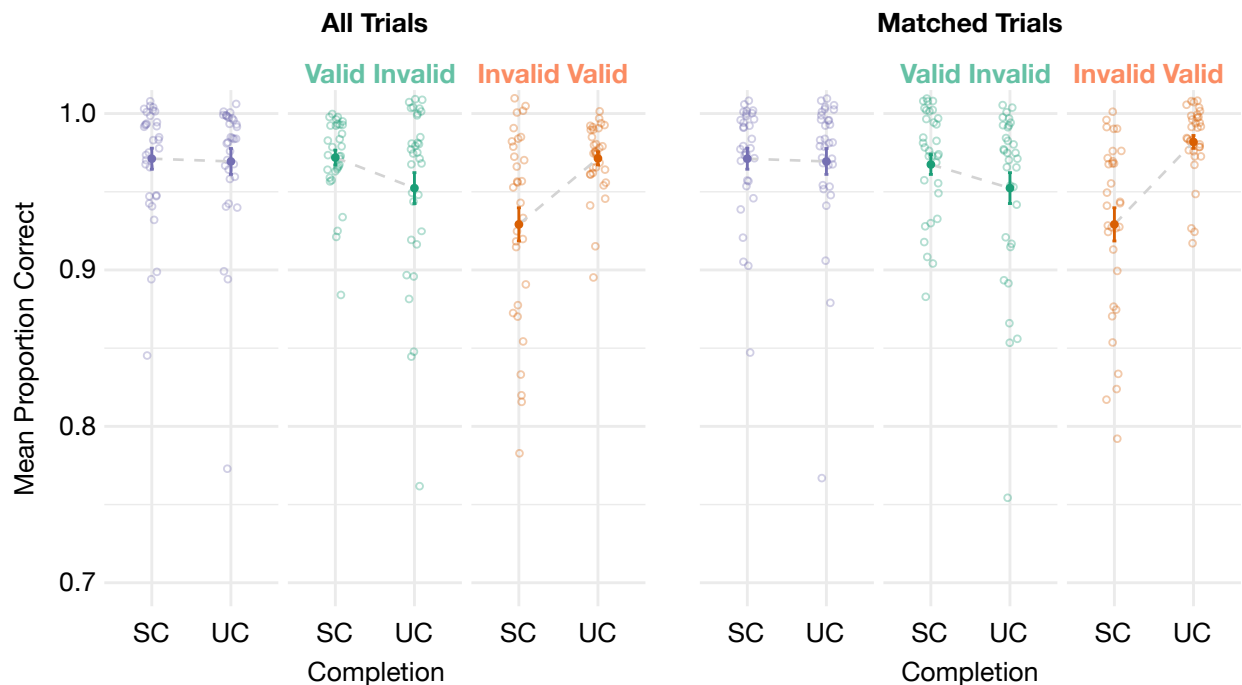


Figure 5.1. Proportion correct results for all trials (*left panel*) and matched trials (*right panel*). Means are depicted by solid circles with SEM error bars, while transparent hollow circles indicate individual participant means. Colors represent cue colors presented to participants during sentence reading. SC = Sensible Completions; UC = Unconnected Completions.

Taken together, these results suggest that participant performance was affected by cue color, with valid and invalid cues improving and disrupting performance, respectively. In other

words, this result provides evidence that participants were not disregarding cue colors. Furthermore, the interaction observed between completion and condition (valid vs. invalid) suggests potentially separable mechanisms for semantic expectation or that the semantic activations from SCs are more difficult to overcome than those from UCs.

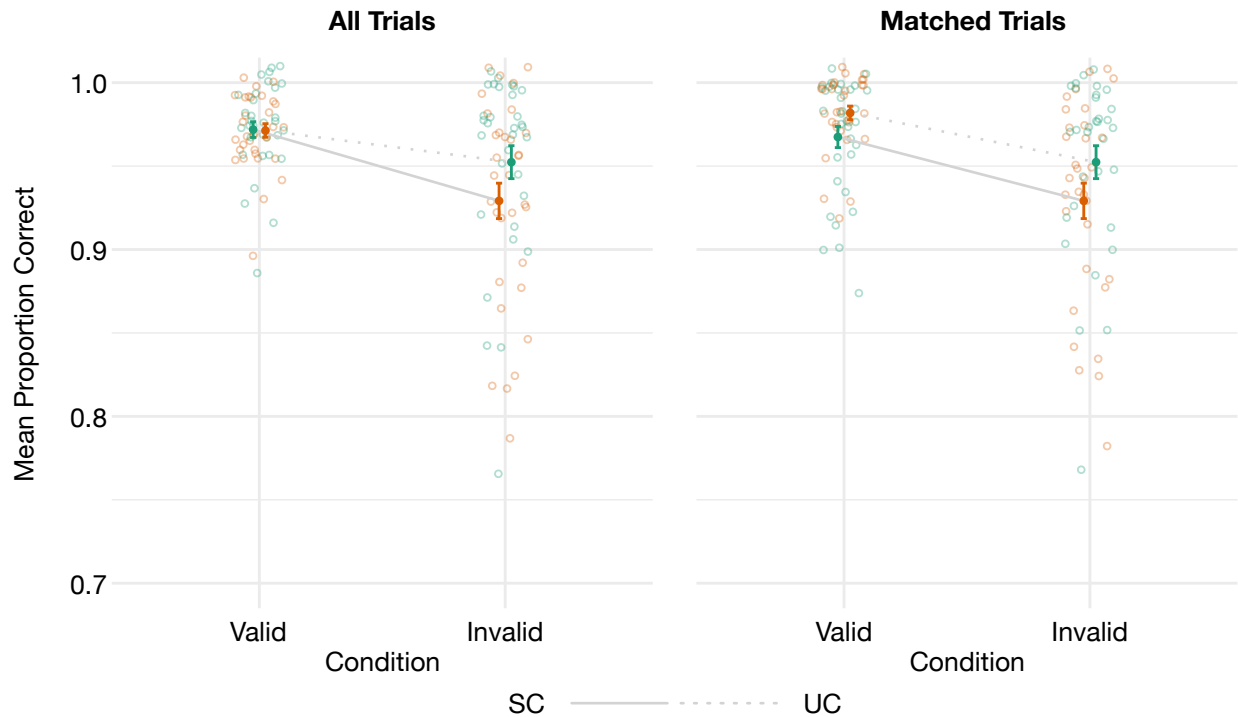


Figure 5.2. Proportion correct interaction effects for all trials (*left panel*) and matched trials (*right panel*). Means are depicted by solid circles with SEM error bars, while transparent hollow circles indicate individual participant means. Colors represent cue colors presented to participants during sentence reading. SC = Sensible Completions; UC = Unconnected Completions.

Multilevel modeling suggested that participants' correct RTs (see left panel of Figure 5.3) were faster for neutral trials compared to valid and invalid trials when collapsed across completion type (see Table 5.3). Furthermore, participants' correct RTs were faster for valid than invalid trials; however, this factor of condition interacted with completion type such

that participants responded disproportionately faster on validly cued SCs compared to all other conditions (see left panel of Figure 5.4).

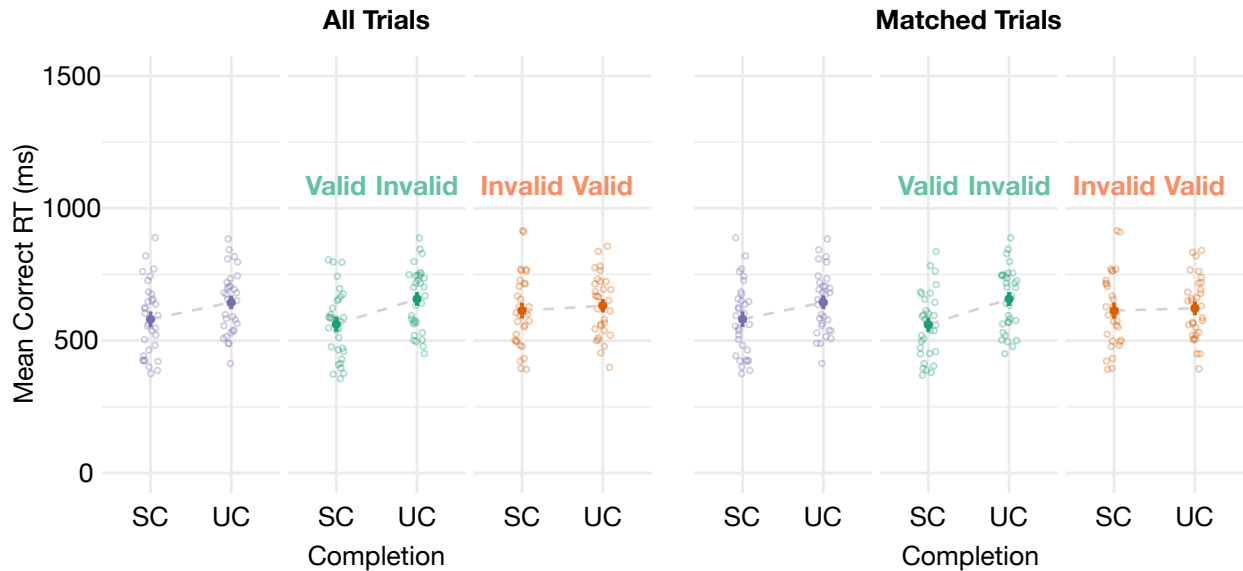


Figure 5.3. Correct RT results for all trials (*left panel*) and matched trials (*right panel*). Means are depicted by solid circles with SEM error bars, while transparent hollow circles indicate individual participant means. Colors represent cue colors presented to participants during sentence reading. SC = Sensible Completions; UC = Unconnected Completions.

Table 5.3. Correct RT Multilevel Modeling Results for All Trials.

Source	<i>b</i>	<i>SS</i>	<i>MSE</i>	<i>F</i>	<i>p</i>	<i>PRE</i>
Between-Subjects	615.17	12110084.16	14210.75	852.18	< .001	.965
Completion	-59.10	111757.93	3501.82	31.91	< .001	.507
Neutral vs. Valid + Invalid	-3.58	409.51	504.61	0.81	.375	.026
Valid vs. Invalid	-38.45	47298.01	1682.02	28.12	< .001	.476
Completion x (N vs. V+I)	-6.91	1527.51	2902.17	0.53	.474	.017
Completion x (V vs. I)	-25.84	21362.13	2420.21	8.83	.006	.222

Note. Degrees of freedom for the numerator and denominator were 1 and 31, respectively; *PRE* = proportional reduction in error also known as R^2 ; N= Neutral; V = Valid; I = Invalid.

Again, these results suggest that participant performance was affected by cue color, with valid and invalid cues speeding and slowing performance, respectively. This result provided more evidence that participants incorporated the cues into their solving strategies.

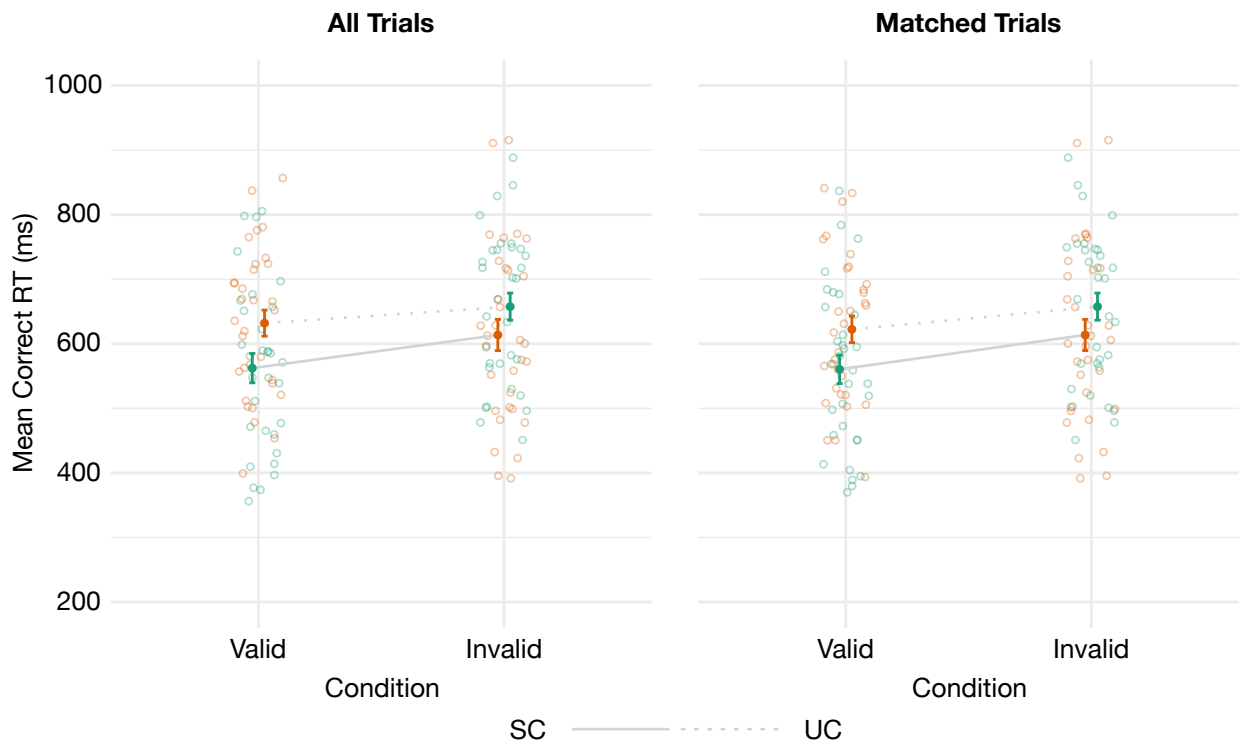


Figure 5.4. Correct RT interaction effects for all trials (*left panel*) and matched trials (*right panel*). Means are depicted by solid circles with SEM error bars, while transparent hollow circles indicate individual participant means. Colors represent cue colors presented to participants during sentence reading. SC = Sensible Completions; UC = Unconnected Completions.

The interaction observed between completion and condition (valid vs. invalid) depicted a different pattern when compared to the proportion correct results. Instead of valid trials equating in performance, participants' correct RTs were 70ms faster for validly cued SCs than UCs but reversed in direction with participants responding 44ms faster for invalidly cued SCs than UCs. Despite similar proportion correct rates for valid trials, these same trials were differentiated in RT. Taken together, the correct RT results for all trials suggest that sentence semantics have a potent influence on decision speeds, such that semantic congruency speeds performance,

especially when congruency matches expectancy, even in the face invalid expectations (i.e., invalid SCs).

5.1.2 Matched Trials

When considering only matched trials (i.e., when excluding the 160 unmatched valid trials), participants were still very accurate on the task correctly answering on average 96.19% ($SD = 3.21\%$) of matched task trials with an average RT of 613ms ($SD = 118\text{ms}$; see Table 5.4 for descriptive statistics and right panel of Figure 5.1).

Table 5.4. Behavioral Descriptive Statistics for Matched Trials.

		Condition					
		Neutral		Valid		Invalid	
Measure	Completion	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Proportion Correct	Sensible	0.97	0.04	0.97	0.04	0.93	0.06
	Unconnected	0.97	0.05	0.98	0.02	0.95	0.06
Correct RT (ms)	Sensible	580.94	136.38	560.47	124.64	613.65	136.80
	Unconnected	644.64	116.01	622.39	116.40	657.53	118.74

Multilevel modeling of participants' proportion of correctly solved trials (see Table 5.5) demonstrated improved performance when evaluating 1) UCs compared to SCs and 2) valid compared to invalid trials. However, unlike the analysis with all trials, an interaction between these two factors did not interact (see right panel of Figure 5.2). These results suggest that participant performance was affected by cue color—even in the case of matched trials that have fewer trial numbers—with valid and invalid cues improving and disrupting performance, respectively. Importantly, this result provides evidence that participants were not disregarding cue colors and strengthens inferences from ERP results. Furthermore, a lack of interaction

observed between completion and condition (valid vs. invalid) limits inferences suggesting separable mechanisms for semantic expectation or that the semantic activations from SCs are more difficult to overcome than those from UCs, especially in regards to ERP evidence.

Table 5.5. Proportion Correct Multilevel Modeling Results for Matched Trials.

Source	<i>b</i>	<i>SS</i>	<i>MSE</i>	<i>F</i>	<i>p</i>	<i>PRE</i>
Between-Subjects	96.19	2960.69	0.10	28406.40	< .001	0.999
Completion	-1.20	0.46	0.07	6.25	0.018	0.168
Neutral vs. Valid + Invalid	1.26	0.51	0.07	7.69	0.009	0.199
Valid vs. Invalid	3.39	3.68	0.20	18.50	< .001	0.374
Completion x (N vs. V+I)	2.06	1.35	0.23	5.76	0.023	0.157
Completion x (V vs. I)	0.88	0.25	0.48	0.52	0.477	0.016

Note. Degrees of freedom for the numerator and denominator were 1 and 31, respectively; values for *b*, *SS*, and *MSE* were multiplied by 100 for visual purposes and are therefore in units of accuracy, not proportion correct; *PRE* = proportional reduction in error also known as R^2 ; N= Neutral; V = Valid; I = Invalid.

Multilevel modeling suggested that participants' correct RTs (see right panel of Figure 5.3) were faster for 1) SCs than UCs and 2) valid than invalid matched trials (see Table 5.6); however, these factors demonstrated a trending interaction ($p = .058$) such that participants responded disproportionately faster on validly cued SCs compared to all other conditions (see right panel of Figure 5.4).

Table 5.6. Correct RT Multilevel Modeling Results for Matched Trials.

Source	<i>b</i>	<i>SS</i>	<i>MSE</i>	<i>F</i>	<i>p</i>	<i>PRE</i>
Between-Subjects	613.27	12035229.54	14054.21	856.34	< .001	0.965
Completion	-56.50	102153.51	3344.43	30.54	< .001	0.496
Neutral vs. Valid + Invalid	-0.72	16.64	574.54	0.03	0.866	0.001
Valid vs. Invalid	-44.16	62398.25	1895.00	32.93	< .001	0.515
Completion x (N vs. V+I)	-10.80	3735.00	3849.53	0.97	0.332	0.030
Completion x (V vs. I)	-18.05	10423.45	2680.20	3.89	0.058	0.111

Note. Degrees of freedom for the numerator and denominator were 1 and 31, respectively; *PRE* = proportional reduction in error also known as R^2 ; N= Neutral; V = Valid; I = Invalid.

These results further suggest that participant performance was affected by cue color, with valid and invalid cues speeding and slowing performance, respectively. Importantly, identical trials were used in the correct RT analysis of matched trials and the ERP analyses. Therefore, the behavioral differences of completion, condition (valid vs. invalid), and their trending interaction are directly comparable to the ERP effects shown below.

5.2 N400 ERP Results

As stated in section 4.8, N400 ERP mean amplitudes were measured between 300-500ms from a cluster of nine central midline electrodes using signals derived from only matched trials (see Table 5.7 for descriptive statistics).

Table 5.7. N400 Mean Amplitude Descriptive Statistics: Completion x Condition.

	Condition					
	Neutral		Valid		Invalid	
Completion	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Sensible	9.78	5.60	10.70	5.59	11.05	6.27
Unconnected	2.88	5.55	3.74	4.82	3.46	5.75

Note. Units are in microvolts (μ V).

I hypothesized that expectancy generated by cues would modulate N400 mean amplitudes between SCs and UCs such that 1) neutral cues would elicit a standard N400 effect with UCs generating more negative mean amplitudes than SCs, 2) green invalid cues would generate a larger N400 effect compared to neutral trials, and 3) orange valid cues could elicit more positive N400 mean amplitudes despite sentence incongruency (i.e., UCs). Multilevel modeling results demonstrated large differences between SCs and UCs for all three comparisons such that UCs elicited more negative N400 mean amplitudes compared to SCs (see Table 5.8 and Figure 5.5).

Table 5.8. Effect of Completion Within *a priori* Comparisons.

Comparison	Cue Color	Source	<i>b</i>	<i>SS</i>	<i>MSE</i>	<i>F</i>	<i>p</i>	<i>PRE</i>
1	Purple	Between-Subjects	6.33	1282.10	27.53	46.58	< .001	.60
1	Purple	Completion	6.90	1522.43	14.21	107.11	< .001	.78
2	Green	Between-Subjects	7.08	1602.56	29.33	54.65	< .001	.64
2	Green	Completion	7.24	1678.81	11.17	150.32	< .001	.83
3	Orange	Between-Subjects	7.39	1749.39	28.14	62.17	< .001	.67
3	Orange	Completion	7.31	1708.19	12.68	134.76	< .001	.81

Note. Degrees of freedom for the numerator and denominator were 1 and 31, respectively; *PRE* = proportional reduction in error also known as R^2 .

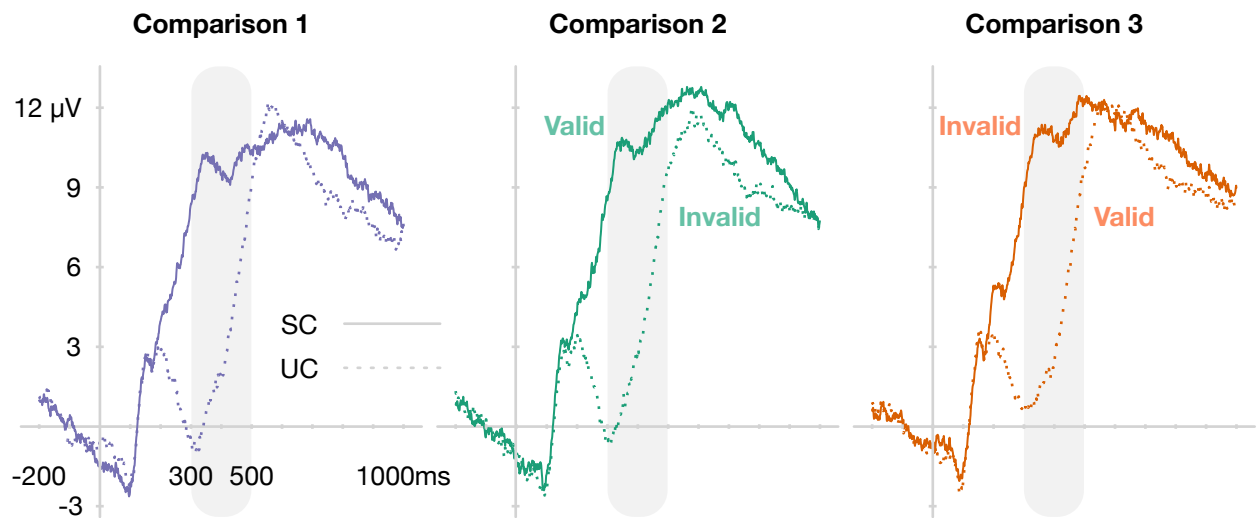


Figure 5.5. N400 effect following the final word across *a priori* comparisons. Colors represent cue colors presented to participants during sentence reading. Signals were averaged across a cluster of nine electrodes surrounding and including Cz. Shaded area represents the 300-500ms time window that mean amplitudes were calculated.

Surprisingly, the neutral trials had the largest effect size⁴ (Cohen's $d = 0.48$ 95% CI [0.23, 0.73]), while similar effect sizes were observed for green ($d = 0.44$ [0.22, 0.66]) and orange cues ($d = 0.44$ [0.22, 0.65]). However, all three cue colors had medium effect sizes and

⁴ Cohen's d estimates were calculated by using the pooled SD as the standardizer.

overlapping 95% confidence intervals, suggesting that their effect size magnitudes were not reliably different from each other. Taken together, these results provide evidence supporting prediction P1, but not predictions P2 and P3. A classic N400 effect was observed between SCs and UCs for neutral cues demonstrating that the stimuli utilized were appropriately constructed for semantic congruency/incongruency. Although an N400 was observed between valid and invalid green cues in the expected direction, this effect size was smaller than the effect size observed for the neutral cues, thus not supporting P2. The most surprising result was that invalid orange cues elicited more positive N400 mean amplitudes than valid trials. This result is opposite of what was initially predicted and suggests that expectation has little influence on N400 mean amplitudes, even when faced with unexpected semantic congruency.

To further test the hypothesis that top-down expectation modulates semantic access, multilevel modeling was conducted to evaluate the effects of completion type, condition, and their interactions. The modeling results (see Table 5.9) demonstrated two significant contrasts of completion (SC vs. UC) and condition (neutral vs. valid + invalid). The latter effect of condition will not be interpreted because it collapses across completion types that are necessary to evaluate prediction P4.

Table 5.9. N400 Mean Amplitude Multilevel Modeling Results.

Source	<i>b</i>	<i>SS</i>	<i>MSE</i>	<i>F</i>	<i>p</i>	<i>PRE</i>
Between-Subjects	6.93	1538.31	26.85	57.30	< .001	.649
Completion	7.15	1635.44	8.99	181.92	< .001	.854
Neutral vs. Valid + Invalid	-0.91	26.24	3.08	8.53	.006	.216
Valid vs. Invalid	-0.03	0.03	2.66	0.01	.914	< .001
Completion x (N vs. V+I)	-0.38	4.55	8.66	0.53	.474	.017
Completion x (V vs. I)	-0.63	12.87	19.24	0.67	.420	.021

Note. Degrees of freedom for the numerator and denominator were 1 and 31, respectively; *PRE* = proportional reduction in error also known as R^2 ; N= Neutral; V = Valid; I = Invalid.

A significant main effect of completion was observed such that SCs elicited more positive N400 mean amplitudes than UCs (see Figure 5.6). In other words, a classic N400 effect was observed when collapsing across condition and/or color cue. P4 predicted that the factors of completion type and condition (valid vs. invalid) would interact by modulating N400 mean amplitudes between 300-500ms; however, this interaction was not observed and, therefore, suggests that the expectancy effects seen in the behavioral results did not affect semantic access at the N400. Chapter 6 will discuss how the behavioral and ERP results inform current debates about the cognitive processing responsible for generating the N400.

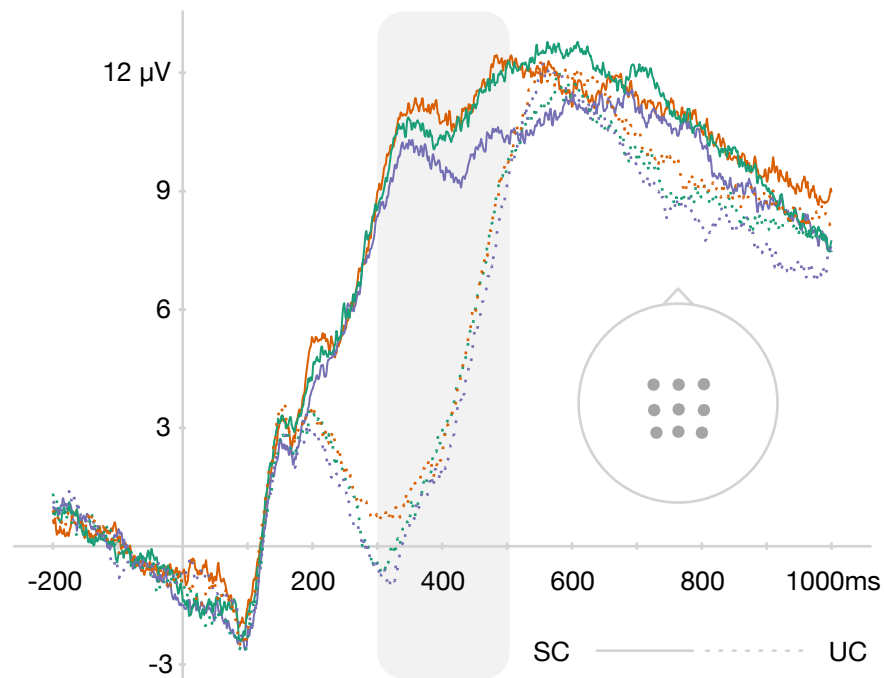


Figure 5.6. Completion x condition N400 ERP plot. Colors represent cue colors presented to participants during sentence reading. Shaded area represents the 300-500ms time window that mean amplitudes were calculated.

CHAPTER 6

DISCUSSION

The purpose of this dissertation was to explore the cognitive mechanisms of top-down volitional control and how our expectations may interact with bottom-up and top-down prediction effects to influence online constructions of semantic meaning. Participants were tasked with reading sentences, one word at a time, and determining whether the final word completed the sentence sensibly. Online constructions of semantic meaning (i.e., semantic access) was measured via N400 ERP mean amplitudes, while expectations of upcoming stimuli were modulated by visually-based non-semantic colored boxes that surrounded each word presented. Green cues indicated to participants that the final word would result in a sensible completion (SC), orange cues signaled an approaching unconnected completion (UC), and purple cues did not signal the completion type, thus forming a neutral condition. Green and orange cue colors correctly signaled their completion type 2/3 of the time (hereafter referred to as valid trials), while incorrectly signaling participants 1/3 of the time (hereafter referred to as invalid trials). It was hypothesized that participants would generate expectations of upcoming stimuli and these expectations would affect semantic access differently depending on the color of the cue.

This hypothesis led to four predictions. (P1) Neutral trials were predicted to demonstrate a classic N400 effect, with SCs eliciting more positive mean amplitudes than UCs, due to the lack of expectancy generation for neutral trials. (P2) Green cues were predicted to generate expectancies during sentence reading that would facilitate semantic access for valid trials, while inhibiting semantic access for invalid trials. In terms of electrophysiological signals, I predicted a larger N400 effect for green cues compared to neutral cues given that expectancy aligned with

sentence semantics in the valid condition but was misaligned in the invalid condition. (P3)

Orange cues were also predicted to generate expectations, but in an opposite fashion compared to green cues, such that validly cued UCs would facilitate semantic access, while invalidly cued SCs would inhibit semantic access. I predicted that the N400 effect would reverse polarity for orange cues, such that valid UCs would elicit more positive N400 mean amplitudes compared to invalid SCs. (P4) Given that green and orange cues facilitate and inhibit semantic access differently, I predicted that the factors of completion (SC vs. UC) and condition (valid vs. invalid) would interact by affecting N400 mean amplitudes. In sum, I predicted that volitional top-down control extracted from cues would modulate semantic access depending on whether the expected semantic representation was presented.

The behavioral results, when analyzing participants' proportion correct and reaction times for correct responses (correct RTs), support the hypothesis that volitional top-down control influences semantic processing by facilitating performance for validly cued trials, while disrupting performance for invalidly cued trials. These behavioral results suggested that cues may impact semantic access, perhaps by pre-activation or inhibition of semantic representations, resulting in behavioral performance differences depending on completion type and condition (i.e., cue color). However, these inferences were qualified by N400 mean amplitude comparisons such that the largest and only difference (when differentiating signals based on completion type) was a main effect of completion. In other words, the validity of the cues did not modulate the N400; rather, the effect of completion (SC vs. UC) was the main factor impacting the N400. At the level of N400 processing, volitional top-down control did not affect neural signatures of semantic access, suggesting that the semantic representations that are

activated via predictions from normal sentence reading are not affected by additional top-down expectation. The following will discuss these findings and how they relate to theories of semantic access, the neuroanatomical theories of semantic processing, and how these results inform the current debate surrounding the cognitive mechanisms that generate the N400 ERP.

As explicated in the behavioral results (see section 5.1), proportion correct and correct RT results were divided into all trials and matched trials analyses. Matched trials represent a subset of all possible trials that are completely matched (i.e., contain the same stimuli) within each cue color for sentence stems, final words, and the hand responsible for motor response. Therefore, behavioral and ERP results are directly comparable for matched trials. In contrast, analyses containing all trials are unbalanced comparisons because of the increased amount of valid trials compared to invalid and neutral trials (see section Materials 4.4). Nevertheless, both matched and all trials analyses depict interesting phenomena and will be discussed in turn.

6.1 Behavioral Results Across all Trials: Semantic Facilitation and Inhibition

When taking all trials into consideration, the participants performed very well on the task ($M = 96.09\%$, $SD = 2.69\%$), suggesting that task was a simple and straightforward. However, participant performance was modulated based on the validity of the cues and completion type. Participants had similar proportion correct rates for validly cued SCs (green cues) and UCs (orange cues), but dissimilar performance for invalidly cued trials (see left panel of Figure 5.2). Participant performance worsened more for invalidly cued SCs (orange cues) than UCs (green cues). This interaction suggested that expectation, when aligned with semantic predictions from normal sentence reading, similarly affected performance, even in the face of semantic incongruency (i.e., UCs). Expectations, when violated by semantic predictions from sentence

reading, were more difficult to overcome in the face of semantic congruency (SCs) than semantic incongruency (UCs). In other words, violations in expectations were easier to correct if semantic constraint was narrow (i.e., expecting the sentence to make sense) rather than when semantic expectations were broad (i.e., expecting the sentence to not make sense).

Nevertheless, correct RTs for all trials qualified the interpretations derived from proportion correct effects alone. Despite similar proportion correct rates for validly cued sentences, participants differentiated in correct RTs for valid trials, such that participants responded faster to validly cued SCs (green cues) than UCs (orange cues), while similar RTs were observed for invalid conditions. These results suggest that despite similar accuracies, participants took longer to overcome the semantic violations in sentence reading generated from UCs, even when these violations were expected. Surprisingly, invalidly cued SCs (orange cues) were slightly, but not significantly, faster compared to their validly cued counterpart (orange UCs) by 25ms. These results suggest that semantic congruency—from predictions generated from normal sentence reading—facilitate processing of meaning even when these violate expectations. Likewise, this effect is amplified when expectations align with semantic predictions generated from sentence reading with selective facilitation observed in validly cued SCs (green cues).

When taking together both the proportion correct and correct RT results for all trials, the factors of condition and completion affected performance in different ways. Validity selectively facilitated accuracy, while completion type affected response speeds to a greater degree. Given that analyses with all trials are unbalanced and not directly comparable to the N400 ERP effects obtained with matched trials, I am hesitant to speculate about how these results may inform

semantic access and inhibition theories other than briefly stating what these results could mean if taken at face value.

First, the behavioral results from the all trials analyses provide evidence that participants did not disregard the cues. A potential risk with the chosen design was that participants would not utilize the cues to their advantage and instead ignore the cues, given that the cues were invalid on 20% of all total trials. However, the strong completion by condition interactions observed for both proportion correct and correct RT (see section 5.1.1) increased the inferential ability that expectation effects were present during final word processing when interpreting modulations to N400 mean amplitudes (or lack thereof).

Secondly, the completion by condition interaction effects support a separable mechanisms approach for expectation of upcoming semantic stimuli. More specifically, these results support the notion that expecting semantic congruency may affect mechanisms of lexical integration (Holcomb, 1993), prediction or pre-activation of semantic representations (Federmeier, 2007), or semantic inhibition (Debrulle, 2007; Debrulle et al., 2008) differently than expecting semantic incongruency. Proportion correct rates were lower for invalidly cued SCs (orange cues) compared UCs. In both conditions, sentence endings were invalidly cued. In contrast, cues modulated semantic expectations such that green cues constrained semantic possibilities, while orange cues broadened semantic possibilities. Equivalent behavior was predicted in a single mechanism model in both cases; however, this idea was not supported given the SC vs. UC differences in invalid trials.

In contrast to the separable mechanism approach is the diffusion model proposed by Ratcliff (1981, 1985, 1987). The diffusion model seeks to explain results obtained from same-

different discriminations of stimuli (e.g., letter strings, sentences, etc.). In the simplest of these paradigms, participants are tasked with discriminating whether the pairs of presented letter strings are either same (e.g., CFJDR – CFJDR) or different (e.g., CFJDR – CFKDR). Depending on experimental conditions, such as instructional manipulations or systematically increasing the number of different letters, RT differences are observed between same/different discriminations; usually, same discriminations are performed faster than different (Ratcliff, 1981, 1985). Models explaining the typical effect seen, that same or semantically congruent responses (Ratcliff & Mckoon, 1982) are usually faster, attribute this advantage as a specialized cognitive process operating independently from other cognitive processes for different judgments (e.g., Proctor, 1981); however, Ratcliff and Hacker (1981) demonstrated that instructing participants to either respond “same” or “different” only when sure biased response times, suggesting same/different discriminations were susceptible to criterion adjustments from instructional manipulations. Therefore, the diffusion model proposed to explain these criterion adjustments posited that evidence accumulates gradually towards same and different decision boundaries. Participants generate responses once enough evidence has accumulated towards a decision boundary. Furthermore, boundary heights are amenable to outside factors, such as instructions or proportion of trials in a specific category, while “drift” or rate of evidence accumulation is mediated by “goodness of fit” (i.e., how close the stimuli match perceptually). The diffusion model explains discrimination differences in terms of a single mechanism approach of criterion adjustment.

Turning to the current investigation, the diffusion model of response bias also provides a framework for interpreting RT differences across completion types and conditions. Neutral trials, that provide a control condition unaffected by valid and invalid cueing, demonstrate faster

RTs for SCs than UCs suggesting that decision boundaries for SCs perhaps were lower compared to UCs at the baseline rate. A larger RT disparity between SCs and UCs during green cues suggest that the decision boundary may have been lowered (i.e., less evidence needed) for SCs and raised (i.e., more evidence needed) for UCs. A smaller disparity between SCs and UCs during orange cues suggest that the boundaries were perhaps more equal between SCs and UCs compared to neutral conditions; however, there was a slight bias towards a lower decision boundary for SCs, despite the cue color (orange/invalid) and presentation probability (10%) suggesting otherwise. All sentences presented were highly constraining (high cloze probabilities between .6 - .9) and SCs were shown at equal proportions to UCs; therefore, the rate of evidence accumulation should have been relatively identical across all trials. The diffusion model provides a single mechanism approach to understanding RT differences between valid and invalid conditions as cue color the main driving force between decision boundary setting.

What is clear from the diffusion model approach is that cue colors had a large impact on the decision boundaries from the baseline (neutral) trials. What remains unclear is why SCs had lower decision boundaries than UCs at the baseline rate. In line with a single mechanism approach, the zero point from which evidence accumulates may shift depending on sentential constraint, prediction, or semantic association effects within across the sentence. Therefore, pre-activation priming from prediction may provide an explanation for faster evidence accumulations in the case of SCs and an underlying driving force behind the slight SC bias for invalid (orange) conditions. However, it is difficult to determine which of these proposed mechanisms (e.g., integration, prediction, inhibition, diffusion) is most affected by expectation given that ERP averaging was unbalanced and therefore not comparable for all trials. Therefore, I turn to

matched trials for further insight to the cognitive mechanisms responsible for these behavioral effects.

6.2 Matched Trials: Expectancy Does Not Affect N400 Semantic Access

In this experimental design, matched trials provided a one-to-one correspondence between presented trials in the behavioral and ERP analyses, especially for correct RT as incorrect trials were also excluded from ERP averaging. Readers are encouraged to refer to the matched trials infographic presented in Figure 6.1 for the remainder of this discussion.

Analyses that included all trials showed a completion by condition (valid vs. invalid) interaction for proportion correct rates that suggested separable cognitive mechanisms for resolving semantic incongruities depending on whether the expected semantic context was narrow (i.e., green cues) or broad (i.e., orange cues). This interaction was no longer significant in matched trials, thus providing no support for the separable mechanism hypothesis. Instead, a significant main effect of validity was observed such that participants performed better on valid than invalid trials by 3.4%. Participants also performed slightly, but significantly, better on UCs than SCs by 1.2% when collapsing across condition. Although UCs were easier to reject than SCs were to confirm, the effect of validity was larger, suggesting it played a larger role in affecting performance than completion types during sentence reading.

Analyses that included all trials showed a completion by condition interaction for correct RTs that suggested separable mechanisms for resolving semantic incongruities. Similarly, correct RTs for matched trials showed a trending interaction ($p = .058$) between completion and condition (valid vs. invalid). These findings provide support for two things. First, the validity of trials modulated behavior suggesting that participants did not ignore the colored cues.

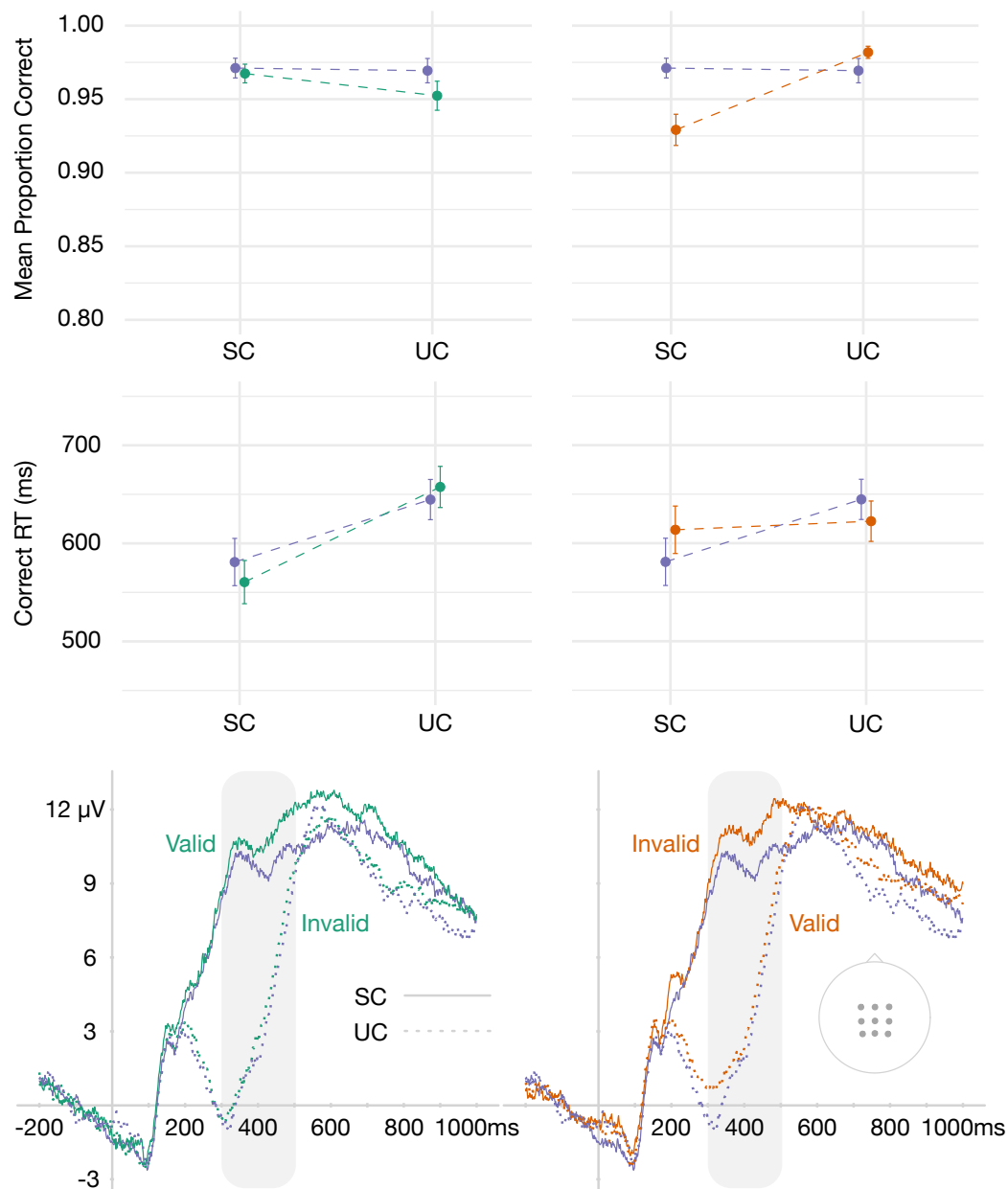


Figure 6.1. Summary of study results for matched trials. All figures are plotted against neutral trials to facilitate comparisons and colors represent cue colors presented to participants during sentence reading. *Top panel.* Cue color affected accuracies, especially in the case of invalid sensible completions (SCs) in the orange cues. *Middle panel.* Participants were slower in evaluating unconnected completions (UCs) compared to SCs; however, this effect is reduced for orange cues, suggesting that expectations derived from cues improved performance, even when participants were faced with semantic incongruity. *Bottom panel.* The effect of condition (neutral, valid, invalid) did not modulate the N400 ERP as measured between 300-500ms, suggesting that top-down expectations did not pre-activate/inhibit semantic representations.

If participants ignored the cues, then behavior would not have been affected by valid/invalid contrasts (proportion correct), nor their interactions with completion (correct RT). Second, these findings provide behavioral support for the main hypothesis of this dissertation that expectancy, driven by volitional use of external cues, can interact with prediction effects, driven by sentence semantics and association, to modulate components of semantic meaning construction. However, it is unclear from the behavioral results at exactly what stage of semantic processing did top-down expectancy exert its influence. Was pre-activation of lexico-semantic representations affected? Were post-lexical semantic integration processes influenced? It is for these reasons I turn to the N400 mean amplitude results to elucidate online cognitive mechanisms during meaning construction.

A classic N400 effect was observed in neutral trials, such that SCs elicited more positive mean amplitudes than UCs. This result confirmed my first prediction (P1), replicated decades worth of N400 research (see Chapter 2), provided a proof of concept that the stimuli were constructed properly, and provided support that LSA estimates (Landauer et al., 1998) perform well in capturing the semantic similarity between sentence stems and final words, and that these LSA estimates translate well to predicted N400 effects (see also Kmieciak et al., 2019). When participants were presented green cues, an N400 effect was observed between validly cued SCs and invalidly cued SCs; however, this N400 effect was not larger than the neutral trials as evidenced by similar Cohen's *d* estimates with overlapping 95% confidence intervals (see section 5.2). Therefore, expectancy did not modulate the N400 over-and-above prediction effects, thus not supporting P2. When participants were presented orange cues, an N400 effect was observed with SCs eliciting more positive mean amplitudes than UCs. This result is

surprising because SCs were invalidly cued, yet they elicited more positive N400s compared to the validly cued UCs. P3 was therefore not supported and the results demonstrated effects in the opposite direction as predicted, suggesting that pre-activation-based prediction effects exert much more influence than purer top-down expectancy effects on semantic access at the level of processing captured by the N400.

When simultaneously considering completion types across all conditions (i.e., the full multilevel model), results demonstrated a main effect of completion, such that SCs elicited more positive N400 amplitudes than UCs⁵ (see section 5.2). The lack of a completion by condition (valid vs. invalid) interaction suggested that validity did not modulate N400 mean amplitudes, thus not supporting P4. In summary, top-down mediated expectancy affected behavioral estimates of proportion correct rates and correct RTs, but not semantic access at the level of the N400 ERP between 300-500ms. Taking the discrepant findings between behavior and electrophysiological into account helps clarify the possible cognitive mechanisms that occur during the interface between expectancy and prediction effects.

The prediction view of the N400 posits that semantic context drives pre-activation of lexico-semantic representations prior to their presentation (see Chapter 2.1) that serve to facilitate semantic access as evidenced by increased positive amplitudes of the N400 (see Federmeier, 2007; Kutas & Federmeier, 2011). This theory explains why N400s are observed when readers process unexpected articles (e.g., a/an; DeLong, Urbach, & Kutas, 2005) and why cloze probability interacts with degrees of sentential constraint (Federmeier & Kutas, 1999;

⁵ A neutral vs. valid + invalid contrast was significant (see section 5.2), but will not be interpreted because it collapses across completion types that are necessary to evaluate P4 and my main hypothesis.

Federmeier et al., 2002). An important feature of the current investigation was that all sentences, prior to generating UCs, chosen from Block and Baldwin (2010) were highly constraining with cloze probabilities between .66 - .99. Keeping this feature in mind, one hypothesized mechanism that expectancy effects may have interacted with pre-activating prediction effects is through increasing the pre-activation strength of semantically-expected items with concomitant inhibition of competing representations. In the case of green cues, activations of predicted semantic representations would strengthen, while orange cues would strengthen activations of unrelated representations. According to Fuster's model of cortical memory (see Chapter 1), focused attention on one aspect of memory is inherently linked with inhibition of competing inputs (Fuster, 2003). It follows that in green cues, valid trials would see increases in positive-going N400 deflections due to excitatory activations from the top-down facilitating semantic access, while invalid trials would see increases in negative-going deflections due to inhibitory activations from the top-down inhibiting access to presented sentence completions. Likewise, orange cues would experience a similar pattern, but instead inhibitory signals would serve to inhibit activations for semantic representations that arise from pre-activating predictions.

However, the N400 results from the current investigation do not support this interpretation of how expectancy may drive excitatory and inhibitory activations of pre-activated semantic representations. When presented with orange cues, participants generated more positive N400 amplitudes for invalid than valid trials. According to the view presented in the paragraph above, expectancy should have inhibited activations of orange-cued SCs, thus reducing the amplitude at the N400. Instead, these N400 amplitudes were positive and even greater than neutral trials where an expectancy was not even generated (see Figure 6.1). The

direction of the N400 effect observed for orange cues (i.e., invalid > valid) does not support the notion that top-down expectancies affect pre-activations of lexico-semantic representations. This is furthered by the effect size comparison between neutral and green cues. Although eliciting an N400 effect in the direction expected (i.e., valid > invalid), green cues maintained a similar, albeit smaller, effect size compared to neutral trials, suggesting validity did not selectively facilitate and inhibit semantically congruent and incongruent pre-activations, respectively. When assuming the N400 reflects facilitated lexico-semantic access due to pre-activations, top-down expectancies did not affect the construction of meaning at the level of the N400 for highly constrained sentential contexts.

Despite absent N400 modulations, expectancy did exert influence on processing as reflected in behavioral accuracy and correct RT differences. The questions that remain are when and how did expectancy exert influence on processing? Van Petten and Luka (2012) argued that the N400 may be insensitive to prediction errors and that costs associated with failed predictions may manifest as positive-going potentials following the N400; a component they referred to as post-N400-positivity (PNP). Furthermore, the scalp topographies of the PNP suggest separable accounts of prediction, such that anterior topographies index failed predictions resulting from differences in cloze probability, while parietal topographies index congruency of sentence completions. In the current investigation, a clear PNP was observed for neutral trials, with UCs eliciting a marked positivity immediately following the N400 that exceeded SCs, providing support for the PNP indexing prediction costs (see Figure 6.1). It follows from the prediction cost theory proposed by Van Petten and Luka (2012) that invalid trials in the current investigation would also have marked positivity following the N400 due to error costs in

expectancy compared to validly cued trials; however, there was no clear pattern observed from visual comparisons of the waveforms in Figure 6.1. In fact, invalidly cued UCs (green cues) elicited more negative PNPs compared to neutral trials, despite maintaining similar N400 mean amplitudes. Likewise, invalidly cued SCs (orange cues) did maintain positive potentials following the N400; however, validly cued UCs (orange cues) maintained a similar morphology as neutral UCs, and a more positive PNP than invalidly cued UCs (green cues), suggesting that the PNP may not reflect prediction costs as proposed by Van Petten and Luka (2012). However, the waveforms that informed these interpretations comprised central electrode positions. Therefore, more work is needed to better understand the scalp distributions of prediction costs and whether more anterior electrode positions better capture the prediction costs proposed by (Van Petten & Luka, 2012).

The resolution of conflict between top-down volitional expectancies and pre-activation prediction effects probably occur between interactions across the N400 and PNP time course. This time window is constrained at the upper bound by mean correct RTs (~613ms) and at the lower bound by when waveforms diverge (~200ms). Evidence from neuropsychology suggests certain neural systems and pathways that are important for executive aspects of semantic processing. Copland (2003) implicated the basal ganglia as important structures for inhibition of semantic representations through frontal-subcortical pathways. Participants performed lexical decisions on target words preceded by primes. Prime-target interstimulus intervals (ISIs) were either short (200ms) or long (1250) and target words were either related or unrelated to primes. Critically, relatedness was crossed with dominant (e.g., bank-money) or subordinate (e.g., bank-river) lexical meaning. It was previously shown that facilitation (i.e., faster lexical decisions) to

dominant meanings occurred at longer ISIs, while dominant and subordinate meanings were equally facilitated at shorter ISIs (Simpson & Burgess, 1985). This result suggested that ambiguous words initially activate both meanings, but subsequent attention-based processing inhibits subordinate meanings resulting in selective facilitation to dominant meanings. Copland (2003) demonstrated that at long ISIs controls and patients with cortical lesions exhibited this selective facilitation to dominant meanings, while patients with Parkinson's disease and patients with nonthalamic subcortical vascular lesions showed facilitation to both dominant and subordinate meanings. These results suggest that damage to basal ganglia structures impairs frontal-subcortical pathways that are responsible for selective attention in semantic priming.

In their model of semantic retrieval, Hart et al. (2013) extended this notion of striatal influence on semantic processing to include a specific pathway between pre-supplementary motor area (pre-SMA), the caudate nuclei, and thalamus to mediate excitatory and inhibitory influence on semantic processing (see also Hart & Kraut, 2007). This theory posits that the pre-SMA initiates semantic item searches, the caudate mediates task complexity through facilitation and inhibition, and the thalamus serves to bridge communication between spatially distinct cortical regions for integration of semantic representations; however, to incorporate findings from subcortical recordings (Wahl et al., 2008) that semantic analysis mainly functions through cortico-thalamic pathways, and not the basal ganglia, it was proposed that the caudate may affect thalamic input at a more strategic non-semantic level. In line with Fuster's integrated model of cortical memory (see Chapter 1), reciprocal connections between anterior-posterior cortex likely pass through the thalamus and are modulated by pre-SMA and caudate influence. Taking into account both Fuster's global cortically-centric account, and Hart and colleagues' (2013) more

specific mechanistic account, the behavioral results of the current investigation may be explained by cortico-thalamic-cortical pathways that are modulated by caudate, or general basal ganglia nuclei, influence.

In the case of evaluating neutral trials, processing likely proceeded through cortico-thalamic-cortical pathways that retrieve and integrate semantic representations with little to no basal ganglia influence (Wahl et al., 2008). Longer RTs for neutral cued UCs compared to SCs likely involved delays in pre-SMA-thalamic selections for semantic incongruities. Introducing green and orange cues, which were non-semantic by nature, may have selectively recruited nuclei within the basal ganglia (e.g., caudate) to actively facilitate and inhibit lexico-semantic representations of predicted sentence endings. Green cues facilitated RTs for valid conditions (SCs) while slowing performance for invalid conditions (UCs) when comparing to neutral cues (see Figure 6.1). Likewise, orange cues facilitated performance for valid trials (UCs), but slowed performance for invalid trials (SCs) when comparing to neutral cues (see Figure 6.1). Although a completion by condition (valid vs. invalid) interaction was not observed at the N400, orange cued valid trials did experience a slight increase in positivity compared to neutral trials (see Figure 6.1), suggesting a possibility for facilitated semantic access in light of semantic incongruity. This naturally leads us to question whether this increase in positivity is attributable to a non-semantic cue-based strategy suggested by Hart et al. (2013) to emerge from caudate influence. More work in subcortical recordings (e.g., Wahl et al., 2008) will elucidate the role of the thalamus and basal ganglia in processing meaning in the face of varying expectations or executive control.

6.3 Limitations

When constructing the stimulus set, sentence stems and completions were perfectly matched *within* each colored cue across each version. The evaluation of predictions 1-3 were unaffected by differences in semantic or lexical properties because these ERP waveforms were constructed from trials that contained the same sentences and completions. However, comparing waveforms across cue color, as was done when evaluating P4, contained different words and sentence completions. In other words, waveforms could have differed based on slight semantic-lexical property differences across stimuli. However, great care was taken to ensure that these conditions did not differ based on word length, sentence length, LSA cosines, word frequency, and contextual diversity estimates. It is possible to counterbalance cues between-subjects by rotating through cue colors such that grand-averages across all colored cues contain the same sentences and final words. This would require shifting cue sets three times across two versions, with each version containing two subversions to balance left/right motor response, for a total of twelve separate versions. Although this would require administering the task to participants in multiples of twelve, it would serve as the best method in eliminating any semantic-lexical differences from waveform comparisons.

6.4 Future Directions

Initial conceptualizations of this project were formed by considering how traumatic brain injuries (TBIs) often cause disruptions to executive functions (Blennow et al., 2016; Cicerone et al., 2011; Constantinidou, Wertheimer, Tsanadis, Evans, & Paul, 2012; Kmiecik, Rodgers, Martinez, Chapman, & Krawczyk, 2018; Poncet, Swaine, Dutil, Chevignard, & Pradat-Diehl, 2017).

Additionally, individuals recovered from TBIs have demonstrated smaller N400 effects that were delayed in latency compared to non-injured controls (Knuepffer, Murdoch, Lloyd, Lewis, & Hinchliffe, 2012; Munte & Heinze, 1994); however, it is unclear whether smaller N400 effects in individuals with TBI are caused by damage to pathways that mediate semantic memory networks or impairments in executive-based processing, such as pre-activation of lexico-semantic representations via prediction. It follows that this dissociation is testable given the various factors that may influence N400 amplitudes (Kutas & Federmeier, 2011), including potential volitional control as assessed in the current investigation. Administering this paradigm in individuals with TBI may elucidate how attentional control aspects of semantic processing, as manipulated by colored cues, interact at the representational level, as reflected via regular sentence reading, with both behavioral and electrophysiological measures.

6.5 Conclusion

This dissertation project investigated whether top-down mediated expectancies of future semantic representations affected pre-activations of lexico-semantic representations that are assumed to occur during highly constrained sentence reading. I discovered that expectations, that were manipulated via colored cues, did modulate behavioral performance by increasing participant accuracy for validly compared to invalidly cued trials and selectively facilitating RTs when sentence congruency aligned with expectancy. Despite increased participant accuracy for validly cued trials, slowed RTs were experienced for UCs, suggesting that the lexico-semantic activations that arise from sentence reading are difficult to overcome when incongruencies arise, even when these incongruencies are expected. At the level of the N400, mean amplitude measures were not affected by top-down generated expectancies, but were strongly distinguished

by semantic congruency. Coupled with behavioral measures, these results suggest that semantic memory representations that are activated via sentence reading are more potent influences on semantic access compared to volitional expectations. Expectancy did influence behavioral measures, suggesting that perhaps the conflict between expectancy and pre-activations of semantic representations is resolved between cognitive interactions across the N400 and post-N400 time course. Expectancies do influence online constructions of semantic meaning; however, this study suggests that this influence operates at later stages of processing than was initially predicted.

APPENDIX A

TASK STIMULI

Table A.1. Cued Sentence Verification Task Stimuli. SC = sensible completion; UC = unconnected completion.

Version	Completion	Condition	Sentence Stem	Ending
1	UC	Valid	A Dalmatian dog is recognized by its black and white	stage
2	SC	Valid	A Dalmatian dog is recognized by its black and white	spots
1	SC	Valid	A flat tire forced Katie to pull to the side of the	road
2	UC	Invalid	A flat tire forced Katie to pull to the side of the	loan
1	SC	Valid	A good way to exercise is to ride a	bike
2	UC	Invalid	A good way to exercise is to ride a	shore
1	SC	Valid	A van gave the hitchhiker a	ride
2	UC	Valid	A van gave the hitchhiker a	ditch
1	SC	Valid	Abbey pushed to open the door when she needed to	pull
2	UC	Valid	Abbey pushed to open the door when she needed to	worth
1	SC	Valid	Abbey turned her nose up at the boy because she was a	snob
2	UC	Invalid	Abbey turned her nose up at the boy because she was a	walls
1	SC	Invalid	After breaking her keyboard she could not use it to	type
2	UC	Valid	After breaking her keyboard she could not use it to	luck
1	SC	Neutral	After coming inside Bob threw the bolt on the	door
2	UC	Neutral	After coming inside Bob threw the bolt on the	club
1	UC	Valid	After dinner he washed his hands with	splash
2	SC	Valid	After dinner he washed his hands with	soap
1	SC	Invalid	After dinner the maid collected the family's	plates
2	UC	Valid	After dinner the maid collected the family's	tune
1	UC	Valid	After driving for hours Kevin rested at the next	tea
2	SC	Invalid	After driving for hours Kevin rested at the next	stop
1	UC	Valid	After every meal it's good to brush your	cake
2	SC	Invalid	After every meal it's good to brush your	teeth
1	UC	Invalid	After hitting the iceberg the ship began to	road
2	SC	Valid	After hitting the iceberg the ship began to	sink
1	UC	Invalid	After inhaling smoke from the fire she needed fresh	cards
2	SC	Valid	After inhaling smoke from the fire she needed fresh	air
1	UC	Valid	After many curves and turns the road suddenly became	cry
2	SC	Valid	After many curves and turns the road suddenly became	straight

1	SC	Valid	After mixing the batter, the muffins were ready to	bake
2	UC	Invalid	After mixing the batter, the muffins were ready to	view
1	UC	Valid	After playing in the sun all day, his face was badly	age
2	SC	Invalid	After playing in the sun all day, his face was badly	burnt
1	SC	Valid	After raking the yard Pat jumped into the pile of	leaves
2	UC	Invalid	After raking the yard Pat jumped into the pile of	stress
1	SC	Valid	After running a mile Josh's shirt was covered in	sweat
2	UC	Valid	After running a mile Josh's shirt was covered in	aisle
1	SC	Neutral	After speaking Allen left the noisy	room
2	UC	Neutral	After speaking Allen left the noisy	could
1	SC	Valid	After the argument Ann went to her room and slammed the	door
2	UC	Valid	After the argument Ann went to her room and slammed the	room
1	SC	Neutral	After the heavy rain the roof began to	leak
2	UC	Neutral	After the heavy rain the roof began to	string
1	UC	Valid	After the hotel emptied the rooms were cleaned by the	bow
2	SC	Valid	After the hotel emptied the rooms were cleaned by the	maids
1	SC	Valid	After the recital she faced the audience and took a	bow
2	UC	Valid	After the recital she faced the audience and took a	maids
1	UC	Neutral	After touching the stove the child burned his	high
2	SC	Neutral	After touching the stove the child burned his	hand
1	UC	Invalid	After winning the carnival game, Tim received a	light
2	SC	Valid	After winning the carnival game, Tim received a	prize
1	UC	Valid	All the crumbs on the floor were sure to attract a	dogs
2	SC	Valid	All the crumbs on the floor were sure to attract a	mouse
1	UC	Valid	All the guests had a very good	scared
2	SC	Valid	All the guests had a very good	stay
1	SC	Valid	Although Keith bowled well he did not have the highest	score
2	UC	Invalid	Although Keith bowled well he did not have the highest	gifts
1	UC	Valid	Amber went to the dealership to purchase a new	play
2	SC	Valid	Amber went to the dealership to purchase a new	car
1	UC	Valid	American Presidents are limited to serving a period of eight	search
2	SC	Valid	American Presidents are limited to serving a period of eight	years
1	SC	Valid	Ana accidentally tripped and fell down the	stairs
2	UC	Invalid	Ana accidentally tripped and fell down the	grade
1	UC	Invalid	April ran her errands during her lunch	word
2	SC	Valid	April ran her errands during her lunch	break
1	SC	Valid	As Shelley walked up the mountain trail it became	steep
2	UC	Valid	As Shelley walked up the mountain trail it became	board

1	UC	Valid	At dinner he cut his food with a	flight
2	SC	Valid	At dinner he cut his food with a	knife
1	SC	Valid	At first the woman refused, but she changed her	mind
2	UC	Valid	At first the woman refused, but she changed her	nap
1	SC	Invalid	At Jessie's birthday party they ate a delicious	cake
2	UC	Valid	At Jessie's birthday party they ate a delicious	teeth
1	SC	Valid	At last the time for action had	come
2	UC	Valid	At last the time for action had	off
1	SC	Invalid	At night the old woman locked the	door
2	UC	Valid	At night the old woman locked the	yarn
1	SC	Neutral	At the pub he ordered another mug of	beer
2	UC	Neutral	At the pub he ordered another mug of	sweat
1	UC	Valid	At the toll Beth realized she did not have any	tour
2	SC	Invalid	At the toll Beth realized she did not have any	change
1	SC	Invalid	Because of his driving ticket the man had to pay a	fine
2	UC	Valid	Because of his driving ticket the man had to pay a	heat
1	UC	Valid	Because there was lightning she could not go to the pool to	phase
2	SC	Valid	Because there was lightning she could not go to the pool to	swim
1	UC	Valid	Before practice he decided to eat a quick	diet
2	SC	Valid	Before practice he decided to eat a quick	snack
1	UC	Valid	Benny tried to make a new resolution each	lawn
2	SC	Valid	Benny tried to make a new resolution each	year
1	UC	Valid	Betty was always cold and liked to keep her room	trees
2	SC	Valid	Betty was always cold and liked to keep her room	warm
1	SC	Valid	Bill jumped in the lake and made a big	splash
2	UC	Valid	Bill jumped in the lake and made a big	soap
1	UC	Invalid	Bill went to the dentist to check all his	wax
2	SC	Valid	Bill went to the dentist to check all his	teeth
1	UC	Valid	Billy hit his sister on the	fog
2	SC	Invalid	Billy hit his sister on the	head
1	SC	Invalid	Bob proposed and gave her a diamond	ring
2	UC	Valid	Bob proposed and gave her a diamond	bread
1	SC	Valid	Bob would often sleep during his lunch	break
2	UC	Invalid	Bob would often sleep during his lunch	waste
1	SC	Valid	Bradley prefers cats over	dogs
2	UC	Valid	Bradley prefers cats over	mouse
1	UC	Valid	Brooke wanted to win but pretended not to	wild
2	SC	Valid	Brooke wanted to win but pretended not to	care

1	UC	Neutral	Captain Sheir decided to stay with the sinking	sense
2	SC	Neutral	Captain Sheir decided to stay with the sinking	ship
1	UC	Valid	Carolyn couldn't start her car without the right	book
2	SC	Invalid	Carolyn couldn't start her car without the right	keys
1	UC	Neutral	Catherine carried a computer in her shoulder	tip
2	SC	Neutral	Catherine carried a computer in her shoulder	bag
1	SC	Valid	Catherine jogged during her lunch	break
2	UC	Valid	Catherine jogged during her lunch	pay
1	SC	Neutral	Charles dunked the basketball through the	hoop
2	UC	Neutral	Charles dunked the basketball through the	fire
1	UC	Valid	Cid needed a belt to hold up his	wrong
2	SC	Valid	Cid needed a belt to hold up his	pants
1	SC	Valid	Cold weather outside meant it was time to turn on the	heat
2	UC	Invalid	Cold weather outside meant it was time to turn on the	floor
1	UC	Valid	Dan gathered more wood for the	voice
2	SC	Invalid	Dan gathered more wood for the	fire
1	UC	Neutral	Dan was asked to be the new coach of the	dock
2	SC	Neutral	Dan was asked to be the new coach of the	team
1	SC	Neutral	Denise struck her attacker a heavy	blow
2	UC	Neutral	Denise struck her attacker a heavy	loans
1	UC	Valid	Derek's feet were cold, so he put on some	road
2	SC	Valid	Derek's feet were cold, so he put on some	socks
1	UC	Valid	Diane slowly sank into the hot	rang
2	SC	Valid	Diane slowly sank into the hot	tub
1	UC	Invalid	Dick wrote a chapter in the	news
2	SC	Valid	Dick wrote a chapter in the	book
1	UC	Neutral	Don't believe everything you	raw
2	SC	Neutral	Don't believe everything you	hear
1	SC	Valid	Due to the storm the Coast Guard called off the	search
2	UC	Valid	Due to the storm the Coast Guard called off the	years
1	SC	Neutral	During class, the teacher discovered the boy could not	read
2	UC	Neutral	During class, the teacher discovered the boy could not	month
1	SC	Invalid	During his cold Mr. Taylor lost his	voice
2	UC	Valid	During his cold Mr. Taylor lost his	red
1	UC	Invalid	During medical school the student was under much	leaves
2	SC	Valid	During medical school the student was under much	stress
1	UC	Neutral	During summers the family had cookouts using their	rank
2	SC	Neutral	During summers the family had cookouts using their	grill

1	SC	Valid	During the holidays it is every expensive to book a	flight
2	UC	Valid	During the holidays it is every expensive to book a	knife
1	UC	Invalid	During the holidays it is expensive to book a	fall
2	SC	Valid	During the holidays it is expensive to book a	flight
1	UC	Valid	During the lecture Jen kept checking the	neck
2	SC	Invalid	During the lecture Jen kept checking the	time
1	SC	Invalid	During the winter holidays people tend to eat a lot of	food
2	UC	Valid	During the winter holidays people tend to eat a lot of	pole
1	SC	Invalid	During the winter it is best to put on your heaviest	coat
2	UC	Valid	During the winter it is best to put on your heaviest	play
1	UC	Invalid	Ellen enjoys poetry, painting, and other forms of	cane
2	SC	Valid	Ellen enjoys poetry, painting, and other forms of	art
1	SC	Invalid	Ellen replaced the fuse that no longer	worked
2	UC	Valid	Ellen replaced the fuse that no longer	grip
1	SC	Valid	Every autumn leaves fall from the	trees
2	UC	Valid	Every autumn leaves fall from the	warm
1	SC	Valid	Every Sunday the family goes to	church
2	UC	Valid	Every Sunday the family goes to	bark
1	SC	Valid	Expecting Jeff's call she waited for the phone to	ring
2	UC	Valid	Expecting Jeff's call she waited for the phone to	nail
1	UC	Invalid	Father carved the turkey with a	heard
2	SC	Valid	Father carved the turkey with a	knife
1	SC	Valid	For breakfast Jim wanted bacon and	eggs
2	UC	Valid	For breakfast Jim wanted bacon and	stake
1	UC	Valid	For Christmas dinner the family ate a	find
2	SC	Valid	For Christmas dinner the family ate a	ham
1	SC	Valid	For her school dance Becky needed a new	dress
2	UC	Invalid	For her school dance Becky needed a new	ball
1	UC	Valid	For his birthday Jan baked a	clean
2	SC	Valid	For his birthday Jan baked a	cake
1	UC	Neutral	For his date Tom bought a long stemmed	crop
2	SC	Neutral	For his date Tom bought a long stemmed	rose
1	SC	Neutral	For his interview Mr. Jones needed a new	suit
2	UC	Neutral	For his interview Mr. Jones needed a new	lake
1	UC	Valid	Fred realized the old house was up for	sun
2	SC	Valid	Fred realized the old house was up for	sale
1	SC	Invalid	George must keep his pet on a	leash
2	UC	Valid	George must keep his pet on a	broom

1	UC	Valid	Glasses greatly improved Mrs. Gibb's	sky
2	SC	Valid	Glasses greatly improved Mrs. Gibb's	sight
1	UC	Invalid	He bought the apartment for the spectacular	bake
2	SC	Valid	He bought the apartment for the spectacular	view
1	UC	Neutral	He bought them in the candy	tip
2	SC	Neutral	He bought them in the candy	store
1	SC	Valid	He brought his bait to the lake to catch	fish
2	UC	Valid	He brought his bait to the lake to catch	break
1	SC	Valid	He cashed his new paycheck at the	bank
2	UC	Valid	He cashed his new paycheck at the	style
1	SC	Invalid	He climbed a ladder in order to reshingle the	roof
2	UC	Valid	He climbed a ladder in order to reshingle the	floor
1	SC	Invalid	He crept into the room without a	sound
2	UC	Valid	He crept into the room without a	half
1	UC	Valid	He eats out because he is a lousy	raise
2	SC	Valid	He eats out because he is a lousy	cook
1	UC	Neutral	He had a long day and was in a bad	pace
2	SC	Neutral	He had a long day and was in a bad	mood
1	SC	Valid	He hoped his grumpy teen was just going through a	phase
2	UC	Valid	He hoped his grumpy teen was just going through a	swim
1	SC	Valid	He knew he needed a new sock when he saw the	hole
2	UC	Valid	He knew he needed a new sock when he saw the	eat
1	SC	Neutral	He lay down and went to	sleep
2	UC	Neutral	He lay down and went to	west
1	UC	Valid	He liked lemon and sugar in his	shoes
2	SC	Invalid	He liked lemon and sugar in his	tea
1	SC	Invalid	He loosened the tie around his	neck
2	UC	Valid	He loosened the tie around his	time
1	SC	Valid	He mailed the letter without a	stamp
2	UC	Valid	He mailed the letter without a	silk
1	SC	Valid	He scraped the cold food from his	plate
2	UC	Valid	He scraped the cold food from his	work
1	UC	Valid	He took the bill although I offered to	break
2	SC	Valid	He took the bill although I offered to	pay
1	UC	Invalid	He turned the page of his favorite	love
2	SC	Valid	He turned the page of his favorite	book
1	SC	Neutral	He turned to channel 13 to watch the daily	news
2	UC	Neutral	He turned to channel 13 to watch the daily	sky

1	UC	Neutral	He was afraid to work the night	friends
2	SC	Neutral	He was afraid to work the night	shift
1	UC	Valid	He was so sure the racehorse would win he made a	pan
2	SC	Valid	He was so sure the racehorse would win he made a	bet
1	SC	Valid	He wore a heavy jacket because it was	cold
2	UC	Valid	He wore a heavy jacket because it was	grave
1	UC	Neutral	Her job was easy most of the	aim
2	SC	Neutral	Her job was easy most of the	time
1	SC	Valid	Her new shoes were the wrong	size
2	UC	Valid	Her new shoes were the wrong	crop
1	SC	Valid	His boss refused to give him a	raise
2	UC	Valid	His boss refused to give him a	cook
1	SC	Valid	His dirty car sparkled after a wash and	wax
2	UC	Invalid	His dirty car sparkled after a wash and	teeth
1	SC	Valid	His job was to keep the sidewalk	clean
2	UC	Valid	His job was to keep the sidewalk	cake
1	SC	Neutral	His leaving home amazed all his	friends
2	UC	Neutral	His leaving home amazed all his	shift
1	UC	Invalid	His teacher helped him improve his	stairs
2	SC	Valid	His teacher helped him improve his	grade
1	UC	Invalid	I could not remember his	risk
2	SC	Valid	I could not remember his	name
1	SC	Neutral	I had no key to open the locked	door
2	UC	Neutral	I had no key to open the locked	wear
1	UC	Valid	I realized I had no umbrella as it began to	days
2	SC	Invalid	I realized I had no umbrella as it began to	rain
1	UC	Neutral	I roasted the marshmallow over the	hoop
2	SC	Neutral	I roasted the marshmallow over the	fire
1	SC	Valid	I would drive but my car is low on	gas
2	UC	Valid	I would drive but my car is low on	soap
1	UC	Valid	If the crowd quiets down the band will	coat
2	SC	Invalid	If the crowd quiets down the band will	play
1	SC	Valid	If the sailor did not find food soon he would	die
2	UC	Invalid	If the sailor did not find food soon he would	slow
1	UC	Neutral	In order to study Karen sat down at her	phone
2	SC	Neutral	In order to study Karen sat down at her	desk
1	UC	Valid	In the first space enter your	fair
2	SC	Valid	In the first space enter your	name

1	UC	Neutral	In the heat of his performance Sean broke a guitar	leak
2	SC	Neutral	In the heat of his performance Sean broke a guitar	string
1	UC	Valid	In the night sky it is easier to see all the	floor
2	SC	Valid	In the night sky it is easier to see all the	stars
1	SC	Valid	In the quiet movie theater, Kim's phone	rang
2	UC	Valid	In the quiet movie theater, Kim's phone	tub
1	UC	Valid	In the shower he washed his skin with	gas
2	SC	Valid	In the shower he washed his skin with	soap
1	SC	Neutral	In the spring it gets warmer and the snow	melts
2	UC	Neutral	In the spring it gets warmer and the snow	milk
1	UC	Neutral	Instead of a full Halloween costume Bill just wore a	home
2	SC	Neutral	Instead of a full Halloween costume Bill just wore a	mask
1	UC	Valid	Instead of dressing I prefer vinegar and	deck
2	SC	Valid	Instead of dressing I prefer vinegar and	oil
1	UC	Neutral	Instead of receiving at the holidays it is better to	tree
2	SC	Neutral	Instead of receiving at the holidays it is better to	give
1	UC	Neutral	It was a rainy day so they decided instead to	purse
2	SC	Neutral	It was a rainy day so they decided instead to	sleep
1	UC	Valid	It was cold in the room so they turned on the	fine
2	SC	Invalid	It was cold in the room so they turned on the	heat
1	SC	Valid	It was dark in the room so she turned on the	light
2	UC	Invalid	It was dark in the room so she turned on the	prize
1	SC	Invalid	It was windy enough to fly a	kite
2	UC	Valid	It was windy enough to fly a	fit
1	SC	Valid	It's hard to admit when one is	wrong
2	UC	Valid	It's hard to admit when one is	pants
1	UC	Neutral	Ivan did not know the time since his watch	boil
2	SC	Neutral	Ivan did not know the time since his watch	broke
1	UC	Valid	Jacob returned the fallen book to the right	ink
2	SC	Invalid	Jacob returned the fallen book to the right	shelf
1	UC	Valid	Jan tried to squeeze in but there was no	door
2	SC	Valid	Jan tried to squeeze in but there was no	room
1	UC	Neutral	Jane fried some bacon in the	wet
2	SC	Neutral	Jane fried some bacon in the	pan
1	UC	Valid	Jane hung the colorful painting up on the	mop
2	SC	Valid	Jane hung the colorful painting up on the	wall
1	UC	Valid	Jenny lit the candles on the birthday	sword
2	SC	Valid	Jenny lit the candles on the birthday	cake

1	UC	Valid	Jenny was creative and loved to study	zoo
2	SC	Invalid	Jenny was creative and loved to study	art
1	SC	Valid	Jenny was the last person to hear the bad	news
2	UC	Invalid	Jenny was the last person to hear the bad	book
1	SC	Neutral	Jessie ran the race at a slower	pace
2	UC	Neutral	Jessie ran the race at a slower	mood
1	SC	Valid	Jill looked back through the open	door
2	UC	Valid	Jill looked back through the open	pain
1	UC	Neutral	Joan fed her baby some warm	melts
2	SC	Neutral	Joan fed her baby some warm	milk
1	SC	Valid	Joe did not like his outfit and decided to	change
2	UC	Valid	Joe did not like his outfit and decided to	rose
1	UC	Neutral	John felt sorry, but it was not his	old
2	SC	Neutral	John felt sorry, but it was not his	fault
1	UC	Valid	John swept the floor with a	leash
2	SC	Invalid	John swept the floor with a	broom
1	UC	Valid	John took his dog out for a	bill
2	SC	Valid	John took his dog out for a	walk
1	UC	Valid	Karen awoke after a bad	loud
2	SC	Valid	Karen awoke after a bad	dream
1	UC	Valid	Katie put the flowers in an expensive	play
2	SC	Valid	Katie put the flowers in an expensive	vase
1	UC	Invalid	Lyle hoped he was not in trouble as he came home	trail
2	SC	Valid	Lyle hoped he was not in trouble as he came home	late
1	SC	Neutral	Maggie kept her wallet and keys inside her	purse
2	UC	Neutral	Maggie kept her wallet and keys inside her	sleep
1	UC	Valid	Many brunettes like to dye their hair	see
2	SC	Valid	Many brunettes like to dye their hair	blonde
1	SC	Valid	Many commuters complain about the price of	gas
2	UC	Invalid	Many commuters complain about the price of	war
1	SC	Neutral	Mark was so angry his blood began to	boil
2	UC	Neutral	Mark was so angry his blood began to	broke
1	UC	Valid	Molly angrily declared that the wedding was	come
2	SC	Valid	Molly angrily declared that the wedding was	off
1	UC	Valid	Most aspiring actors hope for fortune and	coal
2	SC	Invalid	Most aspiring actors hope for fortune and	fame
1	SC	Valid	Most cats see very well at	night
2	UC	Invalid	Most cats see very well at	bloom

1	UC	Invalid	Most shark attacks occur very close to	bike
2	SC	Valid	Most shark attacks occur very close to	shore
1	UC	Invalid	My favorite part of spring is when the flowers	night
2	SC	Valid	My favorite part of spring is when the flowers	bloom
1	SC	Neutral	None of his books made any	sense
2	UC	Neutral	None of his books made any	ship
1	UC	Valid	On Friday, John and his hungry friends went to go	hole
2	SC	Valid	On Friday, John and his hungry friends went to go	eat
1	UC	Invalid	On her birthday she excitedly opened the	score
2	SC	Valid	On her birthday she excitedly opened the	gifts
1	UC	Neutral	On sunny days Fred likes rowing his boat on the	suit
2	SC	Neutral	On sunny days Fred likes rowing his boat on the	lake
1	UC	Valid	On Valentine's Day the woman received a single red	change
2	SC	Valid	On Valentine's Day the woman received a single red	rose
1	UC	Valid	One year after her death Bill visited his mother's	cold
2	SC	Valid	One year after her death Bill visited his mother's	grave
1	UC	Neutral	Pam did not have any clothes to	door
2	SC	Neutral	Pam did not have any clothes to	wear
1	UC	Invalid	Pete broke his arm and needed to wear a	will
2	SC	Valid	Pete broke his arm and needed to wear a	cast
1	SC	Valid	Ray fell down and skinned his	knees
2	UC	Valid	Ray fell down and skinned his	steal
1	UC	Valid	Rob was in a hurry and kept watching the	down
2	SC	Invalid	Rob was in a hurry and kept watching the	clock
1	SC	Valid	Sally knew Julia was frightened because she looked	scared
2	UC	Valid	Sally knew Julia was frightened because she looked	stay
1	SC	Invalid	Sarah saw animals from around the world at the	zoo
2	UC	Valid	Sarah saw animals from around the world at the	art
1	UC	Neutral	Seals can swim better than they can	sick
2	SC	Neutral	Seals can swim better than they can	walk
1	UC	Valid	Several hours into his shift Lyle was ready for a	fish
2	SC	Valid	Several hours into his shift Lyle was ready for a	break
1	UC	Valid	She could not buy the shirt because it did not	kite
2	SC	Invalid	She could not buy the shirt because it did not	fit
1	UC	Valid	She could not drink the coffee because it was too	milk
2	SC	Valid	She could not drink the coffee because it was too	hot
1	SC	Invalid	She could tell he was mad by the tone of his	voice
2	UC	Valid	She could tell he was mad by the tone of his	fire

1	SC	Invalid	She didn't have her watch so she asked for the	time
2	UC	Valid	She didn't have her watch so she asked for the	charge
1	SC	Valid	She enjoyed studying in the library because it was	quiet
2	UC	Invalid	She enjoyed studying in the library because it was	map
1	SC	Valid	She graduated at the top of her	class
2	UC	Valid	She graduated at the top of her	land
1	UC	Valid	She had no idea how much the necklace was	pull
2	SC	Valid	She had no idea how much the necklace was	worth
1	SC	Invalid	She had the flu and needed to drink some hot	tea
2	UC	Valid	She had the flu and needed to drink some hot	stop
1	SC	Valid	She knew how to make the pie filling but not the	crust
2	UC	Invalid	She knew how to make the pie filling but not the	deal
1	SC	Valid	She lied about losing her report card to hide her bad	grades
2	UC	Valid	She lied about losing her report card to hide her bad	pot
1	SC	Valid	She lived in sunny Florida and never saw falling	snow
2	UC	Valid	She lived in sunny Florida and never saw falling	house
1	SC	Invalid	She loved horror flicks because they gave her a good	scare
2	UC	Valid	She loved horror flicks because they gave her a good	round
1	UC	Valid	She loved playing the guitar so she joined the	strike
2	SC	Valid	She loved playing the guitar so she joined the	band
1	UC	Valid	She made herself a sandwich and chips for	fire
2	SC	Invalid	She made herself a sandwich and chips for	lunch
1	UC	Valid	She married just for money and not for	seat
2	SC	Valid	She married just for money and not for	love
1	SC	Valid	She preheated the oven and greased the	pan
2	UC	Valid	She preheated the oven and greased the	bet
1	UC	Valid	She put the pot on the stove so the water would	guards
2	SC	Valid	She put the pot on the stove so the water would	boil
1	SC	Neutral	She stayed home from work because she felt	sick
2	UC	Neutral	She stayed home from work because she felt	walk
1	SC	Invalid	She teased that this year his stocking would contain	coal
2	UC	Valid	She teased that this year his stocking would contain	fame
1	UC	Valid	She threw away the old paper in the	launch
2	SC	Invalid	She threw away the old paper in the	trash
1	UC	Valid	She typed so well she did not have to look at the computer	plane
2	SC	Valid	She typed so well she did not have to look at the computer	screen
1	SC	Neutral	She was expecting a call and kept listening for the	phone
2	UC	Neutral	She was expecting a call and kept listening for the	desk

1	UC	Invalid	She was tired of her life, and felt ready for a	mud
2	SC	Valid	She was tired of her life, and felt ready for a	change
1	SC	Valid	She washed the dirty dishes in the	sink
2	UC	Valid	She washed the dirty dishes in the	pain
1	UC	Valid	She went to bed because she was	work
2	SC	Invalid	She went to bed because she was	tired
1	UC	Valid	She went to the bakery for a loaf of	ring
2	SC	Invalid	She went to the bakery for a loaf of	bread
1	SC	Valid	She went to the beauty parlor to perm her	hair
2	UC	Valid	She went to the beauty parlor to perm her	lights
1	SC	Valid	She went to the post office to collect her	mail
2	UC	Invalid	She went to the post office to collect her	home
1	UC	Valid	She went to the salon to color her	mail
2	SC	Valid	She went to the salon to color her	hair
1	UC	Invalid	She wore a colorful scarf around her	brakes
2	SC	Valid	She wore a colorful scarf around her	neck
1	UC	Valid	Sherry had to read lips because she was	ink
2	SC	Valid	Sherry had to read lips because she was	deaf
1	SC	Valid	Shirley was so embarrassed that she began to	cry
2	UC	Invalid	Shirley was so embarrassed that she began to	town
1	UC	Valid	Since driving at night decreases visibility it is better to turn on the	hair
2	SC	Valid	Since driving at night decreases visibility it is better to turn on the	lights
1	SC	Neutral	Some people say vegetables are healthier if eaten	raw
2	UC	Neutral	Some people say vegetables are healthier if eaten	hear
1	UC	Neutral	Spring was Jo's favorite season of the	pads
2	SC	Neutral	Spring was Jo's favorite season of the	year
1	SC	Invalid	Success is often just a matter of hard	work
2	UC	Valid	Success is often just a matter of hard	tired
1	SC	Valid	Surfers are scared of getting bitten by a	shark
2	UC	Valid	Surfers are scared of getting bitten by a	nest
1	SC	Invalid	Susan bought a dress so now she just needed new	shoes
2	UC	Valid	Susan bought a dress so now she just needed new	tea
1	SC	Valid	Tammy was not a gambler because she had bad	luck
2	UC	Valid	Tammy was not a gambler because she had bad	late
1	SC	Valid	The academic year began in the	fall
2	UC	Invalid	The academic year began in the	flight
1	UC	Valid	The accountant ironed a shirt before going to	plate
2	SC	Valid	The accountant ironed a shirt before going to	work

1	SC	Invalid	The announcer on the radio told the breaking	news
2	UC	Valid	The announcer on the radio told the breaking	hour
1	SC	Valid	The archaeologist knew he had made an exciting	find
2	UC	Valid	The archaeologist knew he had made an exciting	ham
1	UC	Valid	The athlete enjoyed lifting weights at the	bread
2	SC	Invalid	The athlete enjoyed lifting weights at the	gym
1	UC	Invalid	The baby bird was ready to learn to	said
2	SC	Valid	The baby bird was ready to learn to	fly
1	UC	Valid	The baby birds were ready to leave the	shark
2	SC	Valid	The baby birds were ready to leave the	nest
1	UC	Valid	The baby must be fed after his afternoon	mind
2	SC	Valid	The baby must be fed after his afternoon	nap
1	SC	Valid	The baseball player's cap protected him from the	sun
2	UC	Valid	The baseball player's cap protected him from the	sale
1	UC	Neutral	The bill was due at the end of the	read
2	SC	Neutral	The bill was due at the end of the	month
1	UC	Neutral	The birthday card was funny and made me	grow
2	SC	Neutral	The birthday card was funny and made me	laugh
1	SC	Neutral	The boat passed easily under the	bridge
2	UC	Neutral	The boat passed easily under the	words
1	UC	Valid	The book was a steal at such a low	toe
2	SC	Valid	The book was a steal at such a low	price
1	UC	Valid	The boy had a poor excuse for his homework not being	seeds
2	SC	Invalid	The boy had a poor excuse for his homework not being	done
1	UC	Valid	The bracelet fell off her wrist because it was too	shelf
2	SC	Invalid	The bracelet fell off her wrist because it was too	big
1	UC	Valid	The bride smiled as she walked down the	sweat
2	SC	Valid	The bride smiled as she walked down the	aisle
1	SC	Valid	The caboose was at the back of the	train
2	UC	Valid	The caboose was at the back of the	vote
1	SC	Invalid	The candles smelled even better when they were	lit
2	UC	Valid	The candles smelled even better when they were	rain
1	UC	Invalid	The castle was protected by its stone	snob
2	SC	Valid	The castle was protected by its stone	walls
1	SC	Invalid	The cheap pen ran quickly out of	ink
2	UC	Valid	The cheap pen ran quickly out of	shelf
1	SC	Valid	The children ran outside to	play
2	UC	Valid	The children ran outside to	car

1	SC	Valid	The children went outside to	play
2	UC	Valid	The children went outside to	vase
1	SC	Valid	The college student went to the library to read a	book
2	UC	Invalid	The college student went to the library to read a	cry
1	UC	Valid	The control tower cleared the plane to	class
2	SC	Valid	The control tower cleared the plane to	land
1	SC	Neutral	The corn farmer felt this year would yield a good	crop
2	UC	Neutral	The corn farmer felt this year would yield a good	rose
1	SC	Valid	The couple agreed the most important thing to them was	love
2	UC	Invalid	The couple agreed the most important thing to them was	book
1	UC	Valid	The crime rate has gone up this	road
2	SC	Valid	The crime rate has gone up this	year
1	UC	Neutral	The cruise ship sounded its horn as it pulled into	cows
2	SC	Neutral	The cruise ship sounded its horn as it pulled into	port
1	SC	Valid	The dealer shuffled and cut the	deck
2	UC	Valid	The dealer shuffled and cut the	oil
1	SC	Valid	The deer ran out of the woods and across the	road
2	UC	Invalid	The deer ran out of the woods and across the	sink
1	UC	Valid	The dentist recommends brushing your teeth twice a	car
2	SC	Valid	The dentist recommends brushing your teeth twice a	day
1	UC	Valid	The designer's clothing was always in	bank
2	SC	Valid	The designer's clothing was always in	style
1	UC	Invalid	The directions did not match any roads on the	quiet
2	SC	Valid	The directions did not match any roads on the	map
1	SC	Valid	The dirty dishes were piling up in the	sink
2	UC	Invalid	The dirty dishes were piling up in the	walk
1	SC	Neutral	The diving board was scary because it was so	high
2	UC	Neutral	The diving board was scary because it was so	hand
1	SC	Neutral	The doctor's suitcase was worn and obviously very	old
2	UC	Neutral	The doctor's suitcase was worn and obviously very	fault
1	SC	Valid	The dramatic actress preferred acting on the	stage
2	UC	Valid	The dramatic actress preferred acting on the	spots
1	SC	Neutral	The exit was marked by a large	sign
2	UC	Neutral	The exit was marked by a large	school
1	UC	Valid	The expensive tie was made of	stamp
2	SC	Valid	The expensive tie was made of	silk
1	UC	Valid	The farmer decided to paint his barn	voice
2	SC	Invalid	The farmer decided to paint his barn	red

1	SC	Neutral	The farmer spent the morning milking his	cows
2	UC	Neutral	The farmer spent the morning milking his	port
1	SC	Valid	The fishermen cast a broad	line
2	UC	Invalid	The fishermen cast a broad	grow
1	UC	Neutral	The fluffy white clouds are high up in the	news
2	SC	Neutral	The fluffy white clouds are high up in the	sky
1	SC	Valid	The full moon lit up the night	sky
2	UC	Valid	The full moon lit up the night	sight
1	UC	Valid	The gambler had a streak of bad	type
2	SC	Invalid	The gambler had a streak of bad	luck
1	UC	Valid	The game was called when it started to	lit
2	SC	Invalid	The game was called when it started to	rain
1	SC	Valid	The garbage from last week had a foul	smell
2	UC	Valid	The garbage from last week had a foul	cell
1	SC	Valid	The gas station is about two miles down the	road
2	UC	Valid	The gas station is about two miles down the	year
1	SC	Invalid	The genie promised the man he would grant one	wish
2	UC	Valid	The genie promised the man he would grant one	dark
1	SC	Invalid	The girl knew a lot for her	age
2	UC	Valid	The girl knew a lot for her	burnt
1	SC	Valid	The governor vetoed the new	bill
2	UC	Valid	The governor vetoed the new	walk
1	SC	Valid	The grandmother left everything to her son in her	will
2	UC	Invalid	The grandmother left everything to her son in her	cast
1	SC	Valid	The grass was tall because Tim didn't mow the	lawn
2	UC	Valid	The grass was tall because Tim didn't mow the	year
1	SC	Valid	The hikers decided to walk the longer	trail
2	UC	Invalid	The hikers decided to walk the longer	late
1	SC	Valid	The hot shower filled the bathroom with	steam
2	UC	Invalid	The hot shower filled the bathroom with	hand
1	UC	Valid	The indoor plant was growing bigger and needed a new	grades
2	SC	Valid	The indoor plant was growing bigger and needed a new	pot
1	UC	Invalid	The janitor accidentally spilled some water on the	heat
2	SC	Valid	The janitor accidentally spilled some water on the	floor
1	SC	Valid	The janitor cleaned the floor with his bucket and	mop
2	UC	Valid	The janitor cleaned the floor with his bucket and	wall
1	SC	Invalid	The jury found him innocent and set him	free
2	UC	Valid	The jury found him innocent and set him	age

1	SC	Invalid	The kids fed the ducks some stale	bread
2	UC	Valid	The kids fed the ducks some stale	gym
1	UC	Valid	The kitten played with the ball of	door
2	SC	Invalid	The kitten played with the ball of	yarn
1	SC	Valid	The knight readied for battle and drew his	sword
2	UC	Valid	The knight readied for battle and drew his	cake
1	UC	Valid	The landlord did not like when the rent was	luck
2	SC	Valid	The landlord did not like when the rent was	late
1	UC	Valid	The laundry detergent failed to get out the red	store
2	SC	Valid	The laundry detergent failed to get out the red	stain
1	UC	Valid	The lecture should last about one	news
2	SC	Invalid	The lecture should last about one	hour
1	SC	Valid	The librarian sternly told us to be	quiet
2	UC	Valid	The librarian sternly told us to be	prince
1	UC	Valid	The limping horse was obviously in much	sink
2	SC	Valid	The limping horse was obviously in much	pain
1	SC	Valid	The little girl left Santa a plate of cookies and	milk
2	UC	Valid	The little girl left Santa a plate of cookies and	hot
1	UC	Valid	The little girl was very afraid of the	wish
2	SC	Invalid	The little girl was very afraid of the	dark
1	SC	Invalid	The maid dusted the books on the	shelf
2	UC	Valid	The maid dusted the books on the	big
1	SC	Valid	The man happily sat down in the comfortable	chair
2	UC	Valid	The man happily sat down in the comfortable	door
1	SC	Valid	The man liked to play his music too	loud
2	UC	Valid	The man liked to play his music too	dream
1	SC	Neutral	The man presented his new fiancée with an expensive	ring
2	UC	Neutral	The man presented his new fiancée with an expensive	due
1	UC	Valid	The matador ran when the bull began to	time
2	SC	Invalid	The matador ran when the bull began to	charge
1	SC	Neutral	The miner knew he struck it rich when he discovered	gold
2	UC	Neutral	The miner knew he struck it rich when he discovered	tree
1	UC	Invalid	The mother did not want the food to go to	break
2	SC	Valid	The mother did not want the food to go to	waste
1	UC	Valid	The movers put the sofa on the bare	roof
2	SC	Invalid	The movers put the sofa on the bare	floor
1	SC	Valid	The movie was so sad it made the audience	cry
2	UC	Valid	The movie was so sad it made the audience	straight

1	SC	Neutral	The new officer was of a higher	rank
2	UC	Neutral	The new officer was of a higher	grill
1	SC	Invalid	The new space shuttle was ready to	launch
2	UC	Valid	The new space shuttle was ready to	trash
1	SC	Invalid	The old house will be torn	down
2	UC	Valid	The old house will be torn	clock
1	UC	Invalid	The old man has to use a cane to go on his daily	sink
2	SC	Valid	The old man has to use a cane to go on his daily	walk
1	UC	Valid	The only way to kill a vampire is with a wooden	eggs
2	SC	Valid	The only way to kill a vampire is with a wooden	stake
1	SC	Valid	The package was sent through the	mail
2	UC	Valid	The package was sent through the	hair
1	SC	Neutral	The parents pleaded with their daughter to come	home
2	UC	Neutral	The parents pleaded with their daughter to come	mask
1	UC	Neutral	The Parkers' baby could already say three	bridge
2	SC	Neutral	The Parkers' baby could already say three	words
1	SC	Valid	The pen in his pocket had unfortunately leaked	ink
2	UC	Valid	The pen in his pocket had unfortunately leaked	deaf
1	UC	Valid	The piano sounded awful and was out of	plates
2	SC	Invalid	The piano sounded awful and was out of	tune
1	SC	Valid	The pigs wallowed in the	mud
2	UC	Invalid	The pigs wallowed in the	change
1	SC	Valid	The pinecone fell and hit Terry in the	head
2	UC	Invalid	The pinecone fell and hit Terry in the	pool
1	UC	Valid	The politician promised changes in return for their	train
2	SC	Valid	The politician promised changes in return for their	vote
1	SC	Neutral	The port gave the incoming ship permission to	dock
2	UC	Neutral	The port gave the incoming ship permission to	team
1	UC	Valid	The princess was only permitted to marry a	quiet
2	SC	Valid	The princess was only permitted to marry a	prince
1	SC	Valid	The princess would someday become a	queen
2	UC	Valid	The princess would someday become a	flour
1	UC	Valid	The prisoner fell asleep inside his	smell
2	SC	Valid	The prisoner fell asleep inside his	cell
1	UC	Invalid	The quarterback faked the handoff and threw the	dress
2	SC	Valid	The quarterback faked the handoff and threw the	ball
1	UC	Invalid	The radio cord was not plugged into the	purse
2	SC	Valid	The radio cord was not plugged into the	wall

1	UC	Valid	The rain this year caused the farmer to have a poor	size
2	SC	Valid	The rain this year caused the farmer to have a poor	crop
1	UC	Valid	The real estate agent quickly sold the	snow
2	SC	Valid	The real estate agent quickly sold the	house
1	SC	Valid	The room was loud so I had to yell to be	heard
2	UC	Invalid	The room was loud so I had to yell to be	knife
1	UC	Valid	The roommates agreed to split the rent in	sound
2	SC	Invalid	The roommates agreed to split the rent in	half
1	SC	Valid	The runner protested that the match was not	fair
2	UC	Valid	The runner protested that the match was not	name
1	UC	Invalid	The salesman helped Sherry get a great	crust
2	SC	Valid	The salesman helped Sherry get a great	deal
1	UC	Valid	The shape of the woman's crystal ball was	scare
2	SC	Invalid	The shape of the woman's crystal ball was	round
1	SC	Invalid	The ship disappeared into the thick	fog
2	UC	Valid	The ship disappeared into the thick	head
1	SC	Valid	The short driver needed to adjust the	seat
2	UC	Valid	The short driver needed to adjust the	love
1	UC	Invalid	The sign cautioned for people to drive	die
2	SC	Valid	The sign cautioned for people to drive	slow
1	UC	Invalid	The soldier's wife was grief stricken when he went off to	gas
2	SC	Valid	The soldier's wife was grief stricken when he went off to	war
1	SC	Neutral	The squirrel stored nuts in the	tree
2	UC	Neutral	The squirrel stored nuts in the	give
1	SC	Valid	The state trooper told the man to get out of his	car
2	UC	Valid	The state trooper told the man to get out of his	day
1	UC	Valid	The store employees knew it was illegal to	knees
2	SC	Valid	The store employees knew it was illegal to	steal
1	UC	Neutral	The students decided to go out dancing at the	door
2	SC	Neutral	The students decided to go out dancing at the	club
1	SC	Valid	The surgeon promised that the surgery was low	risk
2	UC	Invalid	The surgeon promised that the surgery was low	name
1	UC	Valid	The teacher wrote the problem on the	steep
2	SC	Valid	The teacher wrote the problem on the	board
1	SC	Valid	The thief ran by and snatched the lady's	purse
2	UC	Invalid	The thief ran by and snatched the lady's	wall
1	SC	Valid	The traffic stopped suddenly so Trey hit the	brakes
2	UC	Invalid	The traffic stopped suddenly so Trey hit the	neck

1	UC	Valid	The truck lost control and swerved into the	ride
2	SC	Valid	The truck lost control and swerved into the	ditch
1	SC	Valid	The unpaid workers decided they would	strike
2	UC	Valid	The unpaid workers decided they would	band
1	UC	Neutral	The wealthy child attended a private	sign
2	SC	Neutral	The wealthy child attended a private	school
1	UC	Valid	The weightlifter's hands had an incredibly strong	worked
2	SC	Invalid	The weightlifter's hands had an incredibly strong	grip
1	SC	Invalid	The whole town came to hear their mayor	speak
2	UC	Valid	The whole town came to hear their mayor	hole
1	UC	Valid	The woman took Tylenol to relieve her severe back	door
2	SC	Valid	The woman took Tylenol to relieve her severe back	pain
1	UC	Valid	The woman's shirt was so worn it had a	speak
2	SC	Invalid	The woman's shirt was so worn it had a	hole
1	SC	Neutral	The wonderful waitress received a generous	tip
2	UC	Neutral	The wonderful waitress received a generous	store
1	SC	Valid	The young lovers felt their meeting was due to	fate
2	UC	Valid	The young lovers felt their meeting was due to	fence
1	SC	Valid	There were no extra seats so she sat on the	floor
2	UC	Valid	There were no extra seats so she sat on the	stars
1	SC	Valid	They lost their lottery ticket so they could not	win
2	UC	Valid	They lost their lottery ticket so they could not	bugs
1	SC	Neutral	They paid for their meals but forgot to leave a	tip
2	UC	Neutral	They paid for their meals but forgot to leave a	bag
1	SC	Neutral	They raised pigs on their	farm
2	UC	Neutral	They raised pigs on their	gum
1	SC	Valid	They sat together without speaking a single	word
2	UC	Invalid	They sat together without speaking a single	break
1	UC	Neutral	They turned in their project on the date it was	ring
2	SC	Neutral	They turned in their project on the date it was	due
1	UC	Invalid	They wanted their parents to come	mail
2	SC	Valid	They wanted their parents to come	home
1	UC	Neutral	They went as far as they	room
2	SC	Neutral	They went as far as they	could
1	UC	Invalid	They went to the billiard's club for a round of	head
2	SC	Valid	They went to the billiard's club for a round of	pool
1	SC	Valid	They were out of milk so she sent her son to the	store
2	UC	Valid	They were out of milk so she sent her son to the	stain

1	UC	Valid	They were shocked to find his new wife was half his	free
2	SC	Invalid	They were shocked to find his new wife was half his	age
1	UC	Invalid	Thomas took his date out for a night on the	cry
2	SC	Valid	Thomas took his date out for a night on the	town
1	SC	Valid	Tim joined the Navy because he always wanted to fly a	plane
2	UC	Valid	Tim joined the Navy because he always wanted to fly a	screen
1	UC	Invalid	To afford a new car Tim got a	road
2	SC	Valid	To afford a new car Tim got a	loan
1	UC	Neutral	To get some land of their own the settlers moved out	sleep
2	SC	Neutral	To get some land of their own the settlers moved out	west
1	SC	Invalid	To grow a garden you must first plant	seeds
2	UC	Valid	To grow a garden you must first plant	done
1	UC	Valid	To hang the picture Ted needed a hammer and	ring
2	SC	Valid	To hang the picture Ted needed a hammer and	nail
1	SC	Valid	To help her walk around the girl used a	cane
2	UC	Invalid	To help her walk around the girl used a	art
1	UC	Neutral	To keep his breath fresh he bought a pack of	farm
2	SC	Neutral	To keep his breath fresh he bought a pack of	gum
1	UC	Valid	To keep the dogs out of the yard he put up a	fate
2	SC	Valid	To keep the dogs out of the yard he put up a	fence
1	UC	Neutral	To learn about their ancestors they drew a family	gold
2	SC	Neutral	To learn about their ancestors they drew a family	tree
1	SC	Valid	To lose weight Betty decided to go on a	diet
2	UC	Valid	To lose weight Betty decided to go on a	snack
1	UC	Valid	To make the pie crust Donnie needed eggs and	queen
2	SC	Valid	To make the pie crust Donnie needed eggs and	flour
1	SC	Valid	To pay for the car, Al simply wrote a	check
2	UC	Valid	To pay for the car, Al simply wrote a	wind
1	UC	Neutral	To pay for tuition she took out two student	blow
2	SC	Neutral	To pay for tuition she took out two student	loans
1	SC	Neutral	To prevent football injury all players must wear shoulder	pads
2	UC	Neutral	To prevent football injury all players must wear shoulder	year
1	SC	Invalid	To promote their album the band went on	tour
2	UC	Valid	To promote their album the band went on	change
1	SC	Valid	To protect his family he hired several armed	guards
2	UC	Valid	To protect his family he hired several armed	boil
1	SC	Invalid	Tom handed the librarian the overdue	book
2	UC	Valid	Tom handed the librarian the overdue	keys

1	SC	Neutral	Tom's arrows missed the target due to his poor	aim
2	UC	Neutral	Tom's arrows missed the target due to his poor	time
1	SC	Valid	Vic asked her to repeat what she had	said
2	UC	Invalid	Vic asked her to repeat what she had	fly
1	SC	Valid	Walking through the dark room I accidentally stubbed my	toe
2	UC	Valid	Walking through the dark room I accidentally stubbed my	price
1	UC	Neutral	Wanting color in the room, he bought a can of	beard
2	SC	Neutral	Wanting color in the room, he bought a can of	paint
1	SC	Neutral	Water and sunshine help plants	grow
2	UC	Neutral	Water and sunshine help plants	laugh
1	UC	Valid	We couldn't go sailing because there was no	check
2	SC	Valid	We couldn't go sailing because there was no	wind
1	UC	Valid	We sprayed the yard to keep away the	win
2	SC	Valid	We sprayed the yard to keep away the	bugs
1	UC	Invalid	When babies are hungry they may often	book
2	SC	Valid	When babies are hungry they may often	cry
1	SC	Invalid	When Colin saw smoke he called 911 to report a	fire
2	UC	Valid	When Colin saw smoke he called 911 to report a	lunch
1	SC	Valid	When driving you should keep your eyes on the	road
2	UC	Valid	When driving you should keep your eyes on the	socks
1	SC	Valid	When his loved one died many people sent him sympathy	cards
2	UC	Invalid	When his loved one died many people sent him sympathy	air
1	UC	Valid	When she got out of the car she closed the	chair
2	SC	Valid	When she got out of the car she closed the	door
1	UC	Valid	When the alarm rang the firefighter slid down the	food
2	SC	Invalid	When the alarm rang the firefighter slid down the	pole
1	UC	Valid	When the man entered the dog began to	church
2	SC	Valid	When the man entered the dog began to	bark
1	SC	Valid	When the power went out she could not	see
2	UC	Valid	When the power went out she could not	blonde
1	UC	Invalid	When the two met, one of them held out his	steam
2	SC	Valid	When the two met, one of them held out his	hand
1	SC	Valid	When you go to bed turn off the	light
2	UC	Invalid	When you go to bed turn off the	eyes
1	UC	Neutral	While running a marathon the man's brow began to	beer
2	SC	Neutral	While running a marathon the man's brow began to	sweat
1	SC	Neutral	While shipwrecked, the sailor grew a long	beard
2	UC	Neutral	While shipwrecked, the sailor grew a long	paint

1	SC	Invalid	Without food a man would die in several	days
2	UC	Valid	Without food a man would die in several	rain
1	UC	Invalid	Without her sunglasses the sun hurt Erika's	light
2	SC	Valid	Without her sunglasses the sun hurt Erika's	eyes
1	UC	Invalid	Without rain the garden's plants will not	line
2	SC	Valid	Without rain the garden's plants will not	grow
1	SC	Neutral	You would need a raincoat to avoid getting	wet
2	UC	Neutral	You would need a raincoat to avoid getting	pan
1	SC	Valid	Zoos have many animals only found in the	wild
2	UC	Valid	Zoos have many animals only found in the	care

APPENDIX B

TASK STIMULI CHARACTERISTICS

Table B.1. Stimuli Characteristics: Final Word Length.

Version	Completion	Condition	Trials (<i>n</i>)	<i>M</i>	<i>SD</i>
1	Sensible	Congruent	120	4.37	0.85
1	Sensible	Incongruent	40	4.25	0.81
1	Sensible	Neutral	40	4.13	0.79
1	Unconnected	Congruent	120	4.33	0.85
1	Unconnected	Incongruent	40	4.35	0.80
1	Unconnected	Neutral	40	4.13	0.79
2	Sensible	Congruent	120	4.30	0.86
2	Sensible	Incongruent	40	4.20	0.79
2	Sensible	Neutral	40	4.30	0.76
2	Unconnected	Congruent	120	4.28	0.85
2	Unconnected	Incongruent	40	4.28	0.82
2	Unconnected	Neutral	40	4.30	0.76

Table B.2. Stimuli Characteristics: LSA Estimates.

Version	Completion	Condition	Trials (<i>n</i>)	<i>M</i>	<i>SD</i>
1	Sensible	Congruent	120	0.56	0.10
1	Sensible	Incongruent	40	0.57	0.10
1	Sensible	Neutral	40	0.57	0.11
1	Unconnected	Congruent	120	0.49	0.10
1	Unconnected	Incongruent	40	0.46	0.13
1	Unconnected	Neutral	40	0.48	0.11
2	Sensible	Congruent	120	0.56	0.10
2	Sensible	Incongruent	40	0.58	0.11
2	Sensible	Neutral	40	0.57	0.09
2	Unconnected	Congruent	120	0.48	0.12
2	Unconnected	Incongruent	40	0.50	0.11
2	Unconnected	Neutral	40	0.47	0.11

Table B.3. Stimuli Characteristics: Sentence Length.

Version	Completion	Condition	Trials (<i>n</i>)	<i>M</i>	<i>SD</i>
1	Sensible	Congruent	120	9.21	1.72
1	Sensible	Incongruent	40	9.18	1.53
1	Sensible	Neutral	40	8.68	1.42
1	Unconnected	Congruent	120	9.36	1.61
1	Unconnected	Incongruent	40	9.13	1.68
1	Unconnected	Neutral	40	9.25	1.64
2	Sensible	Congruent	120	9.34	1.69
2	Sensible	Incongruent	40	9.18	1.45
2	Sensible	Neutral	40	9.25	1.64
2	Unconnected	Congruent	120	9.06	1.63
2	Unconnected	Incongruent	40	9.63	1.75
2	Unconnected	Neutral	40	8.68	1.42

Table B.4. Stimuli Characteristics: Contextual Diversity Estimates.

Version	Completion	Condition	Trials (<i>n</i>)	<i>M</i>	<i>SD</i>
1	Sensible	Congruent	120	29.13	25.98
1	Sensible	Incongruent	40	31.20	28.49
1	Sensible	Neutral	40	27.94	26.09
1	Unconnected	Congruent	120	28.66	25.64
1	Unconnected	Incongruent	40	32.61	29.27
1	Unconnected	Neutral	40	27.94	26.09
2	Sensible	Congruent	120	28.88	26.54
2	Sensible	Incongruent	40	31.45	27.00
2	Sensible	Neutral	40	31.41	27.66
2	Unconnected	Congruent	120	29.22	27.72
2	Unconnected	Incongruent	40	30.44	23.18
2	Unconnected	Neutral	40	31.41	27.66

Table B.5. Stimuli Characteristics: Word Frequency Estimates.

Version	Completion	Condition	Trials (<i>n</i>)	<i>M</i>	<i>SD</i>
1	Sensible	Congruent	120	29.13	25.98
1	Sensible	Incongruent	40	31.20	28.49
1	Sensible	Neutral	40	27.94	26.09
1	Unconnected	Congruent	120	28.66	25.64
1	Unconnected	Incongruent	40	32.61	29.27
1	Unconnected	Neutral	40	27.94	26.09
2	Sensible	Congruent	120	28.88	26.54
2	Sensible	Incongruent	40	31.45	27.00
2	Sensible	Neutral	40	31.41	27.66
2	Unconnected	Congruent	120	29.22	27.72
2	Unconnected	Incongruent	40	30.44	23.18
2	Unconnected	Neutral	40	31.41	27.66

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Wlotko, E. W., Federmeier, K. D., & Kutas, M. (2012). To predict or not to predict: age-related differences in the use of sentential context. *Psychology and Aging*, 27(4), 975-988.
doi:10.1037/a0029206

BIOGRAPHICAL SKETCH

Matthew J. Kmiecik was born and raised in the Chicagoland area and graduated from Victor J. Andrew High School in 2009. He completed his undergraduate degree at Loyola University Chicago studying psychology, biology, and neuroscience in 2013. His undergraduate honors thesis advised by Dr. Robert G. Morrison, PhD, explored the time course of verbal analogical reasoning using scalp electroencephalography (EEG) analyzed with event-related potentials (ERPs). Continuing to pursue his interests in the cognitive neuroscience of reasoning, Matt entered the Cognition and Neuroscience PhD program at The University of Texas at Dallas under Dr. Daniel C. Krawczyk, PhD, in 2014. In graduate school, Matt explored questions of executive dysfunction in chronic-phase traumatic brain injury, how people learn to solve problems that increase in relational complexity, and whether the neural correlates of semantic access are susceptible to volition. Matt managed to survive the unbearable Dallas summers and thoroughly enjoyed the mild winters by cheering for the Chicago Bears and Blackhawks. In his spare time, he enjoys programming in R, hockey analytics, reading, data visualization and statistics, and bouldering.

CURRICULUM VITAE

Matthew J. Kmiecik, BS

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Education

2014 – 2019	PhD Cognition and Neuroscience School of Behavioral and Brain Sciences	UT Dallas
2009 - 2013	BS Psychology: Natural Science Biology and Neuroscience Minors	Loyola University Chicago Degree Honors: <i>Cum Laude</i>

Publications

Papers

Krawczyk, D. C., Han, K., Martinez, D., Rakic, J., Kmiecik, M. J., Chang, Z., Nguyen, L., Lundie, M., Cole, R., Nagele, M., Didehbani, N. (2019). Executive Function Training in Chronic Traumatic Brain Injury Patients: Study Protocol. *TRIALS*. 20:435. <https://doi.org/10.21203/rs.2.273/v1>

Kmiecik, M. J., Brisson, R. J., & Morrison, R. G. (2019). The time course of semantic and relational processing during verbal analogical reasoning. *Brain and Cognition*, 129, 25-34. <https://doi.org/10.1016/j.bandc.2018.11.012>

Kmiecik, M J., Rodgers, B. N., Martinez, D. M., Chapman, S. B., & Krawczyk, D. C. (2018). A method for characterizing semantic and lexical properties of sentence completions in traumatic brain injury. *Psychological Assessment*, 30(5), 645-655. <http://dx.doi.org/10.1037/pas0000510>

Stockdale, L. A., Morrison, R. G., Kmiecik, M. J., Garbarino, J., & Silton, R. L. (2015). Emotionally anesthetized: media violence induces neural changes during emotional face processing. *Social Cognitive and Affective Neuroscience*, 10(10), 1373-1382. doi: 10.1093/scan/nsv025

Books

Pongpipat, E. E., Miranda, G. G., Kmiecik, M. J. (2019). A Practical Extension of Introductory Statistics in Psychology using R. Online book written using *bookdown* in R:
<https://rpsystats.com/>

Conference Participation

1. Papers

Kmiecik, M. & Morrison, R.G. (2013). Semantic Distance Modulates the N400 Event-Related Potential in Verbal Analogical Reasoning. In M. Knauff, M. Pauen, & N. Sebanz (Eds.), *Proceedings of the 35th Annual Conference of the Cognitive Science Society*. Austin, TX: Cognitive Science Society.

2. Talks

Kmiecik, M. J., Nagele, M., Sharma, R., Vaughn, A. Thakur, P., & Krawczyk, D. C. (December, 2018). A Method for Characterizing Semantic and Lexical Properties of Sentence Completions in Traumatic Brain Injury. Talk presented at the Brain Performance Institute's Inaugural TBI Research Showcase. Dallas, TX.

Kmiecik, M. J. & Krawczyk, D. C. (2017, October). Reasoning with complex relational structures. Talk presented at the Annual UT Dallas School of Behavioral and Brain Sciences Cognition & Neuroscience Annual Retreat, Dallas, TX.

Kmiecik, M. & Morrison, R.G. (2013, August). Semantic Distance Modulates the N400 Event-Related Potential in Verbal Analogical Reasoning. Paper presented at the 35th Annual Conference of the Cognitive Science Society, Berlin, Germany.

3. Conference Workshops

Dutcher, A., Kmiecik, M.J., & Beaton, D. (2016, April). Analyzing multi-block data: A tutorial of Multiple Factor Analysis in R. Workshop presented at the Society for Applied Multivariate Research, Dallas, Texas.

4. Poster Presentations

Nagele, M., Kmiecik, M. J., Chang, Z., Martinez, D., Juarez, M., Khachaturyan, M., Lundie, M., Kim, L., Didehbani, N., & Krawczyk, D. C. (2019, August). Using the Virtual Multiple Errands Task (VMET) to Assess Executive Functioning in Traumatic Brain Injury. Poster presented at the Military Health System Research Symposium annual meeting, Kissimmee, FL.

Chang, Z., Kmiecik, M. J., Martinez, D., Nagele, M., Lundie, M., Cole, R., Kim, L., Khachaturyan, M., Balloun, B., Juarez, M., Didehbani, N., Clover, M., Rule, G., Scott, G., & Krawczyk, D. C. (2019, August). Using a Virtual-Reality Based Rehabilitation Program to Enhance Daily Functioning in Veterans Surviving Traumatic Brain Injury. Poster presented at the Military Health System Research Symposium annual meeting, Kissimmee, FL.

Nagele, M. M., Kmiecik, M. J., & Krawczyk, D. C. (2019, April). Self-Awareness of Executive Dysfunction in Traumatic Brain Injury. Poster presented at UT Dallas School of Behavioral and Brain Sciences Psychological Sciences annual meeting, Dallas, TX.

Kmiecik, M. J., Martin A. D., Kim, L. M., Perez, R., Martinez, D. M., Pongpipat, E. E., & Krawczyk, D. C. (2019, March). The Influence of Reasoning Ability and Relational Cueing in Solving Relational Match-to-Sample Problems. Poster to be presented at the Cognitive Neuroscience Society Annual Meeting, San Francisco, CA.

Kim, L. M., Kmiecik, M. J., Martinez, D. M., Martin A. D., & Krawczyk, D. C. (2019, March). The Similar Situations Task: Measuring Differing Levels of Reasoning Using Scene Analogies. Poster to be presented at the Cognitive Neuroscience Society Annual Meeting, San Francisco, CA.

Kais, L.A., Lee, C., Kmiecik, M.J., Silton, R.L. (2018, February). The Influence of Affect on Interference Processing in Blocked and Mixed Presentations of a Stroop Color-Word Task. Poster accepted for presentation at the annual meeting of the International Neuropsychological Society: Washington, D.C.

Kmiecik, M. J., Perez, R., Dandu, H., Krawczyk, D. C. (2017, August). Reasoning with Complex Relational Structures. Poster presented at the Fourth International Conference on Analogical Reasoning, Paris, France.

Martinez, D. M., Kmiecik, M. J., Kamat, P. S., Schauer, G. F., Krawczyk, D. C. (2017, August). Aspects of Cognition and Clinical Symptomology in Analogical Reasoning. Poster to be presented at the Fourth International Conference on Analogical Reasoning, Paris, France.

Kmiecik, M.J., Martinez, D., Young, L.R., Krawczyk, D.C. (2016, November). Functional and Structural Neural Patterns in Mild-Moderate Chronic-Phase Traumatic Brain Injury. *Archives of Physical Medicine and Rehabilitation*, 97(10), e55. doi: 10.1016/j.apmr.2016.08.167

Martinez, D., Kmiecik, M.J., Chapman, S., Krawczyk, D.C. (2016, November). Observing Changes in Cognition, Mood, and White Matter in Chronic TBI Using Multiple Factor Analysis After Cognitive Intervention. *Archives of Physical Medicine and Rehabilitation*, 97(10), e75. doi: 10.1016/j.apmr.2016.08.229

Kmiecik, M.J., Schauer, G.F., Martinez, D., & Krawczyk, D.C. (2016, April). The Similar Situations Task: An Assessment of Analogical Reasoning in Healthy and Clinical Populations. Poster presented at the Cognitive Neuroscience Society Annual Meeting, New York, NY.

Kmiecik, M. J., Chapman, S., & Krawczyk, D., (2015). Executive Functioning in Traumatic Brain Injury: A Detailed Investigation of the Hayling Test. *Archives of Physical Medicine and Rehabilitation*, 96(10), e97-e98. doi: 10.1016/j.apmr.2015.08.326

Stockdale, L., Morrison, R. G., Kmiecik, M., Palumbo, R., Garbarino, J., & Silton, R. L. (September, 2014). Negative valence systems distinctly influence bottom-up and top-down attentional processes. Paper presented at the Society for Psychophysiological Research, Atlanta, GA.

Palumbo, R. T., Stockdale, L., Kmiecik, M. J., Silton, R. L., Morrison, R. G. (2014, July). The effect of short-term exposure to film violence on emotional facial processing. Poster presented at the 36th annual meeting of the Cognitive Science Society, Quebec City, Canada.

Brisson, R., Kmiecik, M.J., & Morrison, R. G. (2014, July). The effect of semantic and relational similarity on the N400 event-related potential in verbal analogical reasoning. Poster presented at the 36th annual meeting of the Cognitive Science Society, Quebec City, Canada.

Irwin, J.L., Jones, L.L., Kmiecik, M.J., Unsworth, N., & Morrison, R. G. (2014, July). Attention to detail predicts better verbal analogy performance. Poster presented at the 36th annual meeting of the Cognitive Science Society, Quebec City, Canada.

Jones, L.L., Irwin, J.L., Kmiecik, M.J., Unsworth, N., & Morrison, R. G. (2014, July). Working memory and interference control in verbal analogy. Poster presented at the 36th annual meeting of the Cognitive Science Society, Quebec City, Canada.

Morrison, R. G., Kmiecik, M.J., Irwin, J.L., Unsworth, N., Jones, L.L. (2014, July). Working memory and crystallized knowledge in visual analogy. Poster presented at the 36th annual meeting of the Cognitive Science Society, Quebec City, Canada.

Brisson, R.J., Kmiecik, M.J., Sweis, A.S. & Morrison, R.G. (2014, April). The Effect of Semantic and Relational Similarity on the N400 in Verbal Analogical Reasoning. Poster presented at the Cognitive Neuroscience Society Annual Meeting, Boston, MA.

Stockdale, L., Palumbo, R., Kmiecik, M., Silton, R.L. & Morrison, R.G. (2014, April). The Effects of Media Violence on the Neural Correlates of Emotional Facial Processing: An ERP Investigation. Poster presented at the Cognitive Neuroscience Society Annual Meeting, Boston, MA.

Kmiecik, M.J., Brisson, R.J., & Morrison, R.G. (2013, April). Semantic distance in verbal analogical reasoning modulates the N400 event-related potential. Poster presented at the Cognitive Neuroscience Society Annual Meeting, San Francisco, CA.

Morrison, R.G., Kmiecik, M. & Bharani, K.L. (2012, April). When analogy is like priming: The N400 in verbal analogical reasoning. Poster presented at the Cognitive Neuroscience Society Annual Meeting, Chicago, IL.

Morrison, R.G., Kmiecik, M. & Bharani, K.L. (2012, March). When analogy is like priming: The N400 in verbal analogical reasoning. Poster presented at the Society for Neuroscience Chicago Chapter 2012 Annual Meeting, Chicago, IL.

Grants & Fellowships

2019	Friends of BrainHealth Distinguished New Scientist Award	\$20,000
2017	Dianne Cash Pre-doctoral Fellowship	\$2,500
2015	Friends of BrainHealth Distinguished New Scientist Award	\$20,000
2013	European Network for the Advancement of Artificial Cognitive Systems Interaction and Robotics Travel Award	€500
2013	Mulcahy Research Scholarship, Loyola University Chicago	\$1,000
2012	Provost Research Fellowship, Loyola University Chicago	\$1,000
2011	Provost Research Fellowship, Loyola University Chicago	\$1,000

Academic Awards and Honors

2014	People's Choice Poster Award	Cog. Neuroscience Society
2013	First Place Libraries Undergraduate Research Paper Award	Loyola University Chicago
2013	Psychology Research Award, Department of Psychology	Loyola University Chicago
2013	Psychology Honors Award, Department of Psychology	Loyola University Chicago
2010-2013	Dean's List	Loyola University Chicago

Teaching Experience

Teaching Assistant

Spring 2018	Teaching Assistant Experimental Projects	UT Dallas Dr. Linda Drew
Fall 2017	Teaching Assistant Experimental Projects	UT Dallas Dr. Linda Drew
Spring 2017	Teaching Assistant Experimental Projects	UT Dallas Dr. Jessica Lockhart

Summer 2016	Teaching Assistant Cognitive Psychology	UT Dallas Dr. Vanessa Miller
Spring 2016	Teaching Assistant Experimental Projects	UT Dallas Dr. Gail Tillman
Fall 2015	Teaching Assistant Research and Evaluation Methods	UT Dallas Dr. Gail Tillman

Guest Lectures

Fall 2018	Topic: Language Class: Cognitive Neuroscience	UT Dallas Dr. Bart Rypma
Fall 2018	Topic: Short-term & Working Memory Class: Cognitive Neuroscience	UT Dallas Dr. Bart Rypma
Fall 2018	Topic: Analogical Reasoning Class: Reasoning	UT Dallas Dr. Daniel C. Krawczyk

Internships

Summer 2016	Internship in Neuroscience Internet of Things and Wearable Technologies	UT Dallas Venture Development Center
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Training and Certifications

Spring 2016	Graduate Teaching Certificate	UT Dallas
November 2016	The 22 nd EEGLAB Workshop	UCSD Supercomputer Center