Abstract

Children are selective social learners who resist learning from informants who are either not able or not willing to provide correct information (see Koenig & Sabbagh, 2013; Mills, 2013 for reviews). To date, however, we have a very limited understanding of the underlying cognitive mechanisms by which children’s selective social learning manifests. The few proposals that I know of have been focused on the processes underlying children’s selective word learning. These studies, however, have been restricted to using modified comprehension test questions and word training paradigms to examine the kinds of representations children create for trained novel words. Although informative, findings from these studies do not provide evidence about how, specifically, the word learning process is altered when information about word meanings is provided by knowledgeable versus ignorant sources. To better understand the mechanisms by which children show selective word learning, I recorded children’s event-related brain potentials (ERPs) in response to the presentation of trained novel words. My goal was to assess whether children created semantic representations for novel words that were trained by an ignorant source. To this end, I investigated the N400 component of the ERP, a centro-parietally distributed negative waveform peaking around 400 ms that indexes how meaning-related information is stored in semantic memory. I found that children who were trained novel words by an ignorant source did not integrate the meaning of the novel words into lexical-semantic memory, as evidenced by a tenuous N400 effect, but demonstrated ERP evidence for recognizing the trained novel words. These findings suggest that, when children encounter a word-object link from an ignorant source, they engage a mechanism that specifically disrupts the semantic processes involved in word learning. Furthermore, children who were trained by an ignorant speaker subsequently showed ERP evidence of attenuated attention to novel words relative to
children who were trained by knowledgeable speakers. These findings support the idea that children formed a stable attribution of the speaker’s knowledge state and used this information to block their attention to subsequent information by that speaker.
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Chapter 1

Introduction

There are some things about the world that can only be learned from others. In some cases, social learning is important because the means of accessing the knowledge are generally unattainable. For instance, few people are able to use electron microscopes to image the anatomy of viruses, and so, if and when we need to know this information, we rely on our communicative interactions with more able others to learn what we need to know. In other cases, the foundation of the knowledge itself has a social origin. Word meanings, for the most part, are arbitrarily associated with their referent and so the only reason that a word is an effective tool for communicating about its referent is because people in a community agree on that relation (see Kalish & Sabbagh, 2007). Social learning is thus an extremely powerful skill that allows for the accrual of far more information than would be possible otherwise. Yet, our social informants are intentional human agents themselves, who may lack the willingness or ability to provide us with information that serves our specific learning goals. Because of this, evolutionary theorists have argued that social learning can only be an effective tool if it is paired with strategies that allow learners to selectively learn just the information that is useful and helpful (Chudek, Zhao, & Henrich, 2013; Henrich & McElreath, 2007; Sperber et al., 2010). Although a large body of research over the last 10 years has focused on the extent to which children are selective social learners (see Koenig & Sabbagh, 2013; Mills, 2013 for recent reviews), very little is known about the mechanisms by which that selectivity manifests. The goal of my study is to leverage brain electrophysiological methods to better understand how the products of word learning change when information about the word meaning is provided by a knowledgeable versus an ignorant speaker.
A growing body of research in developmental psychology has mapped out the circumstances under which children will demonstrate selective social learning and how an ability to discount information changes with development. Children use cues in the social environment to evaluate whether a speaker is willing or able to provide valuable information, and they use these evaluations to selectively guide their learning (Koenig & Sabbagh, 2013; Mills, 2013). For instance, 3-year-olds are able to use cues linked to an informant’s epistemic state to resist learning from an informant who expresses uncertainty or a lack of knowledge (e.g., “I think this is a spoon”; Jaswal & Malone, 2007; “I don’t know what a blicket is”; Sabbagh & Baldwin, 2001), or demonstrates a history of inaccuracy when labeling familiar objects (e.g., Koenig & Harris, 2005; Scofield & Behrend, 2008). Beyond these epistemic evaluations, children’s selective social learning is also shaped by conventional, socio-culturally relevant characteristics such as an informant’s accent (Kinzler, Corriveau, & Harris, 2011), moral characteristics (Mascaro & Sperber, 2009), and familiarity with the child (Corriveau & Harris, 2009).

To date, however, we have a very limited understanding of the underlying cognitive mechanisms by which children’s selectivity manifests. The few proposals that I know of have been focused on the processes underlying selective word learning – instances in which children have avoided learning words from speakers who are either not able or not willing to provide correct information. These proposals begin from the observation that in order for children to learn words from others, they first have to attend to and encode an initial representation of the speaker’s labeling event (i.e., “She called that thing a blicket”). Second, based upon this initial representation of the labeling event, they need to create a conventional semantic representation (i.e., “That thing is a blicket”) (e.g., Paller & Wagner, 2002). Although certainly oversimplified, this stripped down picture of word learning brings to light three possibilities for how the factors
that promote selective learning might alter the word learning process. Below, I describe each in some detail.

**Source Monitoring**

The first possibility is that children do not alter the processes associated with learning *per se*, but rather add information to the representation about the reliability of the source. In this way, one might conceptualize selective learning as being intimately tied to children’s source monitoring abilities (e.g., Gopnik & Graf, 1988; Johnson, Hashtroudi, & Lindsay, 1993). For instance, children might encode a novel word-object link and mark the representation with an additional piece of information that indicates the knowledge state of the source. If the source of knowledge is known to be unreliable, children can mark the lexical representation as being provided by a tenuous source and alter it when a more appropriate alternative word link is presented. If the source’s reliability is unknown, children can monitor the source and alter the representation for the word-object link retrospectively when the source proves unreliable in the future.

Findings from Scofield and Behrend (2008) support the possibility that children actively mark the knowledge state of the source when they learn a word and then revise these source markings when presented with new information about the source. In this study, children created a mapping of a novel-word object link provided by a speaker with an unknown reliability. Later in the procedure, the speaker inaccurately labeled familiar objects thereby suggesting that he may not be a reliable source. When tested on their learning of the initial presented word-referent link, 4-year-olds but not 3-year-olds showed evidence that they had revised the original word mapping that they had initially encoded. In order for children to revise word mappings in this study, they needed to monitor and retain the source of the word-object link over time (Scofield & Behrend,
Although three-year-olds detected the source’s unreliability when he labeled familiar objects incorrectly, they were unable to revise the original word mappings perhaps because they were less able to adequately track and monitor sources of information (Gopnik & Graf, 1988; Robinson, Haigh, & Nurmsoo, 2008).

Although impressive, there are some reasons to question whether an active source-monitoring explanation provides a good account of a range of selective learning findings. One reason is that based on the extant data, source-monitoring does not seem to be within the cognitive repertoire of children younger than about 4-years-old. In a number of studies, however, children younger than 4-years-old show adaptive selective learning (Birch, Vauthier, & Bloom, 2008; Koenig & Woodward, 2010).

A second reason is that findings from Sabbagh, Wdowiak, and Ottaway (2003) stand against the possibility that young children deal with word-object links offered by an ignorant source by establishing the link in memory, with an additional piece of information that helps them to track the source of the link. Sabbagh and colleagues (2003) used a proactive interference paradigm to test whether children encode both a representation of the link and the knowledge state of the source. The authors reasoned that if children do engage a source-monitoring strategy when presented with a novel word-object link by an ignorant speaker, they would show deficits when attempting to learn an alternative referent for the same word because of proactive interference. Their results showed that 3- and 4-year olds who initially heard a word-object link presented by an ignorant speaker did not demonstrate difficulty in learning an alternative link (same word – different object) that was later presented by a different speaker who was knowledgeable. This evidence that initial exposure to a word-object link offered by an ignorant
speaker did not affect children’s subsequent learning from a different speaker suggested that children may not be following an encoding and source marking strategy.

**Disrupt Encoding Processes**

A second possibility is that children might weaken or block the encoding processes involved in novel word learning. On this account, children strategically modulate their attention whenever they perceive a speaker as being unlikely to provide an accurate label for a novel object. Children’s decreased attention to an unreliable speaker’s labeling event would result in a degraded encoding representation, reducing the likelihood that they can integrate the novel word that the speaker provides into lexical-semantic memory (Davis & Gaskell, 2009).

Sabbagh and Shafman (2009) investigated whether children block novel word encoding by using a modified comprehension test procedure to ask children a question about an ignorant speaker’s labeling episode (i.e., “which one did I say is a blicket?”) or a standard semantic comprehension question (i.e., which one of these things is a blicket?”). They found that 4-year-olds were more likely to respond correctly to questions about the labeling episode as compared to standard comprehension questions, suggesting that children may have attended to and encoded an ignorant speaker’s labeling event.

It is important to note, however, that the question about the labeling episode included an explicit reminder of the ignorant speaker’s labeling event which may in turn have served to scaffold children’s recognition processes. Thus, it is not clear from these results whether children performed well on the question about the labeling episode because they successfully encoded the word-object link presented by the ignorant speaker or because the question about the labeling episode contained a retrieval cue (i.e., “which one did I say is a blicket?”).
More recently, Koenig and Woodward (2010, study 2) explored whether 24-month-olds attend to and encode novel word-object links that are presented by an unreliable speaker. Toddlers first interacted with a speaker who either consistently provided inaccurate or accurate labels for three familiar objects. Following this familiarization phase, the inaccurate or accurate speaker presented toddlers with a novel word-object pairing along with an unnamed distractor object. Immediately following novel word training, the speaker tested the toddler’s comprehension of the word-object link. Interestingly, toddlers responded systematically on the novel word comprehension tests to both inaccurate and accurate sources. This suggested that children were encoding information from both inaccurate and accurate sources, and were not diverting attention away from the inaccurate speaker’s labeling event.

However, it could be that children in this study strategically varied the attentional resources they devoted to only weakly encode novel word-object pairings from inaccurate sources rather than employ an all-or-nothing attentional filtering strategy. These weakly encoded representations could potentially still have supported children’s correct explicit responses to a comprehension question posed shortly after novel word training. Given the current findings, the extent to which children modulate their attentional resources to affect the encoding of novel word-object links presented by inaccurate versus accurate sources remains an open question.

**Disrupt Semantic Consolidation**

A third possibility is that children act in a way that allows them to encode a novel word presented by an unreliable speaker, but specifically disrupt the processes that transform that encoded representation into a conventional semantic representation. By engaging a mechanism that specifically gates the semantic consolidation of a novel word, children are able to encode information concerning the speaker and the novel word-object link she presented but not the
meaning of the object she labeled. In this way, children have a mechanism that can both avoid lexical mapping errors yet still facilitate communication and learning with that speaker, or potentially another speaker in the same context (Sabbagh & Shafman, 2009). For instance, if a second speaker later uses the same label for the novel object, children might have a basis to revisit the encoded representation and decide whether the word is a shared convention among a circumscribed linguistic community and if it is worth integrating into semantic memory.

Findings from Sabbagh and Shafman’s (2009) modified standard comprehension question paradigm helped shed light on the possibility that children engage a semantic-specific gating mechanism to block the formation of semantic representations for novel words presented by ignorant speakers. Their results showed that children had good performance on a question asking about the ignorant speaker’s labeling episode but not on a standard semantic comprehension question about the novel word. These results suggested that when children encounter novel word-object links provided by an ignorant speaker, they may be altering the products of their word learning by blocking the semantic processes involved in learning new word meanings.

However, it is not clear from these findings that the ignorant speaker’s labeling episode led to the formation of weak semantic representations. Children may simply have created weak episodic and semantic representations of the word-object links offered by the ignorant speaker. On this view, children’s better performance on the question about the labeling episode in comparison to the semantic question would not necessarily reflect that they engaged a semantic-specific gating mechanism. Rather, children could have demonstrated this pattern of responses because the question about the labeling episode contained an explicit reminder of the labeling
event, and was therefore a more sensitive assay of those weak representations than the semantic question.

In sum, findings from these studies suggest that children might not be completely ignoring an ignorant speaker’s labeling utterance and that the products of children’s word learning might be altered when the speaker demonstrates ignorance. This research points to at least three possibilities for how children alter the typical processes that are involved in learning words from an ignorant source. Older children with a capacity to monitor sources of information might employ a strategy that does not disrupt the processes involved in word learning per se, but allows them to provisionally store information provided by an ignorant source in semantic memory, whereas younger children might implement selective strategies that adaptively block either the encoding or semantic processes that are involved in the acquisition of novel word meanings.

To date, investigations into the cognitive mechanisms underlying children’s selective word learning have been restricted to using modified comprehension test questions and word training paradigms to examine the kinds of representations children create for words. Although informative, these studies do not provide evidence about how, specifically, the products of word learning are altered when information about word meanings is provided by an ignorant source. In order to better understand the processes and mechanisms by which children show selective social learning, more work needs to be done detailing how the products of children’s word learning are altered when information is provided by a knowledgeable versus an ignorant source.

Current Study

To investigate how the products of children’s word learning are altered when learning words from ignorant sources, I recorded children’s event-related brain potentials (ERPs) in
response to the presentation of recently trained novel words. My goal was to assess whether children created semantic representations for novel words trained by an ignorant source. To this end, I investigated the N400 component of the ERP, a centro-parietally distributed negative waveform peaking around 400 ms that indexes how meaning-related information is stored in semantic memory (for a review see Kutas & Federmeier, 2011). ERPs elicited by words or any other meaningful stimuli that are semantically incongruent with their preceding context produce larger N400 amplitudes, whereas semantically congruent stimuli produce a reduced N400. This difference in the N400 amplitude between incongruent and congruent stimuli pairings is termed the N400 effect.

The sensitivity of the N400 effect to semantic aspects of language has been used to track changes that occur in lexical-semantic knowledge following novel word training in adult word learning paradigms (Batterink & Neville, 2011; Borovsky, Elman, & Kutas, 2012; Frishkoff, Perfetti, & Collins-Thompson, 2010; Mestres-Missé, Rodriguez-Fornells, & Münte, 2007; Perfetti, Wlotko, & Hart, 2005). In these studies, participants received novel word training with definitions or meaningful sentences that provided strong cues about the meaning of the word. Following training, participants completed semantic judgment tasks in which they were asked to decide if two words were semantically related while having their ERPs recorded. Participants from these studies demonstrated larger amplitudes in the N400 component in response to the presentation of semantically unrelated trained words compared with related trained words, indicating that they had created strong lexical-semantic representations for the trained novel words.

ERP studies of early word learning have also leveraged the semantic nature of the N400 component to investigate whether young children create lexical-semantic representations of
novel words after receiving training. In a series of studies, Torkildsen and colleagues (2008, 2009) trained 20-month-olds with associations between novel words and picture referents. Following this training, children’s ERPs were recorded in response to semantically incongruent trials in which the trained novel words were associated with pictures that were previously paired with other words. Infants displayed greater N400 component amplitudes in response to these incongruent trials compared to congruent trials, indicating that they had successfully encoded the word-referent mapping in lexical-semantic memory. In another study, Friedrich and Friederici (2008) trained 14-month-olds with 16 novel words by consistently pairing a novel word with a certain object so that the word-object mappings could be learned. One day after training, infants completed a memory test in which the trained novel words were presented either in a congruent picture context, being paired with the object with which they were trained, or in an incongruent context, being paired with a distracter object. Results showed that infants produced greater N400 component amplitudes in response to the incongruent trials compared to congruent trials, providing evidence that they had consolidated the newly acquired mappings in lexical-semantic memory (Friedrich & Friederici, 2008). These studies have demonstrated the use of the N400 component of the ERP to index the acquisition of novel word meanings in both adults and very young children.

**Study Overview and Hypotheses**

In the current study, I investigated children’s N400 responses to novel words that were either trained by a knowledgeable or ignorant speaker to index lexical acquisition and assess the extent to which children integrated a novel word’s meaning into lexical-semantic memory. Following Sabbagh and Baldwin (2001, study 2), speakers’ knowledge or ignorance was established by the speaker presenting a novel word for a toy he made himself and thus, he was
knowledgeable (i.e., speaker-made condition), or for a toy made by someone else and thus, he was ignorant (i.e., friend-made condition). Following this novel word training, children’s ERPs were recorded in response to pictures of toys that either violated (incongruent trials) or did not violate (congruent trials) the preceding spoken novel word semantic context.

I hypothesized that children trained novel word-object links by an ignorant speaker would demonstrate an attenuated N400 effect when the ignorant speaker’s word was paired with a picture of a distracter toy (incongruent trials) compared to when the word was paired with a picture of the toy it was associated with during training (congruent trials). The lack of an N400 effect would provide evidence that children form attenuated semantic representations for novel words that are trained by ignorant speakers, providing support for a mechanism that disrupts the semantic processes involved in novel word learning. In contrast to this pattern, I hypothesized that children who were trained novel words by a knowledgeable speaker would demonstrate a robust N400 response whereby incongruent trials elicited a larger negativity compared to congruent trials, providing evidence that they form strong semantic representations for the trained novel words.
Chapter 2

Method

Participants

Seventy-one 6-year-old children were recruited to participate in the study from a database drawn from a primarily white, middle-class population in Eastern Ontario, Canada. Data from 18 children were excluded due to excessive recording artifacts ($n = 14$) and refusal to complete the experimental task ($n = 4$). This proportion of attrition is common in ERP studies with children (e.g., DeBoer, Scott, & Nelson, 2004). There was no significant difference in the proportion of children excluded due to excessive recording artifacts and refusal to complete the experimental task in the speaker-made condition ($p = .17; 5/29$) in comparison to the friend-made condition ($p = .35; 13/37$), $z = -1.63, p > .05, 95\% \text{ CI } [-.39, .03]$. An additional 5 children (2 from speaker-made condition, 3 from friend-made condition) were excluded because of experimenter error ($n = 2$), the child claimed to know what at least one of the toys was called ($n = 2$), and hardware malfunction ($n = 1$).

The final sample included 48 normally developing English-speaking children (20 girls) between the ages of 72 months and 84 months ($M = 77.55, SD = 3.52$). Each condition had 14 boys and 10 girls. There was no significant difference between the groups in age, $t (46) = 1.47, p = .15, 95\% \text{ CI } [-0.55, 3.55]$. All children received either a $10 gift certificate or a t-shirt as thanks for their participation.

Materials

Stimuli. Four fixed pairs of novel toys were used as stimuli during training trials and the experimental task (see Figure 1). Toys within a pair were selected to be distinctive from one another and had been balanced for salience in pilot research.
Novel words. Children were introduced to four novel words: *keck*, *toma*, *danu*, and *bito*. These words were unfamiliar and followed English phonotactic constraints.

Design

A 2 x 2 x 2 mixed factorial design was employed with one between-subjects factor and two within-subjects factors. Children were randomly assigned to one of two between-subjects conditions: (1) *speaker-made* – in which the experimenter linked novel labels with toys he stated were self-made, or (2) *friend-made* – in which the experimenter linked novel labels with toys that he stated were made by a friend. The first within-subjects factor was trial-type (*congruent* vs. *incongruent*) and the second within-subjects factor was the word-type (*novel* vs. *familiar*).

The study consisted of two parts. First, the experimenter trained children on four associations between novel words and novel toys via ostensive naming in four novel word training trials. During each training trial, one of the four pairs of toys was removed from a box that had a label of the associated novel word. One toy in the pair served as the target while the other was the distractor. The labels on the boxes and pairs of toys inside were fixed so that the experimenter always linked the word *keck* to a target toy from pair A, *toma* with a target toy in pair B, *danu* with a target toy in pair C, and *bito* with a target toy in pair D. Following the four novel word training trials, children’s electrophysiological data were recorded in response to 160 experimental trials.
All toys served as targets in the two conditions equally often across all children during the novel word training session. The order in which the pairs of toys were presented during training was counterbalanced across participants. The position of the target toy at time of labeling (left or right) was randomized.

**Procedure**

**Novel word training.** Novel word training closely resembled that of Sabbagh and Baldwin (2001, study 2). First, children sat next to the experimenter at a small table in the reception room of a laboratory and completed a warm-up phase. During warm-up, children were asked to complete various tasks using small wooden blocks (e.g., stacking, building, etc.). The warm-up phase was intended to familiarize children with the experimenter and the experimental setting, and usually lasted only a few minutes. Children were then brought into an experimental room to begin the novel word training. The experimenter described the room as a workshop where toys were created. The four novel word training trials that followed consisted of the same three-episode structure: (1) label introduction, (2) play session, and (3) label training. For succinctness, only one training trial linking the word *keck* with a toy from pair A is described in detail below.

**Label introduction.** Children were seated at a small table in an experimental room. The experimenter began by picking up one of the four boxes that were placed in a blue bin and explained to the children the origin of the pair of toys inside. In the speaker-made condition, the experimenter said, “Yesterday, I made a few toys and put them in these boxes.” In the friend-made condition, the experimenter said, “Yesterday, my friend made a few toys and put them in these boxes.” Before opening the first box, the experimenter introduced the novel word by referring to the label on the box and saying, “Oh look, it says this one has a keck in it.” The
experimenter then asked children to say the word themselves (“Can you say keck?”). After children repeated the word, the experimenter displayed uncertainty about which toy from the box would be the target. In the speaker-made condition, the experimenter said, “Yeah, I’d really like to call one of the toys I made in this box a keck, but I don’t know which one!” In this case, because the speaker himself made the objects inside, his hesitancy did not reflect ignorance of the conventional label; rather, it reflected only that he had not yet decided which toy he wanted to call by the novel name. In the friend-made condition, the experimenter said, “Yeah, my friend said she’d really like to call one of the toys she made in this box a keck, but I don’t know which one!” Because the conventional label in this case originated with the speaker’s friend, the speaker’s uncertainty reflected ignorance of the conventional name.

**Play session.** The experimenter then removed the pair of toys from the box and placed it in front of the child. Children were given the opportunity to explore freely and play with the toys while the experimenter sat quietly in a chair across the table and watched. The experimenter ensured that children played with each of the toys an approximately equal amount of time.

**Label training.** After the play session, the experimenter moved the toys out of children’s reach and labeled the target toy with the novel label. In the speaker-made condition, the experimenter said, “You see these toys I made? Well, I’d really like to call one of them a keck, but I don’t know which one! Hmm, maybe this one [touching the target toy]. Maybe this one is a keck [touching the target toy].” In the friend-made condition, the experimenter said, “You see these toys my friend made? Well, she said that one of them is called a keck, but I don’t know which one! Hmm, maybe this one [touching the target toy]. Maybe this one is a keck [touching the target toy].” The experimenter then asked the child to place the target toy and the distracter in
the box after the referent-toy link was made (“Can you put this one away? Can you put this one away too?”). The experimenter then put the box away and began the next training trial.

**Electrophysiological recording and processing.** Following the four novel word training trials, children’s electrophysiological data were recorded during the experimental task from the scalp using a 128-channel Geodesic Sensor Net (Tucker, 1993), a network of 128 Ag/AgCl electrodes connected in an elastic geodesic tension structure. EEG activity in all channels was recorded in reference to the vertex electrode (Cz), with a sampling rate of 250 Hz. EEG was recorded continuously and impedances were maintained below 40 kΩ.

For the experimental task, children were presented with 160 structurally identical trials on a computer monitor: 40 novel congruent trials in which a spoken novel word (i.e., keck) was paired with a picture of the target toy that was ostensively labeled during novel word training, 40 novel incongruent trials in which a spoken novel word was paired with a picture of the distractor toy, 40 familiar congruent trials in which a spoken familiar word (i.e., dog) was paired with a related picture, and 40 familiar incongruent trials in which a spoken familiar word was paired with an unrelated picture. Each trial began with a fixation cross on the screen for 1000 ms. Children then heard a word spoken by the experimenter through the computer speakers digitized at a rate of 44, 100 Hz. After an interval randomized to be between 1000 ms and 1500 ms from the offset of the spoken word, a colored picture of an object appeared for 1096 ms. I recorded ERPs time-locked to the presentation of the pictures of objects. Children’s electrophysiological data were recorded while sitting on a child-sized seat 50 cm from the computer screen in a sound-attenuated, dimly lit room. The experimental task lasted approximately 13 minutes.

Raw EEG signals were first filtered using a 0.3 – 20 Hz band-pass digital filter. The time-locked epochs were 1096 ms long with a 100 ms baseline. Bad channels were detected by
inspection and were interpolated using a spherical spline in the NetStation software. Next, trials containing large or paroxysmal artifacts or movement artifacts were identified by visual inspection and removed from further analysis. The ERP data were then submitted to the extended runica routine of EEGLAB software (Delorme & Makeig, 2004), a function for automated infomax independent component analysis decomposition algorithm (ICA; Makeig, Jung, Bell, Ghahremani, & Sejnowski, 1997). Ocular artifacts were identified from scalp topographies and the component time series and removed. ICA-cleaned data epochs that contained abnormal spectra (+/- 35 dB amplitude change relative to baseline in the 0-2 Hz frequency window) and abnormal trends (200 µV maximum slope with an R² limit of 0.9) were then rejected using EEGLAB.

**ERP statistical analyses.** Nonparametric Wilcoxon signed-ranks tests were conducted comparing children’s grand-averaged ERP responses for congruent and incongruent trial-types to assess for any congruency effects. The Wilcoxon signed-ranks tests were performed for all time points on all 128 channels (sample-by-sample analysis) to examine the overall topography of congruency effects demonstrated by children in the speaker-made and friend-made condition. I defined congruency effects as significant differences that occurred between congruent and incongruent trials maintained for at least 10 samples (40 ms duration) at five contiguous channels with a per-test significance level of .05 (two-tailed). Results from the sample-by-sample analyses allowed me to isolate the locations (electrode sites) and time spans for the N400 congruency effect, and any other congruency effects such as the N200, that children in each condition demonstrated.

Previous research demonstrating the N400 congruency effect associated with pictures exhibit a central-parietal and slightly right lateralized spatial distribution between 300 – 500 ms
(Barrett & Rugg, 1990; Hamm, Johnson, & Kirk, 2002; McPherson & Holcomb, 1999; Pratarelli, 1994). However, the scalp distributions of the N400 effect are not entirely consistent as some studies have shown the effect to exhibit a more widespread distribution, extending to both frontal and parietal locations (Coch, Maron, Wolf, & Holcomb, 2002; Federmeier & Kutas, 2001; Ganis, Kutas, & Sereno, 1996; Holcomb & McPherson, 1994; West & Holcomb, 2002;). Given that the spatial distribution of the N400 effect has varied widely across numerous studies with both adult and children participants, I chose to explore the overall pattern of congruency effects within the time window of 300 – 500 ms using the sample-by-sample analysis to capture the spatial distribution of the N400 effect elicited by children in the current study. Furthermore, I examined the wave morphology at channel sites that demonstrated significant congruency effects according to the established criteria (10 continuous samples at 5 contiguous channels, \( p < .05 \)). Channels that demonstrated significant congruency effects within the time window of interest but did not demonstrate a wave pattern that was consistent with the identified N400 effect were not considered in further analyses.

I averaged ERP potentials across representative electrode sites and time samples that were identified with the nonparametric sample-by-sample analyses to further characterize the N400 and other congruency effects, and quantitatively assess for differences between children in the speaker-made and friend-made conditions. I conducted robust 2-way mixed-design ANOVAs (between-subjects factor: condition, speaker-made vs. friend-made; within-subjects factor: trial-type, congruent vs. incongruent) using a percentile bootstrap method on the averaged potentials (Wilcox, 2012).

The percentile bootstrap method for mixed-designs works by generating a large number of bootstrap estimates for each of the main effects (condition, trial-type) and the interaction
(condition x trial-type) through the following procedure. A bootstrap estimate for the main effect of condition was calculated by subtracting the median value of the average potentials (incongruent + congruent / 2) for children in the friend-made condition from the median of the average potentials (incongruent + congruent / 2) for children in the speaker-made condition. For the main effect of trial-type, a bootstrap estimate was calculated by adding the median value of the difference potentials (incongruent - congruent) for children in the friend-made condition with the median of the difference potentials (incongruent - congruent) for children in the speaker-made condition. For the condition by trial-type interaction, the bootstrap estimate was calculated by subtracting the median value of the difference potentials (incongruent - congruent) for children in the friend-made condition from the median of the difference potentials (incongruent - congruent) for children in the speaker-made condition. Each of these procedures was repeated to generate a sample distribution consisting of 5000 bootstrap estimates for each main effect and the interaction. I then established a 95% confidence interval for each bootstrap sample distribution by taking the bootstrap estimate that corresponded to the 2.5th ($\alpha / 2$) and the 97.5th (1 - $\alpha / 2$) percentile. I rejected the null hypothesis for each main effect and the interaction if the 95% confidence interval of the corresponding bootstrap sample distribution did not contain zero.
Chapter 3

Results

At anterior sites, all ERP waveforms demonstrated an early, negative-going component peaking at approximately 175 ms (N1), followed by a positive-going component peaking at approximately 265 ms (P2). Following the P2, there was a broad negative deflection peaking at 380 ms, which lasted until the end of the epoch. At posterior sites, a positivity peaking at approximately 160 ms (P1) was followed by a negative-going component peaking at approximately 265 ms (N1). Following the posterior N1 component, there was a broad positive deflection peaking at about 400 ms, which lasted until the end of the epoch.

Preliminary Wilcoxon signed-ranks tests comparing ERP responses to novel and familiar trials for all time points on all 128 channels (sample-by-sample analysis) revealed that children’s responses to novel words were significantly larger than familiar words starting around 220 ms and lasting until the end of the epoch (see Figure 2). Previous research with young children and adults have shown that recently trained words elicit different patterns of brain activity in comparison to familiar words (e.g., Mills, Plunkett, Prat, & Schafer, 2005; Perfetti et al., 2005). I therefore conducted separate analyses for recently trained novel and familiar words.
[Figure 2. The results from the sample-by-sample Nonparametric Wilcoxon signed-ranks tests for each electrode at each time point comparing children’s grand averaged ERP responses to novel words and familiar words. The plot shows the p values according to the color scale for each time sample for each electrode.]

The critical finding I report here is that, following the early visual processing components of the ERPs for novel words, children in the speaker-made condition demonstrated an N400 effect at central and centro-parietal sites with slight right lateralization whereas children in the friend-made condition demonstrated no evidence for an N400 effect. Despite this condition difference for the N400 effect for novel words, children in both conditions demonstrated an N200 congruency effect. Further, children in both conditions demonstrated an N400 effect for familiar words; however, the spatial-temporal features of the effect differed between conditions. Lastly, the peak P1 amplitude responses for novel words differed between conditions at classic occipital and parietal-occipital sites.

**N400 Effect for Novel Words**

Children in the speaker-made condition showed an N400 effect for novel words starting around 340 ms and lasting until approximately 420 ms on a group of electrodes located over the central and centro-parietal regions of the scalp with slight right hemisphere lateralization. In contrast, children in the friend-made condition showed no evidence of an N400 effect for novel words (see Figure 3).
[Figure 3. ERP waveforms and spline-interpolated maps of scalp electrical activity. Top-row left and right, the ERP waveforms from a right centro-parietal electrode (CP2) for children in the speaker-made condition and friend-made condition, respectively. The dashed blue lines indicate the incongruent trials and the solid red lines indicate the congruent trials. Bottom-row left and right, the maps of scalp electrical activity – mean amplitude difference between trial-types (incongruent minus congruent) at 200 ms and 400 ms for children in the speaker-made condition and friend-made condition, respectively. The location of CP2 is shown on scalp maps with an open circle.]
To further characterize condition differences for the N400 responses elicited by novel words, I conducted a robust mixed-design ANOVA percentile bootstrap analysis on potentials averaged across the electrodes and 340 – 420 ms time window identified by the sample-by-sample analysis. There was a significant condition by trial-type interaction, $\bar{\Psi} = -1.74$, $p = .015$, 95% CI [-2.76, -0.32], indicating that children in the speaker-made condition demonstrated larger N400 responses (incongruent minus congruent) for recently trained novel words ($Mdn = -0.66$) in comparison to children in the friend-made condition ($Mdn = 0.35$).

**N200 Effect for Novel Words**

Although children in the friend-made condition did not demonstrate an N400 effect for novel words, children in both conditions showed evidence for an earlier N200 congruency effect. Children in the speaker-made condition demonstrated an N200 effect starting around 150 ms and continuing until approximately 220 ms. This N200 effect appeared over central and centro-parietal electrodes, overlapping the topography of the N400 effect, and extended to right-parietal sites (see Figure 3). A robust mixed-design ANOVA percentile bootstrap analysis on potentials averaged across the electrodes and 150 – 220 ms time window identified by the sample-by-sample analysis revealed a significant trial-type main effect, $\bar{\Psi} = -1.19$, $p = .002$, 95% CI [-3.63, -1.19] but no significant condition by trial-type interaction, $\bar{\Psi} = -0.63$, $p = .21$, 95% CI [-1.79, 0.63]. To further characterize the N200 congruency effect demonstrated by children in the speaker-made condition, I compared children’s averaged potentials to novel incongruent and novel congruent trials using a robust paired-samples percentile bootstrap analysis. There was a significant difference across the trial-types for novel words, $\bar{\Psi} = -1.45$, $p < .001$, 95% CI [-2.54, -0.74], indicating that children in the speaker-made condition demonstrated larger negative N200
responses to novel incongruent trials ($Mdn = -2.11$) in comparison to novel congruent trials ($Mdn = -0.77$).

Children in the friend-made condition demonstrated an N200 congruency effect starting slightly later around 195 ms and continuing until approximately 255 ms, appearing over central electrodes and extended over right-medial sites (see Figure 3). A robust mixed-design ANOVA percentile bootstrap analysis on potentials averaged across the electrodes and 195–255 ms time window identified by the sample-by-sample analysis revealed a significant trial-type main effect, $\hat{\Phi} = -1.37, p < .001, 95\% \text{ CI } [-3.91, -0.81]$ but no significant condition by trial-type interaction, $\hat{\Phi} = 0.33, p = .74, 95\% \text{ CI } [-1.09, 2.03]$. To further characterize the N200 congruency effect demonstrated by children in the friend-made condition, I compared children’s averaged potentials for novel incongruent and novel congruent trials using a robust paired-samples percentile bootstrap analysis. There was a significant difference across the two trial-types for novel words, $\hat{\Phi} = -1.41, p = .01, 95\% \text{ CI } [-2.60, -0.42]$, showing that children in the friend-made condition demonstrated larger negative N200 responses to novel incongruent trials ($Mdn = -2.59$) in comparison to novel congruent trials ($Mdn = -1.63$).

To assess for any condition differences for the N200 effect, I conducted a robust mixed-design ANOVA percentile bootstrap analysis on the averaged potentials identified for the N200 effect for children in the speaker-made and friend-made condition. There was a significant trial-type main effect, $\hat{\Phi} = -1.41, p < .001, 95\% \text{ CI } [-4.27, -1.67]$ but no significant condition by trial-type interaction, $\hat{\Phi} = 0.04, p = .94, 95\% \text{ CI } [-1.37, 1.25]$, providing evidence that children’s N200 responses did not differ between conditions.
N400 Effect for Familiar Words

Children in both the speaker-made and friend-made conditions demonstrated an N400 effect for familiar words. Children in the speaker-made condition demonstrated a widespread N400 effect starting around 340 ms and lasting until approximately 450 ms on a group of electrodes located in frontal, fronto-central, central, and centro-parietal regions of the scalp with extensions over right anterior sites (see Figure 4). A robust 2-way mixed model ANOVA bootstrap analysis on potentials averaged across these electrode sites and time samples revealed a significant condition by trial-type interaction, $\hat{\Phi} = -1.97, p = .032, 95\% \text{ CI } [-3.92, -0.53]$, indicating that children in the speaker-made condition demonstrated larger N400 responses for familiar words ($Md'n = -2.01$) in comparison to children in the friend-made condition ($Md'n = 0.85$) over a widespread scalp distribution.

In contrast, children in the friend-made condition demonstrated an N400 effect that started slightly later around 370 ms and lasted until 460 ms on a group of electrodes mainly located in right central, centro-parietal, parietal, and temporal-parietal regions (see Figure 4). A robust 2-way mixed model ANOVA bootstrap analysis on potentials averaged across these electrode sites and time samples revealed a significant interaction between condition and trial-type, $\hat{\Phi} = 1.72, p = .037, 95\% \text{ CI } [0.10, 3.32]$. Children in the friend-made condition demonstrated larger N400 responses for familiar words ($Md'n = -1.34$) in comparison to children in the speaker-made condition ($Md'n = 0.11$) over a primarily right lateralization central-parietal and parietal distribution.
Figure 4. ERP waveforms and spline-interpolated maps of scalp electrical activity. Top left, the ERP waveforms from a centro-parietal electrode (E106) for children in the speaker-made condition. Top right, the ERP waveforms from a right parietal electrode (P4) for children in the friend-made condition. The dashed blue lines indicate the incongruent trials, and the solid red lines indicate the congruent trials. Bottom left and right, the maps of scalp electrical activity – mean amplitude difference between trial-types (congruent subtracted from incongruent) at 400 ms for children in the speaker-made condition and friend-made condition, respectively. The location of E106 and P4 is shown on scalp maps with an open circle.
P1 Component

Nonparametric sample-by-sample Wilcoxon rank-sum tests comparing children’s ERP responses between conditions revealed significant differences at central-parietal and parietal electrode sites starting around 120 ms for novel words and around 170 ms for familiar words. To assess whether the peak amplitude of the posteriorly distributed visual P1 component was modulated as a function of condition, I selected the most positive peak of the grand averaged ERP waveforms between a 135 – 185 ms time window encompassing the P1 at classic occipital and parietal-occipital electrodes O1, O2, Oz, PO3, PO4, and POz. A robust mixed-design ANOVA percentile bootstrap analysis on the maximum potentials averaged across these electrodes revealed a significant condition main effect for novel words, $\hat{\Psi} = 1.87, p = .042, 95\%$ CI [0.09, 4.12]. Children in the speaker-made condition produced larger P1 peak amplitudes for novel words ($Mdn = 7.55$) in comparison to children in the speaker-made condition ($Mdn = 6.88$) over classical occipital and parietal-occipital electrodes (see Figure 5). There was no significant condition main effect for familiar words, $\Psi = 1.65, p = .12, 95\%$ CI [-0.20, 4.67], indicating that children’s peak P1 amplitude did not significantly differ between conditions ($Mdn_{\text{Speaker-made}} = 7.68; Mdn_{\text{Friend-made}} = 6.78$).

Figure 5. ERP waveforms from an occipital electrode (Oz) for novel and familiar words. The dashed blue lines indicate responses from children in the speaker-made condition, and the solid red lines indicate responses from children in the friend-made condition.
Chapter 4

Discussion

The purpose of this study was to integrate behavioral word training paradigms with brain electrical indices of word learning processes to assess the specific mechanisms underlying children’s selective word learning. Specifically, I investigated 6-year-old’s ERP responses to novel words that were either trained by a knowledgeable or ignorant speaker using a word-picture matching paradigm in which spoken words were paired with pictures of objects that were either congruent (semantically related) or incongruent (semantically unrelated). I was particularly interested in the N400 component of the ERP, which is an index of the acquisition of novel word meaning.

Results in the current study provide the first electrophysiological evidence that children trained by a knowledgeable speaker created stronger semantic representations for novel words compared to children trained by an ignorant speaker. This finding provides evidence that children engaged a mechanism that blocked the integration of a novel word’s meaning into lexical-semantic memory when they were trained by a speaker who demonstrated ignorance. Moreover, this pattern of responses is evidence against the possibility that children are capitalizing on their source-monitoring abilities to enable the formation of a semantic representation that is marked to indicate that the link was provided by an ignorant source. Children used social information provided during novel label training to rapidly evaluate the knowledge state of the informant and then used this evaluation strategically to either block or allow the formation of robust, semantic representations for the word-object links that were provided.
Although children trained by an ignorant speaker produced tenuous N400 responses for novel words, they demonstrated an earlier N200 congruency effect at central and central-parietal electrode sites. This early congruency effect occurred in the latency range of 195 – 255 ms for children in the friend-made condition as novel incongruent trials elicited larger amplitudes compared to congruent trials. In contrast, children who were trained by a knowledgeable speaker demonstrated both an N200 and N400 effect in response to novel words. The N200 effect has been reported in a number of studies as an index of processes involved in object, and auditory and visual word recognition (e.g., Hauk, Davis, Ford, Pulvermüller, & Marslen-Wilson, 2006; Rabovsky, Sommer, & Rahman, 2012; Rodriguez-Fornells, Schmitt, Kutas, & Münte, 2002; Sereno & Rayner, 2003; Zhang, Begleiter, Porjesz, Wang, & Litke, 1995), and recently in a study investigating 8-10 year old children’s N400 responses to picture-word pairs (Henderson, Baseler, Clarke, Watson, & Snowling, 2011). These studies implicate the N200 effect as reflecting initial recognition or access to form-related lexical information (Rabovsky et al., 2012). In this context, I interpret the N200 effect elicited in the current study as reflecting object recognition processes during which children mapped the perceptual features of the presented objects onto conceptual representations that were stored in the mental lexicon. Children who were trained by an ignorant speaker, however, did not integrate these relational representations into lexical-semantic memory as they did not demonstrate an N400 effect, revealing a striking dissociation between the N400 and N200.

Although the current study was not designed to address the functional significance of this dissociation, one hypothesis is that it reflects the involvement, or lack thereof, of two complementary but distinct memory systems that have been implicated in novel word learning (Davis & Gaskell, 2009; McClelland, McNaughton, & O’Reilly, 1995). On this account,
children’s N200 responses reflect that they successfully encoded and established some sort of representations about the form and meaning of novel words, possibly by engaging neural systems located within the hippocampus of the medial temporal lobe memory systems (Ullman, 2004). Subsequently, children may have blocked the activation of neocortical memory regions that typically lead to the consolidation of these episodic representations into stable, lexical-semantic representation. Viewed from this perspective, the dissociation provides further evidence to support a semantic-specific gating strategy by which children disrupt the formation of conventional semantic representations for novel words when they are trained by ignorant speakers while maintaining brief episodic representations.

The neuroanatomical underpinnings of such a semantic gating mechanism are unclear given the findings of the current study. Over some time, memories for words are thought to become largely independent of the medial temporal lobe structures, and dependent upon neocortical regions, particularly in the temporal lobes (Hodges & Patterson, 1997; Squire, Clark, & Knowlton, 2001). Although there is neuroimaging evidence from fMRI studies indicating that successful acquisition of a new lexicon depends on an interaction between the hippocampus and neocortical regions (e.g., Breitenstein et al., 2005), there is limited evidence regarding how hippocampal and neocortical lexical representations are coupled (Davis & Gaskell, 2009). An important direction for future research, therefore, is to combine social learning paradigms with brain imaging techniques to explore which brain areas are activated or perturbed when children selectively block word learning from others.

In addition, more research is needed to delineate the nature of children’s semantic gating mechanism. For instance, it could be that children’s resistance to learning novel words from ignorant speakers is attributable to a gating strategy in which children strategically modify the
strength of lexical representations gradationally once they are retrieved. Within this framework, the semantic gating mechanism would not be an all-or-none process in which children would either completely block or allow the consolidation of semantic representations from episodic representations.

The overall pattern of ERP findings indicate that children attended to the utterances made by an ignorant speaker during novel word training. Children in both conditions demonstrated an N200 congruency effect which could only be possible if they had attended to and encoded information about a novel object’s label during the teaching event. This finding is consistent with behavioral results which stand against the possibility that children’s resistance to learning from ignorant and inaccurate sources is attributable to a lack of attention during the teaching event (Koenig & Woodward, 2010; Sabbagh & Shafman, 2009). More research, however, is needed to directly assess whether children modulate their attention to resist learning words provided by ignorant speakers by examining ERP components that are related to sensory processing during the labeling event itself and using electrophysiological procedures that allow the indexing of novel word encoding. For instance, it is possible that children in the current study did modulate their attention during an ignorant speaker’s labeling event, however devoted sufficient attentional resources to create an episodic representation of the word-object link provided.

Interestingly, I found that children who were trained by an ignorant speaker subsequently showed attenuated P1 responses during the experimental task to novel words relative to children who were trained by knowledgeable speakers. The P1 component is thought to index attentional processes and it is known to be modulated by attentional effects in children (Mills et al., 2004). This finding suggests that children evaluated the speaker’s knowledge state and used this information to establish speaker-specific cognitive profiles that then affected how they processed
subsequent information from that speaker generally (Harris, 2007). Indeed, previous research has shown that 5-year-olds use a speaker’s past accuracy when labeling familiar objects to generate broader explicit judgments about that individual’s future word knowledge, factual knowledge, and prosocial and antisocial attributes (Brosseau-Liard & Birch, 2010). Research with 3- and 4-year olds demonstrates that even young children monitor the knowledge states of informants to form stable attributions regarding the value of information subsequently presented by that speaker (Corriveau & Harris, 2009; Scofield & Behrend, 2008). An alternative possible explanation for these findings is that children’s attenuated attention to and encoding of recently trained novel objects presented by an ignorant speaker could have been due to condition-specific processing costs involved in making the initial judgment about the speaker’s ignorance (Sperber et al., 2010). That is, the increased processing demands placed on children to assess and monitor a speaker’s credibility when the speaker demonstrated ignorance could have depleted children’s cognitive resources and hindered their ability to process even known words relative to children in the knowledgeable condition, which did not include those demands. Investigating between these possibilities and whether children do establish long-lasting knowledge assessments that modulate their subsequent processing of information from that speaker is an important direction for future research.

Finally, it is important to note that for familiar words, children in both conditions demonstrated a robust N400 effect whereby familiar incongruent trials elicited a deeper negativity than congruent trials, providing evidence that the N400 paradigm worked well with 6-year-olds in the current study and indexed semantic anomaly. However, the spatial topography of this semantic congruency effect differed between conditions. Children who were trained by a knowledgeable speaker demonstrated a more widespread N400 effect for familiar words on a
group of electrodes located in frontal, fronto-central, central, and centro-parietal regions of the brain with extensions over right anterior sites, whereas children in the friend-made condition demonstrated a wholly different N400 effect for familiar words over right centro-parietal and parietal regions, extending to the right temporal-parietal sites. It would be interesting to use brain imaging techniques to investigate the localization of the N400 effect elicited in response to familiar words that are presented by speakers with differing knowledge states to determine if different neurocognitive operations subserve children’s semantic processing.

Conclusions

In summary, I have provided electrophysiological evidence showing that children resist learning words from ignorant speakers by blocking the formation of semantic representations despite forming episodic representations of the labeling event. Furthermore, I have shown that children who were trained by an ignorant speaker subsequently showed ERP evidence of attenuated attention to novel words relative to children who were trained by knowledgeable speakers. These findings support the idea that children formed a stable attribution of the speaker’s knowledge state and used this information to block their attention to subsequent information from that speaker. Future work can extend this paradigm to better understand the underlying processes by which children show selective social learning in a host of additional contexts.
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GREB Ref #: GPSYC-648-14; Romeo # 6011951
Title: "GPSYC-648-14 Neural Correlates of Children’s Selective Word Learning"

Dear Mr. Mangardich:

The General Research Ethics Board (GREB), by means of a delegated board review, has cleared your proposal entitled "GPSYC-648-14 Neural Correlates of Children’s Selective Word Learning" for ethical compliance with the Tri-Council Guidelines (TCPS) and Queen’s ethics policies. In accordance with the Tri-Council Guidelines (article D.1.6) and Senate Terms of Reference (article G), your project has been cleared for one year. At the end of each year, the GREB will ask if your project has been completed and if not, what changes have occurred or will occur in the next year.

You are reminded of your obligation to advise the GREB, with a copy to your unit REB, of any adverse event(s) that occur during this one year period (access this form at https://eservices.queensu.ca/romeo_researcher/ and click Events - GREB Adverse Event Report). An adverse event includes, but is not limited to, a complaint, a change or unexpected event that alters the level of risk for the researcher or participants or situation that requires a substantial change in approach to a participant(s). You are also advised that all adverse events must be reported to the GREB within 48 hours.

You are also reminded that all changes that might affect human participants must be cleared by the GREB. For example you must report changes to the level of risk, applicant characteristics, and implementation of new procedures. To make an amendment, access the application at https://eservices.queensu.ca/romeo_researcher/ and click Events - GREB Amendment to Approved Study Form. These changes will automatically be sent to the Ethics Coordinator, Gail Irving, at the Office of Research Services or irvingg@queensu.ca for further review and clearance by the GREB or GREB Chair.

On behalf of the General Research Ethics Board, I wish you continued success in your research.

Yours sincerely,

Joan Stevenson, Ph.D.
Chair
General Research Ethics Board

c: Dr. Mark Sabbagh, Faculty Supervisor
Dr. Stanka Fitneva, Chair, Unit REB
Ms. Marie Tooley, Dept. Admin.