Examining Cumulative Semantic Interference in Children

by

Tieghan Baird

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Department of Communication Sciences and Disorders
University of Alberta

Abstract

When speakers are asked to name a series of semantically related pictures (e.g., *apple, pear, banana*), response times increase as more pictures are named. This effect is known as cumulative semantic interference (CSI). Researchers who have studied these effects in adults have proposed that these interference effects are due to durable changes in the strength of representation of a word, otherwise known as incremental learning (Howard et al., 2006; Oppenheim, Dell & Schwartz, 2010). This effect has been well documented in adults, but few studies have focused on this phenomenon in children. This gap invited further investigation as cumulative semantic interference has the potential to offer a window into how children strengthen or change their representation and processing of words.

The present study examines cumulative semantic interference in preschool-aged children using a continuous list method with unrelated, intervening items. Forty children (17 male, M_{age} = 3 years; 11 months, range 3;0 – 4;11) named 100 images, consisting of 72 experimental items (six exemplars drawn from 12 different semantic categories) and 28 filler items. There were two to eight intervening trials between related category members. Potential factors impacting cumulative semantic interference effects, such as vocabulary size, conceptual organization and inhibitory control, were also examined. Children demonstrated robust cumulative semantic interference effects as evidenced by increased response latencies and decreased response accuracy for each successive category image. The effects were persisting and independent of intervening naming experiences, consistent with the incremental learning account. Exploratory analyses were completed to investigate factors contributing to individual differences. Two variables were identified to have moderating effects: vocabulary size and age. As children's vocabulary scores increased, predicted slopes suggested worsening accuracy over ordinal position; however, the degree of worsening was attenuated as compared to children with poorer vocabularies. Older children demonstrated a greater increase in reaction times as ordinal position increased, thereby indicating stronger cumulative semantic interference effects.

This study supports the application of the incremental learning account to cumulative semantic interference effects in preschool aged children. While only vocabulary and age were identified as moderating factors, this indicates there are certain abilities and knowledge that contribute to the presence of these effects. This study provides important insights into lexical representation and processing in typical language development, and offers a foundation for future work with children with language delays.

Preface

This thesis is an original work by Tieghan Baird. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Learning from Speaking: The Children's Picture Naming Study, Study ID: Pro00076501, April 2019.

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Introduction

When speakers are asked to name a series of semantically related pictures (e.g., *apple*, *pear*, *banana*) there is a slowing of responses as more pictures are named. This inhibitory effect is known as cumulative semantic interference (Howard, Nickels, Coltheart & Cole-Virtue, 2006). This effect is potentially counterintuitive – we might assume that naming pictures that all come from the same category would lead to faster naming, given evidence from the semantic priming literature showing that the presentation of an item often facilitates the naming of an ensuing semantically related item. Based on prior demonstrations of priming (Bajo, 1988; Lupker, 1988), the shared characteristics among semantically related items should facilitate production. However, while this semantic priming effect can be found in single word naming, the interference effect that arises over time when naming multiple exemplars from the same category has now been well documented (Howard et al., 2006; Oppenheim, Dell & Shwartz, 2007; Schnur, 2014).

In a seminal study, Howard and colleagues (2006) demonstrated that cumulative semantic interference (CSI) occurs even when there are intervening items from different semantic categories. Participants named 120 pictures from 24 semantic categories with 45 unrelated filler pictures. Rather than present the semantically related stimuli successively, they were presented with a lag between each successive same-category member (2, 4, 6 or 8 intervening trials). The design of the study minimized confounding of ordinal position with trial position within the experimental list, and included statistical controls for general fatigue across trials. The results demonstrated that, on average, naming was slowed by 30 milliseconds for each subsequent member of a given semantic category. The results of this study demonstrated that cumulative semantic interference effects are long lasting (at least beyond several seconds) and accumulate over time

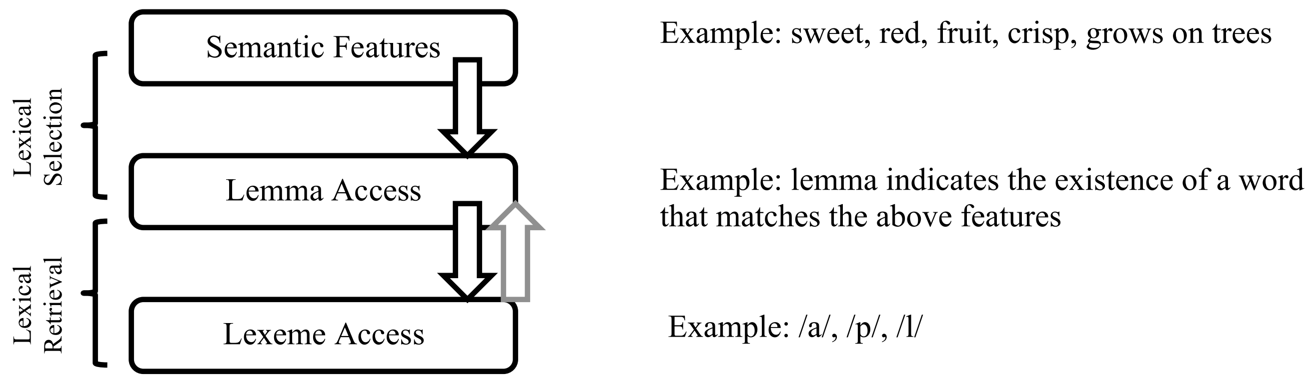
Posited Mechanisms

The slowing of response times for each preceding semantically related item prompted Howard and colleagues (2006) to consider two potential mechanisms to explain cumulative semantic interference, both framed within a general connectionist network view of the lexical system: residual activation and incremental learning. Residual activation occurs when target words that are selected retain some activation, which interferes with future selection. This is a temporary phenomenon that is not very durable. Incremental learning, on the other hand, is a longer lasting effect that occurs when there are more permanent changes to the strength of representation of a word that result in slower subsequent word retrieval seconds to minutes later. Howard et al. (2006) argued that the cumulative effects in their study reflected incremental learning.

The distinction between learning and residual accounts of CSI is understood within the connectionist framework that characterizes current theories of language production. Two general connectionist principles have been used to characterize the process of turning thoughts into speech (Goldrick, 2007). The first is that representations refer to patterns of activation and the second is that processing is the spreading of activation among representations or levels of representation. That is, a single unit does not represent a word; rather there are multiple units that are processed via activation spreading from unit to unit in a given pattern. Models of language production include at least two distinct content or word processing stages: lexical selection and lexical retrieval (Ferreira & Slevc, 2007; see Figure 1). The first step is lexical selection. This occurs when a concept is mapped onto a lemma – a nonphonological representation of a word

(Dell, Chang & Griffin, 1999). Lemmas indicate the existence of potential words that match the activated semantic features and help guide further processing of these words. The lexical retrieval of the morphophonological information, otherwise known as lexemes, forms the second step of content processing. Activation of semantic features spreads to the most strongly activated lemma and the lemma spreads activation throughout the morphophonological network, which retrieves the most strongly activated lexemes[1].

Figure 1: Generalized example of lexical selection and retrieval



It is generally accepted that during the word selection process, several conceptually related lemmas receive activation during the spreading of activation from semantic features to the lemma level (Belke & Stielow, 2013). The most activated entry is then selected from the potential set for production. If the target lemma is clearly more activated than potential competitors, selection is quick and effortless, but if several lemmas qualify as the target then selection will be more effortful and require more time (Thompson-Shill, D'Esposito, Aguirre & Farah, 1997).

Howard and colleagues (2006) argued that the interference effects that were observed occurred at the level of lemma access. Howard and colleagues (2006) also made the argument that the effects of cumulative semantic interference cannot be interpreted as residual activation

[1] There is debate surrounding whether the spreading activation between these local

because the effects of cumulative semantic interference still persist even when there are intervening unrelated items. Residual activation is thought to be very short lived. If cumulative semantic interference is due to residual activation then the slowing of responses should dissipate after unrelated lags. However, this is not what Howard and colleagues (2006) found and they argued instead that the effect arises from more durable changes in the strength of the connections within the lexical-semantic network – conceptualized as incremental learning. They posited that interference arises based on three principles: shared activation, competition and repetition priming. When a target word is retrieved, that activation is shared with semantically related words. The stronger the shared activation, the more competitive the semantically related words become – which makes selecting the target more difficult. Finally, by selecting the target, it receives priming and becomes a stronger competitor for future target words due to repetition priming or strengthening of connection weights. Additional studies support the position that these long lasting interference effects cannot simply be interpreted as residual activation, and should instead be interpreted as incremental learning (Oppenheim, Dell & Shwartz, 2010; Schnur, 2014). [2]

Cumulative Semantic Interference in Children

While there is a large body of research that examines how cumulative semantic interference manifests in adults (Howard et al., 2006; Oppenheim, Dell & Shwartz, 2010;

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[2] Oppenheim, Dell and Shwartz (2010) proposed a lexical model that integrates error-based learning, but does not require competition. They conceptualize lexical selection as a race between potential targets that leads to selection when one target crosses the activation threshold. This selection doesn't become more or less difficult based on the number or strength of other potential targets in the race. This differs from Howard and colleagues' (2006) view that hinges on multiple competitors causing selection to become more difficult. However, it was concluded that the underlying mechanism of cumulative semantic interference was incremental learning.

Schnur, 2014), this is not the case for children. This gap invites further investigation since CSI has the potential to offer a window into an integral learning process – how children strengthen or change their representation of words and the role of speaking experiences in these changes.

While there is not an extensive literature investigating cumulative semantic interference, there are some studies that offer information. Charest (2017) examined whether or not cumulative semantic interference is observed in 3-year-old children during a continuous naming task. Children named two sets of images: 28 animal images (semantically homogenous) and 28 images from 10 various categories (semantically heterogeneous). Within each block, 28 items appeared one time each without repetition. Reaction times for the two conditions were similar at the start of the set, but increased across trials with a greater increase in the semantically homogenous set. This suggests that children experienced greater growth of interference when the categories were semantically homogenous than when they were mixed. The results demonstrated that children as young as 3 years old do exhibit cumulative semantic interference and suggested that incremental learning may account for interference effects across development. However, while the results reported by Charest support the conclusion that preschool aged children experience cumulative semantic interference in naming, the key manipulation that supports the learning perspective was not included in the study, namely the observation of interference between non-contiguous items.

Charest and Baird (2019) examined cumulative semantic interference effects using methodology that not only demonstrated interference, but cumulative effects as well. The study examined cumulative semantic interference in 8-year-old children using methodology that aligned closely with the Howard and colleagues (2006) study. Children named 90 coloured images presented in 6 blocks of 15. The list was comprised of 6 exemplars from 12 semantic categories and 18 fillers. The list was also structured to include 2 to 8 intervening, unrelated items between related target items. The results showed a linear increase in reaction time within semantic sets as a function of ordinal position. This suggests not only that school aged children demonstrate cumulative semantic interference, but that it is durable to non-contiguous items. The results provide support for an incremental learning account.

More research is required to examine whether or not there is developmental continuity in the effects of cumulative semantic interference. It has been clearly shown in adults that cumulative semantic interference persists even when there are non-contiguous items intervening, and the data from Charest & Baird (2019) point to these effects in school-age children. However, is this the case for very young children? The purpose of the current study was to further investigate the manifestation of these effects in preschool-aged children.

Charest (2017) conducted the first published study to examine the effects of cumulative semantic interference using a continuous naming task with children; that is a task that requires a single naming response for each stimulus item. However, several other studies have examined cumulative semantic interference in children from a different perspective (Snyder & Munakata, 2013; Ladányi & Lukács, 2016; Boelens & La Heij, 2017). They used a blocked cyclic naming paradigm, which differs from continuous naming. Blocked cyclic naming requires participants to name a small set of items, repeating a set several times within a block, rather than naming different items successively. These blocks are composed of semantically homogeneous sets or mixed sets. The typical finding in the adult literature (Schnur, Schwartz, Brecher & Hodgson, 2007; Belke & Stielow, 2013) is that there is a growing difference in response latencies between the semantically homogenous sets and mixed sets. Successive cycles of naming mixed sets show increasingly faster reaction times, which indicates repetition priming. When all items come from the same semantic set, responses do not get faster across trials, which can be interpreted as interference from the semantic set competing with facilitative effects of repetition.

Snyder and Munakata (2013) utilized the blocked cyclic naming paradigm to investigate whether interference effects were observed in 6-year-old children. Their results demonstrated that children show a robust interference effect using the blocked cyclic naming task. This effect occurred in the semantically homogeneous set, which supports that it is more difficult to name objects when they are semantically related. Additional studies using blocked cyclic naming with children have also found that response times are slower when naming the semantically homogeneous set (Ladányi & Lukács, 2016; Boelens & La Heij, 2017). These results paired with results from continuous naming tasks support that cumulative semantic interference does occur in children.

Researchers, however, have argued that blocked cyclic naming involves top down strategic processing and modulation of levels of activation of the word representations making it a less straightforward measure of cumulative semantic interference than continuous lists (Belke & Stielow, 2013). Belke & Stielow (2013) demonstrated a selective role for working memory and top down processes in blocked cyclic naming tasks but not continuous naming tasks. Therefore, the two paradigms may actually rely on different cognitive processes. Arguably, the continuous list method is better suited as a measure of learning or experience-driven change in lexical representations because it does not require top down processing and more closely simulates natural language use.

To summarize, there is evidence that children exhibit cumulative semantic interference, however we do not know whether or not this phenomenon occurs when there are intervening, non-contiguous items present in very young children. This distinction is important because in order for the learning perspective to be supported, there needs to be evidence that children exhibit cumulative semantic interference with intervening, non-contiguous items. Therefore, it is worthwhile to examine the presence of cumulative semantic interference with this key manipulation using the continuous naming paradigm.

Predictors of Individual Differences in Cumulative Semantic Interference

There may be some significant differences in computational capacities between children and adults (McDaniel, McKee, & Garrett, 2010) and the process of accessing target words may be more susceptible to disruption overall in young children than adults (Budd, Hanley, & Griffiths, 2011). Despite these differences, the evidence, where available, leans more towards similarities than differences in the language processing systems of children and adults (Rosinski, 1977; Jerger, Martin & Damian, 2002; McDaniel, McKee & Garret, 2010). Additionally, given the prior evidence based on Charest (2017) and Charest and Baird (2019), we hypothesized that children will demonstrate cumulative semantic interference across non-contiguous items. However, there may be individual differences that modulate the degree to which this interference is experienced. This could provide additional insight into the potential mechanisms involved. In particular, we identified three potential modulators: vocabulary size, conceptual organization and inhibitory control.

Vocabulary. As previously mentioned, if a target word is clearly more activated than potential competitors, selection is quick and easy. If a child had a smaller vocabulary, there would be fewer potential competitors. This may lead to a faster selection for production. However, if there are several potential competitors, selection becomes more effortful and takes longer (Thompson-Shill et al., 1997). Therefore, children who have a larger or more developed lexical network may show the effect more clearly because there are more potential competitors interfering with selection. This would lead to an increase in interference.

Additionally, cumulative semantic interference is argued to be a learning effect rooted in adjustments to the connections between words and their semantic features (Howard et al., 2006; Oppenheim, Dell & Shwartz, 2010). This implies that there must be shared connections between words and semantic features in order for there to be interference. A child who lacked a developed lexical network may not have connections between certain words and their semantic features. For example, if a child named *apple, peach, banana* they would require lexical-semantic connections in their network that link all of those as fruit or sharing some semantic features in order for interference to manifest. If they are able to recognize the shared semantic feature of a category, it is likely they will experience interference. As more objects are named from the same category, interference will grow which results in slower response times during a continuous naming task.

Conceptual organization. CSI effects in children could be rooted in the nature of relationships that are relevant within children's lexicons. As previously noted, the effect observed in CSI is thought to rely, in part, on shared activation of lemmas (Howard et al., 2006). Concepts can have two different kinds of relations: similarity based on shared features or relationships based on co-occurrence in events or scenarios (Mirman, Landrigan & Allison, 2017). When concepts are grouped based on shared features this is a taxonomic relationship and when they are grouped based on co-occurrence it is a thematic relationship. In almost all previous CSI research with adults, stimuli have been related taxonomically. However, there is some debate surrounding whether children organize conceptual and lexical information taxonomically or thematically (Waxman & Namy, 1997; Ware, 2017). It may be the case that young children do not find taxonomic relationships salient. Prior studies with adults (Howard et al., 2006; Oppenheim, Dell & Schwartz, 2010; Schnur, 2014) have made use of taxonomic relationships between stimuli to investigate the effects of cumulative semantic interference. However, do children recognize taxonomic relationships and do these relationships affect word processing? It is important to consider how children use information to categorize items. Research suggests that there are developmental shifts in the relative significance of these grouping criteria during the preschool years (Ware, 2017).

The majority of studies examining children's categorization preferences presented the child with images and asked which one is most like the target, or which one goes best with the target. Research has generally found that children older than 7 years will sort objects based on their taxonomic characteristics, however younger children sort on another basis (Markman & Hutchison, 1984). Young children seem to show an overreliance on thematic characteristics, perhaps because they are simpler or more readily constructed than taxonomic characteristics.

However, a study by Ware (2017) found individual and developmental differences in preschooler's categorization within and across task contexts that were opposite to previous findings. Children aged 3, 4 and 5 years completed a task pitting taxonomic and thematic relationships against each other to see which they preferred. There was an accompanying knowledge task that required the children to explain why the objects went together to ensure they had sufficient knowledge of taxonomic and thematic relationships. There was a significant effect of age on thematic categorization. Fewer children, mostly 3-year-olds, exhibited taxonomic preferences. These results suggested that preschoolers focus increasingly on thematic relationships as they develop, with younger children less able to access relational information.

Another study found that children revealed no pervasive preference for either thematic or taxonomic relationships (Waxman & Namy, 1997).

Thus, it is still unknown whether or not children truly show a categorization bias and whether the bias favours taxonomic or thematic relationships. For the purpose of this study, it is important to determine whether or not taxonomic relationships are meaningful to children because if there is no evidence of cumulative semantic interference in children it is possible that this is due to the nature of the relationships being tested.

Inhibitory control. A child's ability to inhibit co-activated competitors must also be taken into account as it has been shown that inhibitory abilities are related to the ability to resolve competition between potential lexical targets. In a study of adults, Shao, Meyer and Roelofs (2013) examined the relationship between selective and nonselective inhibition and how it relates to the ability to name pictures during a picture-word interference task. Nonselective inhibition is used when all unwanted responses are inhibited and selective inhibition is used when a specific competing response has to be inhibited. In the study by Shao, Meyer and Roelofs (2013), participants were asked to name pictures while a distractor word was also present. This distractor word could either be semantically related or unrelated to the target picture. The results demonstrated that participants who were able to more effectively utilize selective inhibition performed better on the interference naming task than those who were not. Therefore, it might be expected that individuals with the ability to inhibit the competitors of a target word should also be faster at naming and potentially individuals who are better at inhibiting will show less cumulative semantic interference because they resolve the competition more quickly.

Thus, there are several potential contributors to cumulative semantic interference effects at the individual level that may impact the observed effects in different ways. The current study's primary aim was to establish the effect of cumulative semantic interference across non-contiguous trials in young children. The secondary aim was to document potential contributing factors to individual differences in the manifestation of the effect.

Summary and Implications

Based on the breadth of research that has examined cumulative semantic interference in adults, it is clear that the effect is relatively durable (Howard et al., 2006; Oppenheim, Dell & Schwartz, 2010; Schnur, 2014) and is likely the result of an incremental learning mechanism. However, there are limited studies that have examined how this effect manifests in children and this leaves a gap that must be filled by further research in order to provide important insights into lexical representation and processing in typical language development, and a foundation for future work with children with language disorders. There are potential implications provided by examining the effects of cumulative semantic interference. It is important to understand whether or not children experience cumulative semantic interference the same way as adults do as it speaks to the continuity of development. If there are differences between children and adults, are these differences in processing or representational structure? Additionally, cumulative semantic interference could provide an important window into refinements or changes in representational strength within a child's semantic network.

Hypothesis

The objective of this research project was to further investigate whether incremental learning account can be applied to cumulative semantic interference in children. This study examined whether young preschool-aged children showed cumulative semantic interference across non-contiguous responses, and explored the contribution of vocabulary size, inhibitory control and sensitivity to taxonomic or thematic relationships to observed effects. We hypothesized that there would be an effect of cumulative semantic interference and that each successive item from a semantically related set would be named more slowly, regardless of the non-contingent intervening items. It was also hypothesized that children would be sensitive to taxonomic relationships, but this task also explored if children had a preference for them over thematic relationships. Finally, it was hypothesized that children who had larger vocabularies would show greater effects of cumulative semantic interference because they are thought to be better word learners; while children with better inhibitory control would show reduced effects of cumulative semantic interference because they would be able to better inhibit those potential competitors.

Methods

Participants

Forty preschool aged-children (17 male, M_{age} = 3 years; 11 months, range 3;0 – 4;11) participated in this study. Participants were part of a larger, ongoing study examining how 3- to 6-year-old children's naming responses in a picture naming task are affected by recent experiences naming other related pictures. Recruitment occurred through flyer distribution, posters in facilities that parents and children frequent, shared through email lists and information/consent packages distributed to daycares. Children were eligible to participate if they were typically developing as determined by parent report, fell in a suitable age range and had English as their primary language. Participants were excluded if they had been diagnosed with a language delay/disorder or a condition that would affect language learning (e.g., autism, intellectual disability). Maternal education was obtained as a proxy for socioeconomic status. Five mothers reported completion of high school, 17 reported some or all of a college/university degree completed, 17 reported some or all of an advanced degree completed and 1 did not report their education level.

Procedure

Children participated in two experimental sessions, either at their daycare, or at the Language Development and Disorder Lab at the University of Alberta. The order of the tasks was constant across children so any potential fatigue or task crossover effects were constant across participants.

For children seen in the lab, the parent or legal guardian of the participant provided informed consent for the child before the experimental tasks began. The language background questionnaire was given to the parent or legal guardian to complete. If data collection occurred at a daycare or school, the parents were required to have completed a consent package, including the language background questionnaire, prior to the first visit. Verbal assent from the participants was also obtained.

In the first session, the child completed a familiarization task for the cumulative semantic interference naming task, then the CSI naming task, followed by the word association task and finally the Recalling Sentences subtest of the Clinical Evaluation of Language Fundamentals – Preschool 2 (Semel, Wiig & Secord, 2004). This task was used to further screen out any concerns of language disorders. The mean difference between children with language impairments and typical development on this task is substantial (1.78 SD, Semel, Wiig & Secord, 2004) and therefore unlikely that children with language impairments will score in the typical range. The Recalling Sentences subtest evaluated the child's ability to repeat verbatim spoken sentences of increasing length and complexity. Standard administration protocol was followed for this assessment. The average standard score on this subtest was 10.6 (range 8-18, *SD* = 2.4). Breaks were provided as needed throughout the session.

In the second session, the child completed the Expressive Vocabulary Test – 2 (Williams, 2007), followed by the Big-Little Stroop task (Wiebe et al., 2011; adapted from Kochanska et al., 2000). They then completed the final task, Shape School (Espy, 1997). Again, breaks were provided as needed. Descriptions of each experimental task are as follows.

Measures

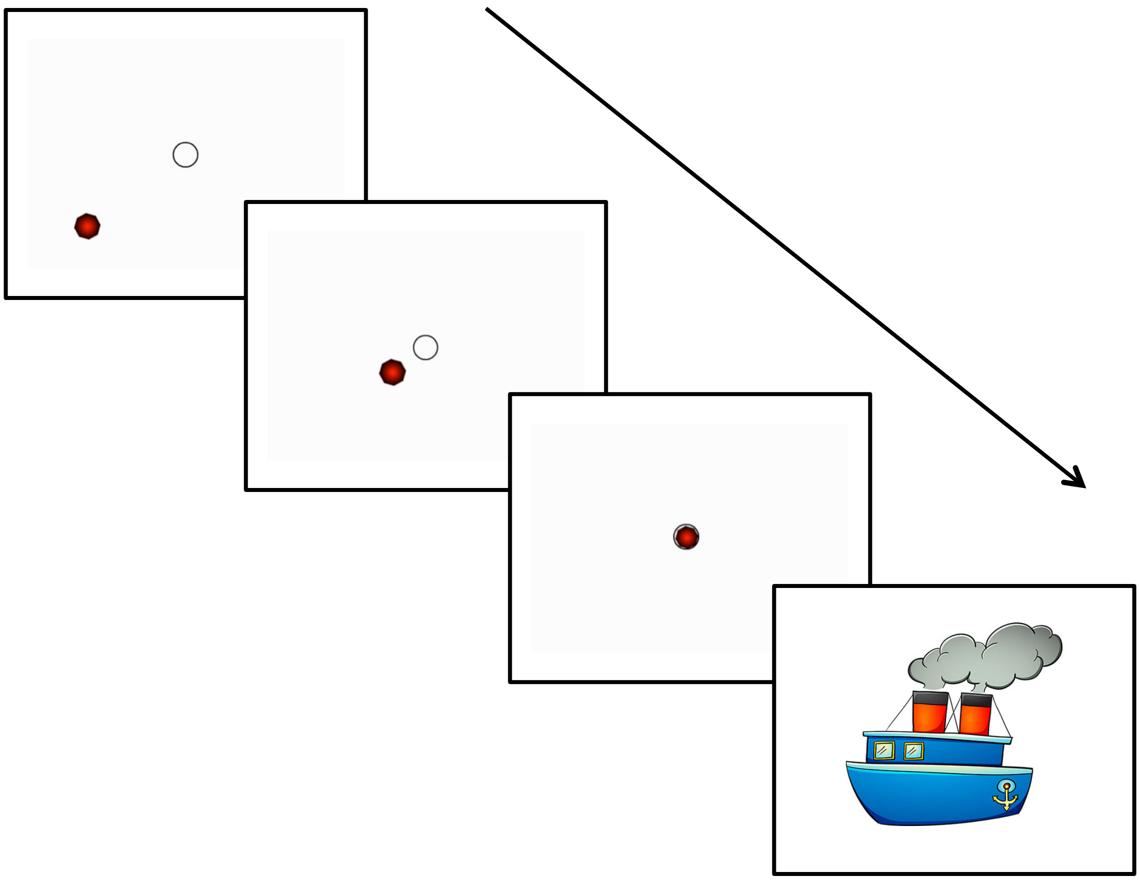
Cumulative Semantic Interference Naming Task. This task was used to assess cumulative semantic interference effects using a continuous list method.

Task description and administration. This task required children to name 100 coloured pictures of items from different semantic categories. Children named each picture once, without repetition. The stimulus list contained six exemplars from 12 different semantic categories (*four legged animals, fruits, insects, desserts, vehicles, celestial, furniture, body parts, clothes, tableware, birds, vegetables*), as well as 28 filler items (see Appendix A). To test for durable effects of cumulative semantic interference, the items from each semantic category were not presented successively. Rather, they were presented with 2, 4, 6, or 8 intervening, unrelated items between the target stimuli. For example, if a picture of cake was presented, a picture of a dog and then a bell would follow before another dessert item, such as a pie, was presented.

A list of 50 stimulus items was created that controlled for the number of intervening, unrelated items (2 or 4; 6 or 8) between related target items. The next 50 items were presented in the opposite order. This created a list with a total of 100 stimuli slots, with 72 experimental slots and 28 filler slots. We created 4 list orders that varied the assignment of semantic category to category position. Each list order was split into order ‘A’ for the first 50 items and ‘B’ for the next 50 items. Six semantic categories were presented in list A and the remaining six were presented in list B. Some categories were intentionally separated between the 'A' list or 'B' list because of potential semantic similarity (e.g., *fruits* and *vegetables* did not co-occur). Each semantic category was presented in order A and B equally. Each semantic category was also assigned to either the short lag category (2 or 4 intervening items) or the long lag category (6 or 8 intervening items). Each semantic category was presented with either short or long lags equally between the 4 potential list orders. The lists were constructed in order to minimize the confound between ordinal position within a semantic set and serial position. This allowed us to account for general fatigue effects in the analytic approach.

Children were familiarized to the stimulus items at the start of the task. Once familiarized, the children were instructed to name each picture on the computer as soon as they could. The cumulative semantic interference naming task began with two demonstration trials and three practice trials presented on a laptop computer. Within each semantic category, the order of presentation of the exemplars was randomized by the E-Prime software. Pictures were presented for naming one at a time, each preceded by an orienting cue lasting 1 second. As the images appeared on screen, an auditory tone accompanied the presentation. The picture appeared on the computer screen until the experimenter removed it from the screen after the participant's response. Children's naming accuracy and reaction time was recorded for each trial. The stimulus list was presented in 5 blocks of 10 images, with children receiving positive reinforcement (a happy face with the message "Great Job!!") after every block. Sessions were audio and video recorded for later transcription and analysis. The average response-stimulus interval (RSI) between trials was 1.97 seconds; between blocks of 10 trials the average RSI was 6.32 seconds. The total time needed for the naming portion of the task was approximately 3-8 minutes, with small breaks and encouragement at regular intervals and a longer break if needed at the halfway point.

Figure 2. Example of cumulative semantic interference naming task trial.



Transcription, scoring and reliability. Naming responses and RTs for the CSI naming task were recorded by 4 research assistants. Responses were scored as correct if they provided the correct label for the image or a reasonable synonym (e.g., *mitten* for *glove*). Responses were scored as incorrect if there were: (1) naming errors (e.g., *moose* for *cow*); (2) hesitations (responses preceded by 'uh' or 'ummmm); (3) revisions of part-words (e.g., *sss…moon*) or whole words (e.g., *hand… glove*) or (4) no response. Response times were manually measured using

Adobe Audition. The research assistant recorded the onset of the auditory tone presented with the image and the onset of the actual response. The difference between these values was used to calculate each RT.

Eight (20%) randomly selected sessions were transcribed by a research assistant and the author, recording the content and timing of the responses. The author and the author's supervisor independently scored those same sessions for whether or not trials were usable, and accuracy of the naming response. RT reliability was computed as the number of trials with less than 10 ms difference divided by the total number of computed RTs. RT reliability was 97% with an average difference of 8.8 ms between transcribers. For naming response and judgment of trials as usable or not, reliability was computed as the number of agreements divided by the total number of responses (out of 100 per participant). Reliability for content of the response was 99% (794/800). For judgment of a trial as usable or unusable, reliability was 99% (799/800) and for judgment of a response as correct or in error, as well as the type of error, reliability was 97% (781/800).

Word Association Task. This task was used to assess sensitivity to taxonomic versus thematic relationships.

Task description and administration. This task required children to look at coloured pictures and match the target image to one of three possible test items. There were a total of 36 trials, 12 of 3 different conditions. In one condition, the target item best matched with a test item that was related thematically (e.g., *dog* with *bone*) and in another the target item best matched with a test item that was related categorically (e.g., *dog* with *cat*). In the last condition, the target could potentially match with a thematically or categorically related item (e.g., *dog* with *cat* or *bone*). The stimulus list is included in Appendix B. Stimuli were presented on paper in a binder. Instructions were provided, but there were no familiarization or practice trials so to not bias the child's responses. Children selected the best match one at a time by either pointing or verbally indicating their answer. On select trials, children were asked to verbally provide a reason for their selection. We chose to prompt the child's response by asking, "*Which one goes best with ____?*" Research has shown that verbal instructions can bias categorization (Ware, 2017). Therefore, we tried to minimize categorization bias by using "goes with" phrasing as it is arguably more neutral than other potential cues such as "*Which one is like _____?*" This task examined if children are sensitive to pertinent relationships examined in the naming task.

Figure 3: Example of a categorical match trial (match is cow and horse).

Figure 4: Example of thematic match trial (match is spider and web).

Figure 5: Example of categorical and thematic match stimuli images (categorical match is dog with cat; thematic match is dog with bone).

Transcription, scoring and reliability. Each trial had a predetermined relationship that the participants had to identify. Each response was recorded as thematic, taxonomic or unrelated. These responses were used to inform a cumulative taxonomic and thematic score. Each of these scores were out of 24 as there were a total of 24 opportunities for either a thematic or taxonomic response. An additional score out of 12 was also computed which represented how often the participants chose either taxonomic or thematic responses when they had the option of choosing either. Eight (20%) randomly selected sessions were scored by a research assistant and myself. Reliability was computed as the number of agreements divided by the total number of responses (out of 36 per participant). Reliability was 98% (282/288).

Expressive Vocabulary Test – Second Edition (Williams, 2007). This task was used to assess the size of the children's lexical network.

Task description and administration. The EVT-2 is a standardized, norm referenced test of expressive vocabulary. Children were asked to name a series of coloured pictures using one word in response to specific prompts, until 5 consecutive items were scored as incorrect and the ceiling score was obtained. Standard administration protocol was followed for this assessment

Transcription, scoring and reliability. Standardized scoring procedures were followed for each participant. Eight (20%) randomly selected sessions were scored by a research assistant and myself. Reliability was computed as the number of agreements of raw score divided by the total number of raw scores. Reliability was 100% (8/8).

Big-Little Stroop (Wiebe et al., 2011; adapted from Kochanska et al., 2000). This task examined children's inhibitory control.

Task description and administration. This task required children to name smaller images embedded within a larger image, while inhibiting the name of the larger image. Before the test trials began, participants completed 10 trials to practice using the correct name for each stimuli in the task. Then they received instructions to only name the small shape and completed 4 additional trials to practice that rule. Feedback was provided during these trials. Once practice was completed, the experimental items were presented. The order of presentation of stimuli items remained constant across all participants. An auditory tone marked the beginning of the trials as the image appeared on the screen. The picture appeared on the computer screen until the experimenter removed it from the screen after the participant's response. Pictures were presented for naming one at a time in one continuous block until the children were done. Children viewed 20 line drawings of everyday objects containing smaller embedded pictures that either matched (see Figure 6) or conflicted (see Figure 7) in identity with these objects. Ten trials matched in identity and 10 conflicted. To prime the salience of the large shape, each trial was preceded by a brief presentation of the large shape. Children were asked to name the smaller embedded pictures. We measured the proportion of times that children correctly named the smaller, inset pictures rather than the larger distractor images.

Figure 6: Example of matching trial (small boats nested within a large boat).

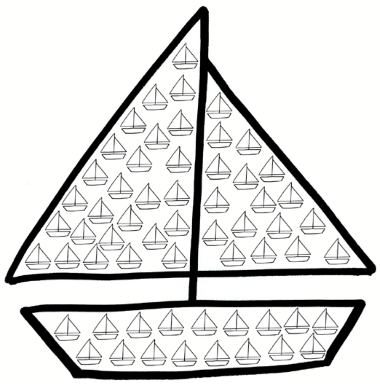
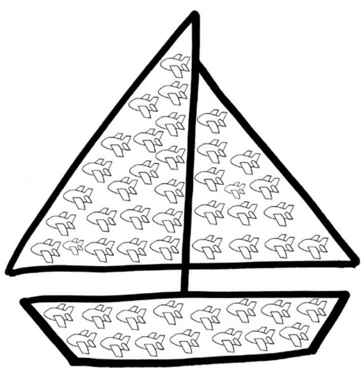


Figure 7: Example of a conflicting trial (small airplanes nested within a large boat).

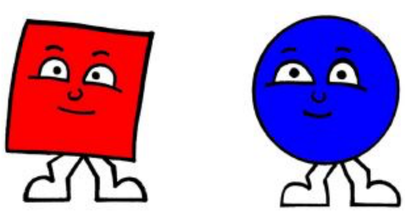


Transcription, scoring and reliability. Naming responses were coded by 2 research assistants. Responses were scored as incorrect if they named: (1) the big shape (e.g., *star* for *moon*); (2) both shapes (e.g., *stars and moons* for *moon*); (3) an unrelated item or no response (e.g., *butterfly* for *bunny*) or (4) self corrected (e.g., *tree…. no flower*). Eight (20%) randomly selected sessions were coded by a research assistant and myself for the content of responses. For naming responses, reliability was computed as the number of agreements divided by the total number of responses (out of 20 per participant). Reliability for the content of the response was 99% (158/160). For judgment of a trial as correct or in error, reliability was 98% (156/160).

Shape School (Espy, 1997). This task examined children's set shifting and inhibition.

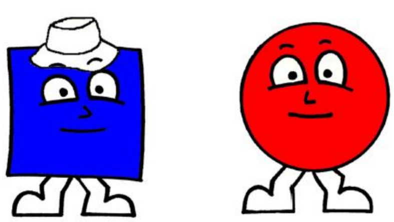
Task description and administration. Children were asked to shift their attention between an object's shape and colour. The stimuli were presented as red and blue circle and square students attending Shape School. Children are asked to call the students' names so they will line up before they attend lunch, recess, gym, etc. Children completed a practice condition to learn the naming rules before each testing condition. In condition A, children were presented only with the shapes wearing hats and asked to name them by their colour. In condition B, children were presented only with shapes that were not wearing hats and asked to name them by their shape. In test condition C, children were presented with children who are wearing and not wearing hats, so the children had to switch between naming by colour and by shape. In test condition D, children were asked to name children with happy faces, but not name children with sad faces. See Figures 8, 9 and 10 for examples of stimuli.

Figure 8: Example of colour condition stimuli.



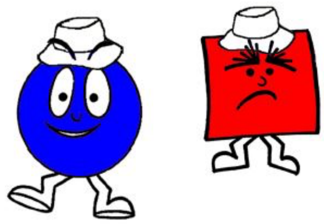
Red Blue

Figure 9: Example of shape condition stimuli.



Square Circle

Figure 10: Example of inhibit condition stimuli.



Happy Sad

Transcription, scoring and reliability. Condition A and B were both scored out of 12 and a time was recorded for how long it took the child to complete the condition. Eight (20%) randomly selected sessions were scored by a research assistant and myself. For responses, reliability was computed as the number of agreements divided by the total number of responses (out of 24 per participant). Reliability for the judgment of a trial as correct or in error was 100% (192/192). An additional switch score was provided as either 1 or 0 which represented whether or not they were able to switch the naming rules between Condition A (naming by colour) and Condition B (naming by shape). Condition C and D were not scored or included in this analysis as only 41% of participants completed Condition C and 49% of participants completed Condition D.

Statistical Methods

Primary hypothesis. Two regressions using linear mixed effects modeling were used to answer the primary research question of whether or not children exhibit cumulative semantic interference effects across unrelated trials. A linear mixed effects approach simultaneously accounts for fixed and random effects, so it accounts for random noise and error attributed to subject and items (Baayen, Davidson & Bates, 2008). This approach also allows for multiple observations per participant, which avoids aggregation. Both regressions were completed using R (R Core Team, 2015) with the packages *lme4* and *lmerTest* (Bates, Maechler, Bolker &

Walker, 2015; Kuznetsova, Brockoff, & Christenson, 2017). The first analysis regressed accuracy on ordinal position and lag category (2 or 4 unrelated items between related, or 6 or 8 unrelated items between related), and included trial number as a main effect to control for general fatigue. The second analysis examined the same independent variables, but examined their effect on response latencies.

Secondary hypothesis. Separate analyses were run to test the secondary research question – what factors impact cumulative semantic interference effects in children. This analysis was completed using Stata 12 software (StataCorp, 2011). This analysis examined whether vocabulary scores, conceptual organization and inhibitory performance predicted interference at the individual level. Individual slopes for accuracy and reaction time across ordinal position within a semantic set were obtained for each child using linear mixed effects modeling in R (R Core Team, 2015) using the same packages as the primary analysis.

Results

Analyses of Accuracy and Latencies

Accuracy. Three participants were removed from the data set due to low accuracy (more than 2 SD below the mean). For the remaining 37 participants, there were 2557 experimental trials available for analysis after the removal of unusable and filler trials. Of these, 382 (14.9%) were scored as errors; overall naming accuracy on the CSI naming task was 85.1%. Figure 11 presents the percentage of errors per ordinal position.

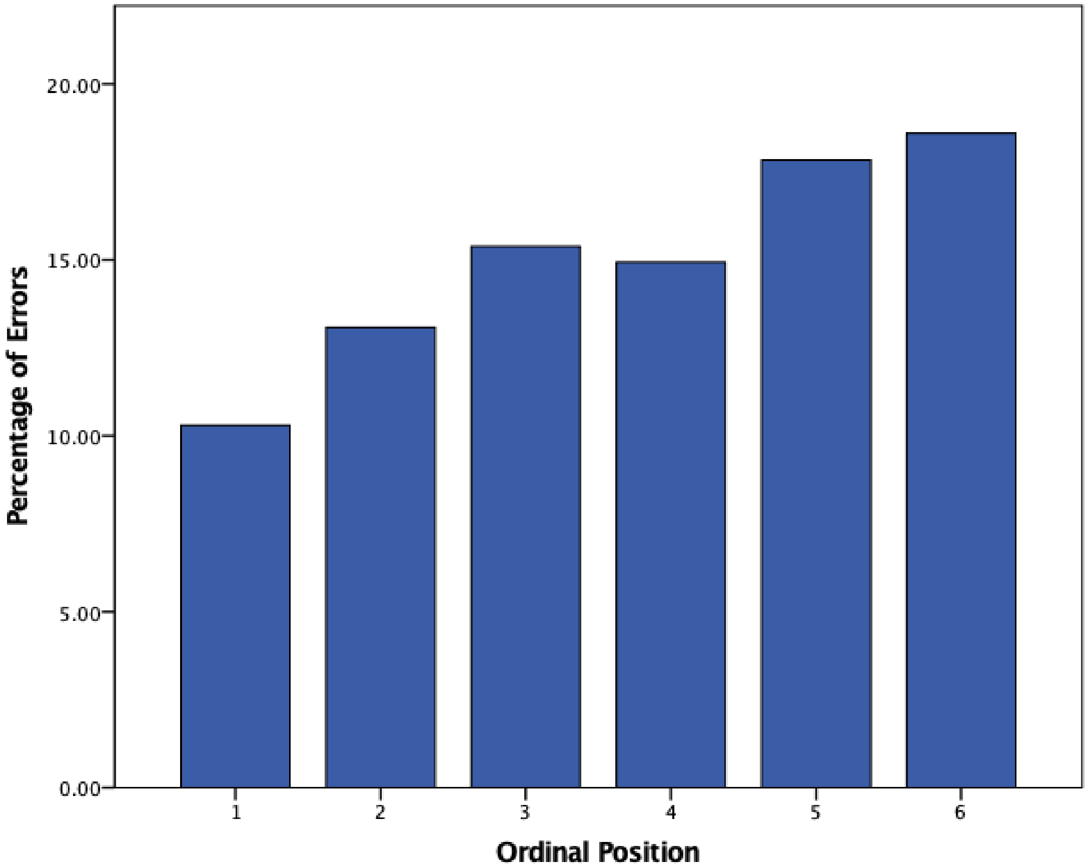


Figure 11. Percentage of errors during the cumulative semantic interference naming task by ordinal position within a semantic set.

Table 1. Errors by ordinal position on cumulative semantic interference naming task.

Ordinal Position	Hesitation Errors (%)	Revision Errors (%)	Naming Errors (%)	No Response Errors (%)	Total Errors (%)
1	9 (2.11)	14 (3.28)	16 (3.75)	5 (1.17)	44 (10.30)
2	12 (2.80)	9 (2.10)	22 (5.14)	13 (3.04)	56 (13.08)
3	15 (3.50)	17 (3.96)	22 (5.13)	11 (2.56)	66 (15.38)
4	7 (1.66)	7 (1.66)	29 (6.87)	20 (4.74)	63 (14.93)
5	17 (3.99)	16 (3.76)	31 (7.28)	11 (2.58)	76 (17.84)
6	21 (4.94)	14 (3.29)	32 (7.53)	12 (2.82)	79 (18.59)
All Data	81 (3.17)	77 (3.01)	152 (6.02)	72 (2.82)	382 (14.94)

The linear mixed effects models examined the effects of ordinal position, lag condition (short vs. long) and trial on naming accuracy. Generalized linear mixed effects models were utilized and models were compared on the basis of the Akaike Information Criteria (AIC) and likelihood ratio (X^2), starting with the most complex model. If the removal of a predictor resulted in a significantly worse model fit, then the predictor was retained. If there was no significant difference, the simpler model was preferred and the predictor was removed. Predictors were systematically removed until the preferred model was indicated. For all linear mixed effect analyses, model comparisons for random effects were computed using Restricted Maximum Likelihood Estimates (REML). Comparisons involving fixed effects were computed using Maximum Likelihood Estimation (ML). For these analyses, trial number was centered with Trial 1 as the intercept, and ordinal position was centered with Word 1 as the intercept. Table 2 presents the model outcomes.

Table 2. Summary of LME models of accuracy.

Model	**Fixed Effects**	**Random Effects**	**AIC**	**Comparison**	X^2(*df*)	**p**
Generalized Effects Model Comparisons (fit with REML)						
m1	Ordinal Position *Lag Condition + Trial	Ordinal Position | Participant	1907.1			
m2	Ordinal Position *Lag Condition + Trial	Random intercepts only	1908.7	m1	5.58(2)	0.06
Generalized Effects Model Comparisons (fit with ML)						
m2	Ordinal Position *Lag Condition + Trial	Random intercepts only	1908.7			
m3	Ordinal Position + Lag Condition Category + Trial	Random intercepts only	1906.8	m2	0.14(1)	0.70
m4	Ordinal Position + Trial	Random intercepts only	1905.3	m3	0.45(1)	0.50
m5	Ordinal Position	Random intercepts only	1905.5	m4	2.24(1)	0.13
m6	None	Random intercepts only	1917.7	m5	14.2(1)	<0.001

Note: All models included random intercepts for participants and items.

First, a series of models were tested to determine which random effects were required. Table 2 summarizes the model comparisons. The first model (m1) contained the fixed interaction effect of ordinal position and lag, as well as the main effect of trial. The random effects structure contained the intercepts for participants and items, as well as random slopes for ordinal position by participant. The next model (m2) tested for the removal of the random slope. The removal of the random slope did not significantly worsen the fit of the model, therefore only the random intercepts were retained (m2). The fixed effects included in the initial model were the interaction effect of ordinal position and lag condition, as well as the main effect of trial. We first tested the removal of the interaction term. This did not result in a significant decrement in model fit, and thus the interaction term was not retained. The model was further simplified by removing the fixed main effect of lag condition. Again, the simpler model was retained, as the removal did not result in a significant decrement in model fit. The main fixed effect of trial was then removed, which also did not significantly decrease the model fit and was therefore not retained. The final model removed the main fixed effect of ordinal position. The removal of the main effect of ordinal position did result in a significant decrement in model fit, so it was retained in the final preferred model (m5). Coefficients for this model predicted a decreased likelihood of a correct response (b = -0.14, SE = 0.04, p<0.01) for each ordinal position within a semantic set.

Naming errors. Naming errors were further analyzed at a descriptive level for the types of errors produced and whether or not the error reflected content from a previous trial. Errors were coded as semantically related if the response was part of the same semantic category as the target (e.g., *butterfly* for *caterpillar*) or if they named the semantic category of the target (e.g. *clothes* for *shirt*). Errors were coded as thematically related if the response was related to the target through theme or function (e.g., *park* for *slide*). Errors were coded as perceptually related if the response looked like (e.g., *ball* for *tomato*) the target. Some errors had no relation to the target (e.g., *hot* for *cucumber*) or were incomplete/unintelligible responses (e.g., *pah* for *pear*).

The majority of naming errors were semantically related (79.6%). Thematically related naming errors accounted for 6.6% of errors, perceptually related naming errors accounted for 1.3% and 12.5% of responses had no relation to the target. Of all naming errors, 37.5% (57/152) were previously named or presented trials. A summary of the types of naming errors observed is available in Table 2.

Table 3. Types of naming errors.

Ordinal Position	**Semantically related naming error**	**Thematically related naming error**	**Perceptually related naming error**	**No relation**	**Total Naming Errors**
1	14	0	1	1	16
2	19	2	0	1	22
3	17	0	0	5	22
4	23	4	0	2	29
5	26	1	1	3	31
6	22	3	0	7	32
All Data	121	10	2	19	152

Response Latencies. After removing the error trials (384), 2173 observations remained. An additional 2 observations were discarded due to difficulty obtaining the reaction time. The remaining trials with RTs that were more than 2.5 SD above the mean for the ordinal position (Word 1-6 within semantic set) were removed as outliers. A total of 72 (3.3%) RTs were discarded, leaving 2099 observations for analysis. Figure 12 presents the observed mean response latencies by ordinal position.

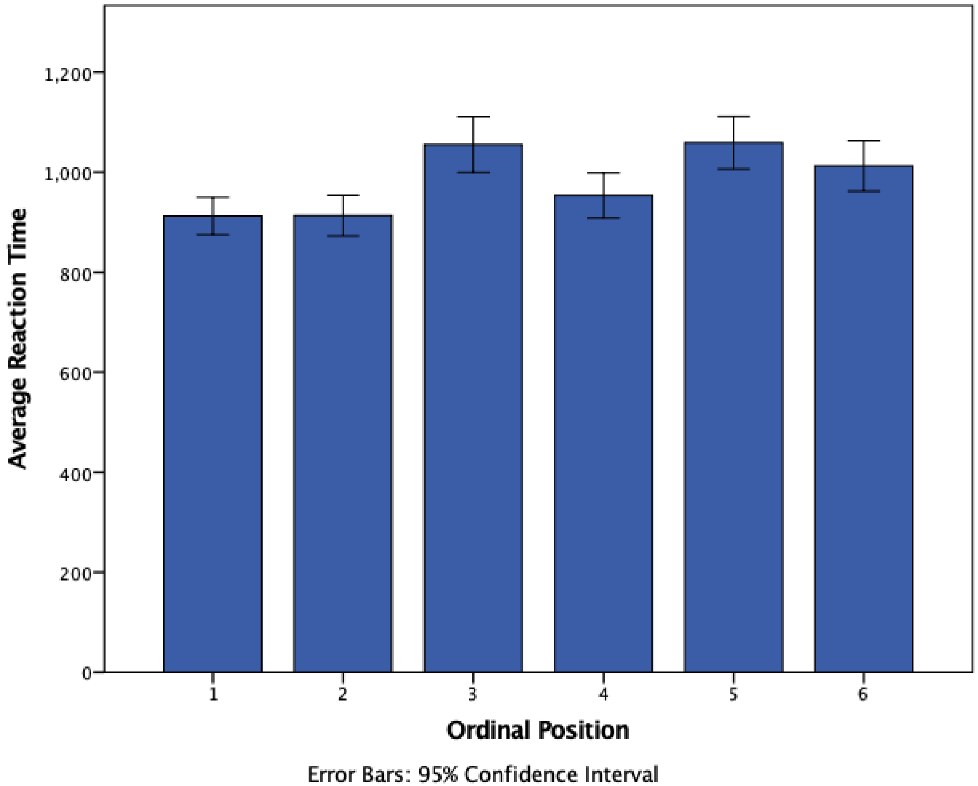


Figure 12. Mean observed reaction times (ms) during the cumulative semantic interference naming task by ordinal position within a semantic set. Error bars represent 95% CI.

Table 4. Reaction times by ordinal position.

Ordinal Position	***N* Observations**	**Mean RT (ms)**	**Standard Deviation**	**Minimum**	**Maximum**
1	370	966.28	301.46	527	2205
2	362	991.06	306.17	553	2231
3	350	1120.52	464.83	440	3011
4	343	1023.62	332.06	534	2328
5	341	1125.58	411.15	578	2873
6	333	1093.19	386.315	591	2710
Total	*2099*	*1051.65*	*375.56*	*440*	*3011*

In order to examine the effects of trial, ordinal position and lag on response latencies, linear mixed effects models were used. The same approach was used to compare models and determine the preferred model. Table 5 presents the model outcomes.

Table 5. Summary of LME models of response latencies.

Model	Fixed Effects	Random Effects	AIC	Comparison	$X^2(df)$	p
Random Effects Model Comparisons (fit with REML)						
m1	Ordinal Position *Lag Condition + Trial	Ordinal Position | Participant	30538			
m2	Ordinal Position *Lag Condition + Trial	Random intercepts only	30535	m1	0.26(2)	0.88
Random Effects Model Comparisons (fit with ML)						
m2	Ordinal Position *Lag Condition + Trial	Random intercepts only	30560			
m3	Ordinal Position + Lag Condition + Trial	Random intercepts only	30559	m2	0.49(1)	0.48
m4	Ordinal Position + Trial	Random intercepts only	30557	m3	0.10(1)	0.75
m5	Ordinal Position	Random intercepts only	30578	m4	23.2(1)	<0.001
m6	Trial	Random intercepts only	30571	m4	15.8(1)	<0.001

Note: All models included random intercepts for participants and items

The model comparisons began with determining the random structure. Table 5 summarizes the model comparisons. The first model (m1) contained the fixed interaction effect of ordinal position and lag, as well as the main effect of trial. The random effects structure contained the intercepts for participants and items, as well as random slopes for ordinal position by participant. The next model (m2) tested for the removal of the random slope. The removal of the random slope did not lead to a significant difference, therefore only the random intercepts were retained.

The fixed effects included in the initial model were the interaction effect of ordinal position and lag, as well as the main effect of trial. As with the accuracy analysis, the following models were further simplified and compared to the more complex model. The interaction term was removed first. Upon comparison, the simpler model was preferred, as the removal of the interaction term did not result in a significant decrement of fit. The model was further simplified by removing the fixed main effect of lag. Again, the simpler model was preferred. The following models tested for the removal of trial first and then ordinal position. When either the main effect of ordinal position or trial were removed it resulted in a significant decrement to model fit, therefore both main effects were retained.

The final preferred model (m4) contained fixed main effects of ordinal position and trial. Coefficients for this model indicated a predicted response latency of 954.56 ms (SE = 29.18) at the beginning of the experiment (Trial 1). There was a predicted slowing of 1.3 ms per trial (SE = 0.28, p <0.001). There was a predicted slowing of 18.94 ms for each ordinal position within a semantic set (SE = 4.76, p < 0.001).

Analyses of Child-Driven Factors

Additional Predictor Tasks. Table 6 provides a summary of the descriptive statistics for the predictor tasks. As Condition C and D of Shape School were not completed by the majority of participants, a score measuring rule switching was derived from Condition A and B. If a child successfully switched from naming colours in Condition A, to naming shapes in Condition B they demonstrated rule switching and the ability to inhibit prior naming rules. Of the 32 children that completed Condition A and B, 91% (29/32) switched naming rules and 9% (3/32) did not.

Table 6. Summary of scores on additional tasks.

Observed Variable	% (n/total)	Mean	Standard Deviation	Minimum	Maximum
EVT-2 Standard Score	100 (37/37)	110.08	13.27	88	138
EVT-2 Raw Score	100 (37/37)	56.03	12.67	30	88
Big Little Stroop Accuracy (all trials)	97 (36/37)	0.77	0.22	0.2	1
Big Little Stroop Accuracy (incongruent trials)	97 (36/37)	0.63	0.34	0	1
Word Association – Taxonomic Proportion	100 (37/37)	0.23	0.13	0	0.58
Word Association – Thematic Proportion	100 (37/37)	0.70	0.20	0.08	1.00

Slope Values. The purpose of these analyses was to provide a term to capture the individual differences in susceptibility to cumulative semantic interference. The slope values captured this difference. Separate linear mixed effects models were created to generate individual slopes for accuracy and reaction time from the cumulative semantic interference naming task. This was done by adding a slope term (e.g., Ordinal Position | Participant) back to the random structure of each of the final preferred models and extracting the predicted slope by using the *coef* function. For the accuracy model, this generated an individual value for each participant that indicated the change in the likelihood of a correct response as ordinal position increased. For the response latency model, this generated an individual value for each participant that indicated the degree of slowing as ordinal position increased. Table 7 summarizes the descriptive results. We noted that the linear mixed effects models indicated that random slopes for ordinal position by individual participant were not needed, suggesting there was not sufficient variability between participants to be included in the model. It should be noted, however, that there is more variability to explain for accuracy than there is for reaction time as the p-value contributing to the decision of whether or not to retain the slope approached significance (p =

0.06). Despite the lack of significant variability, based on our a priori plans, we conducted follow-up exploratory analyses to better understand the potential roles of age, categorization, vocabulary, inhibition and set shifting on cumulative semantic interference accuracy and response latencies. While the slope terms were not significant, inclusion of these slope terms when re-running the models returned the same pattern of significant effects as were observed in the primary analyses models. It should also be noted that these models were rerun with the final fixed effects and the slopes and the main fixed effects were still significant in both models.

Table 7. Descriptive results for slope values.

Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
Accuracy Slope	37	-0.12	0.10	-0.36	0.073
Reaction Time Slope	37	18.91	2.80	13.69	24.36

Univariate Analysis. A linear regression approach was taken to determine which independent variables had an effect on the dependent slope values for accuracy and response latencies. Table 8 details the variables that were significant and not significant in the separate univariate analyses. Additionally, Appendix C presents the correlations among the variables.

Table 8. Univariate analysis for individual accuracy slopes and response latency slopes.

Predictive Factor	Accuracy			Response latency		
	n	Coefficient (95% CI)	p	n	Coefficient (95% CI)	p
Age (in months)	37	-0.003 (-0.008, 0.003)	0.34	37	0.16 (0.007, 0.31)	0.04*
Taxonomic Naming Score	37	-0.16 (-0.41, 0.09)	0.21	37	-1.59 (-8.82, 5.63)	0.66
EVT-2 Raw Score	37	0.003 (0.001, 0.006)	0.02*	37	0.03 (-0.05, 0.10)	0.47
Big Little Stroop Accuracy	36	0.030 (-0.072, 0.131)	0.56	36	-0.72 (-3.59, 2.14)	0.61
Shape School Switch	32	0.063 (-0.066, 0.192)	0.33	32	2.51 (-0.89, 5.91)	0.142

The EVT-2 raw score was the only predictor significantly associated with individual slopes for accuracy. There was a positive relationship between the EVT-2 raw score and accuracy slope. Figure 13 presents accuracy slopes as a function of EVT-2 raw scores. While the mean accuracy slope (-0.12) indicates overall that accuracy decreased as ordinal position increased, the rate of decline became less steep as vocabulary scores increased (b = 0.003, p = 0.02). For example, the predicted accuracy slope for children with an average vocabulary was -0.12, which indicates as ordinal position increases, accuracy decreases by approximately 12%. The predicted accuracy slope for children with an EVT-2 raw score one standard deviation above the mean was -0.08 and children with an EVT-2 raw score one standard deviation below the mean was -0.16. This indicates that children with a lower EVT-2 raw score, or in other words a less developed vocabulary, were more susceptible to CSI interference effects on naming accuracy, and therefore disproportionately higher error rates with each list item within a category.

Age (in months) was the only variable significantly associated with individual slopes for response latencies. There was a positive relationship between age and response latencies as well. Figure 14 presents the response time slope by age in months. The older the participant, the more reaction time increases as a function of ordinal position (b = 0.16, p = 0.04). For example, the predicted reaction time slope for children the mean age was 18.91 ms, which indicates that as ordinal position increases, reaction time increases by 18.91 ms. The predicted reaction time slopes for children who are one standard deviation above the mean was 19.86 ms and children who are one standard deviation below the mean age was 17.96 ms. This indicates that older children showed a greater amount of cumulative semantic interference than the younger children. A multivariate analysis was completed using backward stepwise regression to test for potential models for accuracy and response latency, however this resulted in the same relationships as outlined in the univariate analyses.

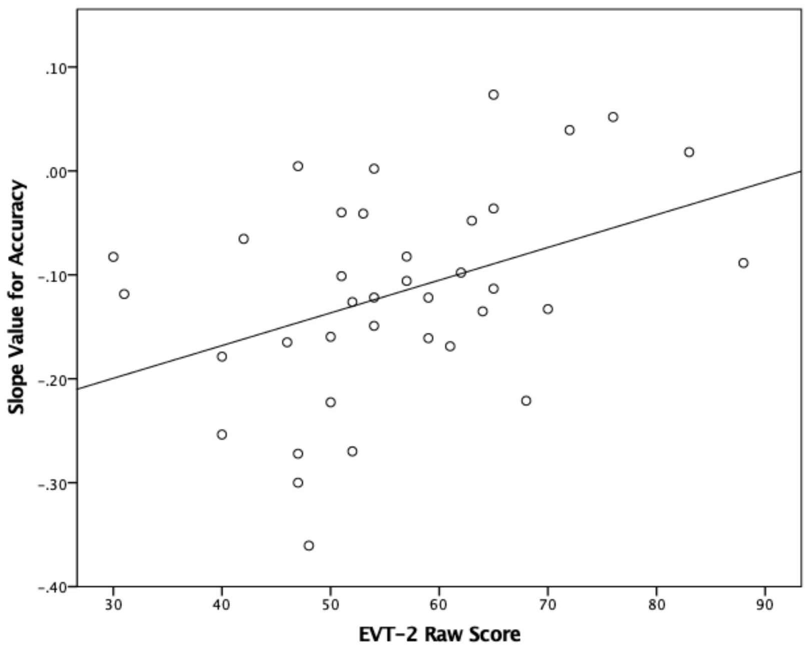


Figure 13. Relationship between the accuracy slope value on the cumulative semantic interference naming task and the EVT-2 raw score.

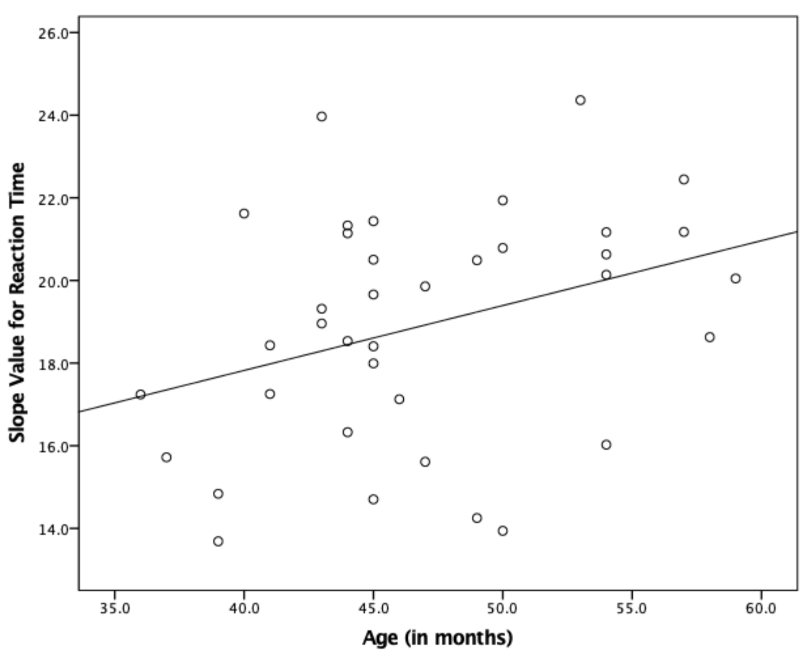


Figure 14. Relationship between the reaction time slope value on the cumulative semantic interference naming task and the participants' age (in months).

Discussion

The primary aim of this study was to examine whether cumulative semantic interference effects could be observed in preschool aged children using a continuous list method with intervening, unrelated items. Our primary hypothesis was supported by the results: robust cumulative semantic interference effects were observed in children as evidenced by decreased response accuracy and increased response latencies as ordinal position increased. Although our primary hypothesis had focused on increases in reaction time as a function or ordinal position, in this study, accuracy showed a robust effect as well. As more items from the same semantic category were named, interference arose not just in the form of slower reaction times, but as an increase in naming errors. The probability of a correct response significantly decreased as a function of ordinal position. This decrease was also independent of lag length, with equivalent increases for the short lag and long lag categories. The total number of errors nearly doubled from the first ordinal position to the last. As originally hypothesized, reaction times significantly increased as a function of ordinal position, which remained significant even when general effects that lead to slowing over the course of the task, such as trial, were accounted for. This increase was independent of lag length, with equivalent increases for the short lag (2 or 4 unrelated intervening items) and long lag (6 or 8 unrelated intervening items) categories. In our study, the magnitude of the overall cumulative semantic interference effects was consistent with the range of values previously reported for adults and older children. Our study clearly demonstrates robust cumulative semantic interference in young children.

Evidence for Incremental Learning

We examined CSI effects across intervening, unrelated items in order to address the question of whether cumulative semantic interference effects appear to be best explained as due to short-lived residual activation or as due to longer-lasting adjustments to connection strengths. If residual activation could account for these effects, we would expect to see the effects diminish when intervening, unrelated items were named. Instead, we observed a significant decrease in accuracy and a significant increase in reaction time as ordinal position increased, even with the presence of unrelated, intervening items. There was no apparent difference between short and long lags, as lag condition was not retained in the mixed effects models for accuracy or reaction time. This supports the incremental learning account reported in previous adult literature (Howard et al., 2006; Oppenheim, Dell & Schwartz, 2010). Every time a word is retrieved, connections between the target word and the activated semantic features are strengthened through incremental learning. This helps inform how the act of naming an object, and thereby retrieving a target word, has the potential to shape lexical representation in a developing language system. This indicates that cumulative semantic interference effects may be a fruitful method of understanding the robustness of a lexical network and the factors that influence these changes. This is important because it provides a window into the role of speaking experiences in word learning.

Relations to Adult Literature

There are a number of ways in which the findings point to continuities in lexical-semantic representations and processing between young children and adults. Evidence suggests that there are more similarities than differences in the language processing systems of children and adults (Rosinski, 1977; Jerger, Martin & Damian, 2002; McDaniel, McKee & Garret, 2010). This is reflected in the demonstration of cumulative semantic interference effects in young children, as well as adults. On average, children's reaction times slowed by 18.94 ms for each ordinal position. This result is within the range of previous adult findings, such as Belke and Stielow

(2013) who reported 12 ms, Schnur (2014) who reported 14.2 ms and Howard et al. (2006) who reported 30 ms, as well as previous child findings of 20.6 ms (Charest & Baird, 2019). The presence of these effects suggests that children experience incremental learning in a similar way to adults (Howard et al., 2006; Oppenheim, Dell & Schwartz, 2010; Schnur, 2014). According to Howard and colleagues (2006), in order for cumulative semantic interference to be observed, certain representations and processes are assumed to be required: shared activation amongst semantically related items, competition during selection and repetition priming which increases competition. If significant effects were not found, we would have to consider which factors might be responsible – representation (the connections that enable shared activation) or processes. However, the existence of interference effects suggests at least some degree of developmental continuity.

At the same time, there are important differences in computational capacities between young children and adults (McDaniel, McKee & Garret, 2010). Given these differences, it is perhaps not surprising that there are several differences between the reported performances on the naming task in the adult literature versus our findings. Response latencies significantly increased across ordinal positions for both groups, but there are differences in the average response time between adults and children. For example, Howard et al. (2006) reported a mean response time of 610 ms for ordinal position 1 and 735 ms for ordinal position 5. The participants in our study had a mean response time of 1119 ms at ordinal position 1 and 1365 ms at ordinal position 5. This is likely a reflection of differences in processing speed, a factor that substantially improves with age (Cepeda, Blackwell & Munakata, 2013). Processing speed has been shown to predict automaticity and fluency, two important factors in picture naming (Finkel, Reynolds, McArdle & Pedersen, 2005).

Robust differences in accuracy responses between the adult literature and our study were noted. Howard and colleagues (2006) examined whether or not errors increased with ordinal position in adults, but they found no evidence that ordinal position had an impact on number of errors. Schnur (2014) did not report any significant effects of ordinal position on number of errors either. This is in opposition to the results from our study, which indicated a significant increase in errors as ordinal position increased. Previous research has demonstrated that it is not unusual to find that children make errors where adults show effects in reaction time. Davidson, Amso, Anderson and Diamond (2006) examined children and young adult's performance on memory and inhibition tasks. They found that effects only seen in reaction times in adults were seen in accuracy in young children. In order to preserve accuracy, adults slowed down when they encountered difficult trials. Young children were more impulsive, which led to fewer accurate responses. Additionally, studies have shown that children have more fragile lexical networks and the processing of accessing target words is likely more susceptible to disruption in young children (Budd, Hanley & Griffiths, 2011). Young children do not have the same amount of retrieval practice as an adult lexical network, therefore the relatively fragile representations put under the stress of a competitive naming process would lead to an increase in retrieval errors. These findings indicate that this could be a fruitful method to better understand the factors that influence the changes that a lexical network undergoes from young childhood to adulthood.

Predictors of Individual Differences in Cumulative Semantic Interference

The secondary purpose of this study was to examine potential modulating factors in order to gain a better understanding of individual differences that could contribute to cumulative semantic interference. Our secondary hypotheses were partially supported as some modulating factors were identified, but not all that were originally hypothesized. We tested the inclusion of random slopes by ordinal position for participants, but the model outcomes (see Table 2 and 5) suggested that there was not sufficient individual variation in accuracy or response latencies to include the slope values in either model. However, part of our original research question was investigating potential factors that could influence cumulative semantic interference. When examining accuracy, the only significant predictor was vocabulary. The slope value indicates that accuracy decreases as ordinal position increases (-0.12). However, the slope became less negative as vocabulary scores increased (see Figure 13). This suggests that while accuracy is still decreasing as ordinal position increases, the better a child's vocabulary, the less interference they experience. It has been demonstrated that children with better receptive vocabularies perform better on naming tasks (Fowlert, Swainson & Scarborough, 2004). It has also been suggested that the stronger the connections are within a lexical network, the less vulnerable the system is to interference during lexical access (Gershkoff-Stowe, 2002). Therefore, it is not surprising that a child with a more developed expressive vocabulary would experience less interference, thereby displaying fewer naming errors. It is also worth noting that there was no observed tradeoff between improved accuracy and significantly slower reaction times, based on no observed correlation between the predicted slope values. The only significant predictor for reaction times was age. This suggests that the older a child, the slower their reaction times were as ordinal position increased. As children develop, their lexical networks mature towards an adult like organization (Wulff et al., 2019).

While two modulating factors were identified, not all that were originally hypothesized were. For example, inhibition was not indicated to be a significant predictor for accuracy or response latencies on the continuous naming task. It was hypothesized to be a modulating factor, as inhibition allows children to override stimulus-driven responses. If a child recently named an apple, when they see the next piece of fruit they must inhibit the potentially easier accessed word, apple, in order to access the correct target word. Inhibitory control is one of the earliest executive functions to appear, with initial signs observed in infants as young as 4 months (Johnson, 1995). Therefore, we had reason to suspect that it played an important role in cumulative semantic interference and that it would be observable in our sample, but this hypothesis was not supported. It is possible that inhibition does not modulate this effect, but there are several other potential interpretations of the limited effects observed.

It is possible that the measures used did not adequately index the abilities of interest. Young children can only be expected to complete a certain length or number of tasks. This means that when we tried to measure a construct, such as inhibition, we could only have them complete one to two tasks. This makes it difficult to know that the tasks chosen have tapped into the identified construct. If more measures of a construct were completed, a confirmatory factor analysis could be completed to try and identify a single latent factor. This would arguably be a stronger measure of inhibition than a single task and may have tapped into the observed individual variability for response latencies on the naming task. It is also possible that, as previously mentioned, there are other abilities that influence cumulative semantic interference that we did not consider. Additionally, the limited variability across participants in the cumulative semantic interference slopes likely made it difficult to identify predictors.

Taxonomic vs. Thematic Organization

The primary outcome of this study was to investigate the presence of cumulative semantic interference in preschool aged children and the secondary outcome was to investigate individual differences in those effects. An additional outcome of the study was further investigation of differences between conceptual organization categories. The results support the notion that children are sensitive to both thematic and taxonomic relationships. On the word association task, the proportion of thematic responses (0.73) was greater than the taxonomic responses (0.46), yet children were successful at identifying either relationship. In contrast, on the CSI naming task, the majority of naming errors (79.6%) were taxonomic in nature. This pattern of performance suggests that children may not show a distinct preference and that they have the capacity to access both types of relationships. Considering the different patterns observed between the CSI naming task and the word association task, it is possible that these differences arose as a result of the different ways these tasks assessed organization, with the word association task being explicit and the CSI naming task implicit. We attempted to examine lexical semantic relationships more directly through verbal fluency, but were unable to complete the task with the young children.

Rose and Abdel Rahman (2016) examined cumulative semantic interference in adults, but wanted to explore the influence of thematic relationships rather than the traditional taxonomic. They used a continuous list method that incorporated 2 to 8 lag items (Howard et al., 2006). The participants named 120 stimuli; 5 exemplars from 16 themes and 30 filler items. The results of their experiments demonstrated that robust cumulative semantic interference effects could be elicited using thematic relationships. As our study found robust effects in children using the traditional categorical relationships, examining cumulative interference using thematic relationships has the potential to provide new insights into lexical and conceptual organization in childhood. Further investigation of similarities and differences between taxonomic and thematic cumulative semantic interference effects in young children could offer more understanding of their lexical and conceptual processes.

Future Directions

In future work, it would also be interesting to further investigate how semantic categories influence the interference effects. Since we observed cumulative semantic interference in young children, it supports the notion that the categories are relevant to young children. However, it could be argued that some semantic categories are likely to produce stronger interference effects than others. For example, it stands to reason that four-legged animals may be a more developed construct than tableware as the average age of acquisition for the animal category members is 23.2 months, while tableware is 27 months based on Macarthur Bates Communication Development Inventories (Jørgensen, Dale, Bleses & Fensen, 2009).

Alario and Moscoso del Prado Martín (2008) extended the results of the Howard and colleagues (2006) study by examining the magnitude of effect across semantic categories. They found that cumulative semantic interference was present across categories, however there was a significant variability in the magnitude of these effects. The cause of the variation could be a result of category properties that influence lexical access. Items that are more similar in a category result in inhibitory effects while less similar could result in facilitative effects. The patterns observed by Alario and Mosocos del Prado Martín also suggested that a single grouping category was not sufficient to account for the interference effects. The pattern of cumulative interference cannot be captured by a single category. Rather, categories that evoke similar semantic features (e.g., winter clothing and summer clothing), known as co-categories, and categories that can be nested within a general category (e.g., winter clothing and summer clothing within the general category of clothing), known as supra-categories, play an important role in the pattern. For example, they grouped categories such as fruits with vegetables as well as farm animals with zoo animals. These were viewed as co-categories with potential supra-categories of food and mammals respectively. It was found that having a co-category earlier in the experiment affected naming latencies in a systematic fashion. We attempted to control for this by keeping categories that could be constructed as related (e.g., fruits and vegetables, clothing and body parts) separated as much as possible by including only one of the co-categories in the first half of the list and presenting the second co-category in the latter half of the list. However, it is difficult to completely avoid potential overlap or similarities from items within different semantic categories. Therefore, this type of analysis would be a worthwhile extension of this study not only because of the possible relationships between categories but because it could offer insights into the status of each category for these young children.

Additional future directions for research include examining the presence of cumulative semantic interference in children with language delays or disorders. Developmental language disorder (DLD) is a significant deficit in language that has no known biomedical etiology (e.g., neurological damage, hearing impairment, intellectual disability) (Bishop et al., 2017). As a group, children impacted by DLD often have marked deficits in lexical semantics and lexical learning. In general, they seem to use similar learning strategies as typically developing children, but not as efficiently (McGregor, 2017). They require more exposures and forget faster. This leads to knowing fewer words, as well as having less information associated with each word and fewer connections amongst those words (Brackenbury & Pye, 2005). Cumulative semantic interference effects could potentially offer more fine-grained insight into the categories and relationships that are relevant for children with DLD, as well as the potential difference in the extent to which naming experiences seem to impact changes in strength. The present study provides a foundation for future, clinically-oriented work in this area.

Conclusions

This study supports the application of the incremental learning account to cumulative semantic interference effects in preschool aged children. Patterns of cumulative semantic interference were reflected in both accuracy and response latencies, irrespective of intervening, unrelated lag items. Each act of naming an object results in a permanent, incremental adjustment in the weights of connections between words and semantic features within a child's lexical network. While we were unable to identify all the originally hypothesized individual modulating factors, the presence of vocabulary and age as predictor of cumulative semantic interference indicates that certain abilities and knowledge are being refined and that is contributing to the presence of these effects.

There are limitations of this study to be acknowledged, namely difficulty accessing lexical organization through verbal fluency tasks and constrained list construction. We were limited by the words that a 3-year-old could be expected to know, as well as keeping co-categories separated. However, notwithstanding these limitations, the results of this study provide a meaningful contribution to our understanding of changes to the representational strength of words within a child's lexicon. Future research should aim to continue exploring cumulative semantic interference across the aging developmental spectrum and try to identify predictors of these effects. Additionally, improvements in our knowledge of lexical semantic networks could provide a better foundation to understand and address the learning needs of children with language impairments.

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Appendix A: List of Words – Continuous Naming Task

4-legged animals: bear, cat, cow, dog, horse, pig
Fruits: apple, banana, cherry, orange, pear, strawberry
Insects: ant, bee, butterfly, caterpillar, ladybug, spider
Desserts: cake, candy, cookie, donut, ice cream, pie
Vehicles: airplane, boat, bus, car, truck, train
Celestial: cloud, moon, rainbow, snow, star, sun
Furniture: bed, chair, couch, lamp, stool, table
Body parts: ear, eye, foot, hand, mouth, nose
Clothes: dress, glove, hat, shirt, shoe, sock
Tableware: bowl, cup, fork, knife, plate, spoon
Birds: chicken, duck, flamingo, owl, peacock, penguin
Vegetables: broccoli, carrot, corn, cucumber, potato, tomato
Fillers: baby, balloon, bell, book, broom, hammer, heart, kite, ladder, pen, present, puzzle, slide, tent, ball, tree, dragon, sandwich, robot, crayons, scissors, candle, drum, clock, bone, flag, clown, phone

Appendix B: List of Words – Word Association Task
Words with a thematic relationship to the target word are *italicized* and words with a taxonomic relationship to the target item are underlined.

Horse: cow, box, tent
Dog: cat, *bone*, paintbrush
Bear: *forest*, puzzle, button
Apple: *worm*, kite, ladder
Banana: orange, *monkey*, hammer
Cherry: strawberry, robot, ball
Ladybug: caterpillar, book, comb
Spider: *web*, pencil, star
Bee: *honey*, ant, money
Ice cream: candy, scissors, piano
Cookie: *milk*, computer, castle
Cake: *candle*, pie, slide
Car: truck, *traffic light*, pig
Train: *track*, table, pear
Boat: airplane, backpack, fridge
Snow: *sled*, donut, alligator
Moon: sun, *rocket*, stove
Rainbow: cloud, house, tractor
Bed: *pillow*, chair, bell
Couch: stool, pumpkin, butterfly
Lamp: *light bulb*, elephant, bike
Nose: *flower*, telephone, key
Hand: foot, *mitten*, tree
Eye: mouth, bathtub, plant
Shirt: dress, *hanger*, whistle
Hat: *head*, dragon, clock
Shoe: sock, crayons, donkey
Knife: spoon, tape, dinosaur
Plate: *sandwich*, bowl, shovel
Cup: *water*, flag, helicopter
Chicken: *egg*, clown, glasses
Duck: *pond*, owl, skates
Flamingo: peacock, bat, pen
Carrot: *rabbit*, tomato, drum
Corn: broccoli, umbrella, paper
Potato: *fries*, crown, balloon

Appendix C: Correlation matrix for predictor variables included in the univariate analysis.

	Age (in months)	EVT-2 Raw Score	Taxonomic Naming Score	Big Little Stroop Accuracy	Shape School Switch
Age (in months)	1.00 n = 37	-	-	-	-
EVT-2 Raw Score	0.339* *p* = 0.04 n = 37	1.00 n = 37	-	-	-
Taxonomic Naming Score	0.103 *p* = 0.551 n = 36	0.134 *p* = 0.435 n = 36	1.00 n = 36	-	-
Big Little Stroop Accuracy	0.417* *p* = 0.011 n = 36	0.545** *p* = 0.001 n = 36	0.077 *p* = 0.654 n = 36	1.00 n = 36	-
Shape School Switch	0.288 *p* = 0.110 n = 32	0.325 *p* = 0.069 n = 32	-0.044 *p* = 0.814 n = 31	0.292 *p* = 0.111 n = 31	1.00 n = 32

Note: **. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).