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ARTICLE

Cumulative semantic interference across unrelated responses in school-age children's picture naming

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Abstract

Naming semantically related images results in progressively slower responses as more images are named. There is considerable documentation in adults of this phenomenon, known as cumulative semantic interference. Few studies have focused on this phenomenon in children. The present research investigated cumulative semantic interference effects in school-aged children. In Study 1, children named a series of contiguous, semantically related pictures. The results revealed no cumulative interference effects. Study 2 utilized an approach more closely aligned with adult methods, incorporating intervening, unrelated items intermixed with semantically related items within a continuous list. Study 2 showed a linear increase in reaction time as a function of ordinal position within semantic sets. These findings demonstrate cumulative semantic interference effects in young, school-aged children that are consistent with experience-driven changes in the connections that underlie lexical access. They invite further investigation of how children's lexical representation and processing are shaped by speaking experiences.

Keywords: cumulative semantic interference; picture naming; children; lexical access; vocabulary

Introduction

Language production research has revealed an important manifestation of experience-dependent change in lexical processing: when individuals name several pictures from within a semantic category (e.g., *dog-pig-cow-horse*), responses to later items are slowed (Howard, Nickels, Coltheart & Cole-Virtue, 2006; Schnur, 2014; Belke, Meyer & Damian, 2005). This phenomenon, cumulative semantic interference (CSI), is well-documented in adults and manifests as slowed responding in healthy adults and a rise in naming errors in adults with aphasia (Schnur, Schwartz, Brecher & Hodgson, 2006). In the continuous naming method reported by Howard et al., speakers named a series of pictures a single time each. Multiple semantic categories (e.g., farm animals, fruits, furniture) were embedded within the stimulus list, with unrelated items intervening among related items (e.g., *cow, bed, apple, horse, chair* etc.). The results revealed a linear slowing in response latency with each successive item from within a semantic set. The CSI effect does not depend on contiguous relationships between the related items, with the degree of slowing unaffected across two to eight intervening, unrelated items (hereafter *lags*; Belke & Stielow, 2013; Howard et al., 2006; Navarrete, Mahon & Caramazza, 2010, Experiment 1; Schnur, 2014). It is also unaffected by variations in the interval between a given response and the next stimulus item (response-stimulus interval; RSI; Schnur, 2014). That is, the prior related responses create interference in a manner that is cumulative and relatively persistent.

The CSI phenomenon has important application to understanding lexical processing in development and the role of speaking experiences in shaping processing. Crucially, based on the observed properties of the CSI effect, it is interpreted as a manifestation of relatively durable changes that occur with every naming response, rather than short-term interference from residual activation of prior responses (Howard et al., 2006; Oppenheim, Dell & Schwartz, 2010). That is, despite the fact that CSI manifests as a decrement in performance (i.e., slowing or naming errors), the effects are interpreted as a manifestation of experience-driven learning within the lexical system. Howard et al. (2006), for example, proposed that three properties together give rise to CSI: (1) competition during lexical selection in which activation of competing responses leads to a slower response time, (2) persistent repetition priming of previous responses (i.e., learning), and (3) shared activation of related items during lexical access, in which the target receives activation and semantically-related items also receive some (lesser amount of) activation. Howard et al. demonstrated CSI effects within a computational model that contained these features. The priming or learning element was modeled as strengthening of connections from semantic to lexical units of target items, that would then produce stronger competitors in a shared activation context. Building on the work of Howard et al., Oppenheim et al. (2010) described cumulative semantic interference as incremental learning, and further elaborated on the properties required to give rise to CSI. Oppenheim et al. also emphasized shared activation, changes in connection weights (i.e., learning), and competition, but modeled the competition in two ways: within a system in which competition occurred during lexical access (as in Howard et al.) and within a system in which the competition was located in the learning mechanism. In the competitive learning model, following a response, the semantic-to-lexical connections of the target (e.g., *pig*) were strengthened and connections from shared semantic features to related, non-target items (e.g., *horse*) were weakened, leading to greater difficulty activating and selecting the non-target item (e.g., *horse*) in turn. Thus, Oppenheim et al. proposed four properties needed to account for CSI: (1) shared activation, (2) activation-based selection time (i.e., words with more activation selected more quickly), (3) persistent priming of previous responses (i.e., learning), and (4) competition – possibly within lexical selection or possibly within the learning component.

In the present paper, we do not attempt to distinguish between the potential locations of the competitive mechanism, but instead focus more broadly on the view that CSI effects are a manifestation of experience-driven changes in the strength of connections within the lexical network (i.e., learning, shared between the Howard et al. (2006) and Oppenheim et al. (2010) accounts), and on the measurement of these effects in children. Childhood is not only a time of important changes in the size and content of the lexicon, but also, arguably, a time of varying susceptibility to retrieval errors (e.g., Booth & Vitkovitch, 2008; Budd, Hanley & Griffiths, 2011; Gershkoff-Stowe, 2002). Researchers have argued for the developmental importance of changes in the strength of connections to support efficient, successful lexical access. Gershkoff-Stowe (2002), for example, argued that competitive retrieval processes coupled with new and fragile representations lead to retrieval errors in young children; with Gershkoff-Stowe also proposed that increases in activation strength or connection weights within the lexical system, as a function of retrieval practice, play a role in retrieval improvements with age. Budd et al. (2011) demonstrated that age-related differences in school-age children's picture naming performance was captured by a model of linearly-increasing strength of semantic-to-lexical and lexical-to-phonological connections with age. Cumulative semantic interference effects, if they occur in children, offer the potential to index some of the small changes that may underlie larger-scale changes in connection strengths across development, and may invite new interpretations of retrieval challenges that have been observed.

Prior developmentally oriented studies have reported findings that call to mind aspects of the CSI phenomenon. Demonstrations of interference during naming in children have largely come from patterns of perseverative errors. For example, Gershkoff-Stowe (2001; 2002; Gershkoff-Stowe & Smith, 1997) reported a high rate of perseverative errors produced by toddlers in book sharing (picture naming) contexts. Both longitudinal (Gershkoff-Stowe, 2001) and cross-sectional (Gershkoff-Stowe, 2002) data revealed that these errors are particularly prominent in children undergoing the vocabulary spurt, with a lower rate of occurrence in somewhat older, post-spurt toddlers. In addition, Gershkoff-Stowe (2002) demonstrated that less familiar or unpracticed words were more susceptible to interference from prior responses. Gershkoff-Stowe argued that previously produced words may temporarily disrupt retrieval of a current target. Focusing on older children, Booth and Vitkovitch (2008) had 3-4 and 6-year-old children name a series of animal pictures. They reported a higher overall rate of error in the younger group, and almost twice as many within-list perseverative errors for the younger versus older group. In both of these studies, the majority of perseverations occurred as the repetition of the immediately preceding response; Booth and Vitkovitch additionally reported above-chance perseverations with one intervening response for their older group of children only. These studies both reported interference from prior, semantically related responses, but these effects were considered at the level of the individual trial, where interference patterns could also be interpreted as short-lived activation effects between contiguous responses. Growth in interference across trials was not examined, and learning-based accounts of the observed interference phenomena were not pursued.

Cumulative semantic interference studies with children

To our knowledge, there are four existing studies reporting on effects from the CSI framework in children. Three of these studies report interference effects using a blocked cyclic naming (BCN) approach. In the BCN approach, speakers repeatedly name small sets of pictures, alternating blocks of either semantically homogeneous items (e.g., *dog-pig-cow-horse*) or semantically mixed items (e.g., *dog-shirt-key-apple*). Adults demonstrate slower responding in the homogenous condition than the mixed condition, with the difference between conditions emerging in the second cycle of naming (Belke et al., 2005). Existing studies using the BCN paradigm have demonstrated interference effects in children from 5 to 12 years of age (Ladányi & Lukács, 2016; Snyder & Munakata, 2013; Boelens & La Heij, 2017). Snyder and Munakata demonstrated interference effects in 6-year-old children that were similar to those observed in adults, with the exception that the interference effects were present from the first cycle. The authors surmised that this earlier appearance of interference was due to the more extensive practice provided for their young participants. Ladányi and Lukács (2016) demonstrated equivalent interference effects in eight-year-old children with typical language development and Developmental Language Disorder[1], appearing as slower responding in the homogenous block in the fourth cycle. Boelens and La Heij (2017) examined age-related differences in interference effects in the BCN paradigm with 5-7 and 8-10-year-old children. They reported a significant interference effect for both age groups that appeared in the second cycle, as is typically seen in adults, with no interaction of interference with age group.

Thus, semantic interference effects in the BCN paradigm are relatively well-documented in school-age children. However, although the BCN paradigm reveals interference among semantically-related responses, there is evidence that this method invokes strategic, top-down processing and working memory functions that are not invoked in the simpler continuous list paradigm. The effects that are observed using the BCN method do not show the cumulative pattern seen in continuous naming (Belke & Stielow, 2013). Moreover, growth of interference effects demonstrated for individuals within the BCN paradigm are not correlated with growth in interference demonstrated using the continuous list paradigm, a disconnect attributed to the different requirements of the tasks (Hughes & Schnur, 2017). The continuous naming approach arguably provides a more straightforward window into experience-driven changes in connection strengths.

Evidence of CSI in children from continuous naming is much more limited. Charest (2017) reported cumulative interference effects in three-year-old children using a variation on the continuous naming approach. In this study, children named 28 animals in sequence in a semantically homogeneous condition. The pictures were presented in a random order and each animal appeared a single time. Children also named 28 varied items in a mixed condition that served as a control for response latency increases driven by fatigue or loss of attention across trials. The lexical items in the two lists were matched for age of acquisition (AoA), frequency and initial phoneme. Charest hypothesized that, if young children experience cumulative, semantically-based interference, this would be demonstrated as an interaction between condition and trials, with greater slowing in responses across trials for the semantically homogenous animal set than the mixed stimulus set. The results revealed the expected pattern. There was no difference in response latencies between the semantically homogeneous and mixed conditions at the start of each condition. There was a linear, progressive slowing across trials in both conditions, with greater growth in the semantically homogeneous condition.

Charest (2017) employed a method that varied from standard continuous naming approaches used with adults, examining interference across 28 items from a single

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[1] Following the terminology recommendations arising from the CATALISE Consortium (Bishop, Snowling, Thompson, Greenhalgh & Catalise-2 Consortium; 2017), we adopt the term Developmental Language Disorder (DLD), acknowledging that Ladányi and Lukács (2016) described their participants as having specific language impairment (SLI).

semantic category. This method was selected because of its parallels to previous studies with young children that demonstrated interference, but did not examine cumulative effects (Booth & Vitkovitch, 2008; Gershkoff-Stowe, 2002) The method also maximized the likelihood of capturing a semantic category (animals) that was relevant to the very young participants. The data from Charest (2017) provided the first evidence with very young children of cumulative semantic interference measured in response latencies within a continuous list method, consistent with experience-driven changes in connection strengths. The results invited further investigation of how these effects manifest across childhood development. As a first step in extending the study of CSI effects with the continuous list method in childhood, we sought to replicate in older children the results observed by Charest (2017). To anticipate the results, we did not find evidence of cumulative interference effects. We summarize the study and results below. We then adopted an approach more closely aligned with the methods used for adults, demonstrating CSI effects in eight-year-olds across lags of 2 to 8 intervening, unrelated items.

Study 1: replication of Charest (2017)

Method

Participants

Eighteen children (8 girls) with a mean age of 8;7 (range : 7;10 to 9;3) participated. All children spoke English as their first and primary language according to parent report. Parents reported no concerns with the children's language abilities.

Stimuli and procedure

The stimuli and procedure were identical to those described in Charest (2017). Children named 56 pictures: 28 animals in the semantically homogeneous condition (hereafter animals condition) and 28 items in the mixed condition, comprised of 2 or 3 items from each of 10 different categories (*clothing, foods, furniture, animate beings, nature, outside objects, household objects, toys, vehicles, body parts*). Conditions were blocked with the order counterbalanced across participants. The order of stimulus items within condition was randomized for each participant. Pictures appeared on the screen one at a time for up to 5 s, preceded by a 1 s orienting cue. After every 7 trials, a happy face appeared with the message "Great Job!!". Trials were advanced manually by the experimenter after the onset of the naming response. The average RSI was 1.3 s ($SD = 311.9$ ms; range: 1.05–5.1 s), and the average time between each set of 7 responses was 8.4 s (range: 5.2–17.4). Responses were scored as correct if they contained the expected label or a reasonable synonym (e.g., *alligator / crocodile*). Responses coded as errors included: (1) naming errors (e.g., *tiger / lion*); (2) responses with vocal hesitations (filled pauses such as *uh* or *um*); (3) revisions of part-words (e.g., *t - drum)*, and (4) non-responses (silence).

Results

The analysis focused on response latencies for correct responses, with linear mixed effects models conducted in R (R Core Team, 2015) with the packages *lme4* and *lmerTest* (Bates, Maechler, Bolker & Walker, 2015; Kuznetsova, Brockhoff & Christensen, 2017). We examined the fixed effects of trial, condition, and their

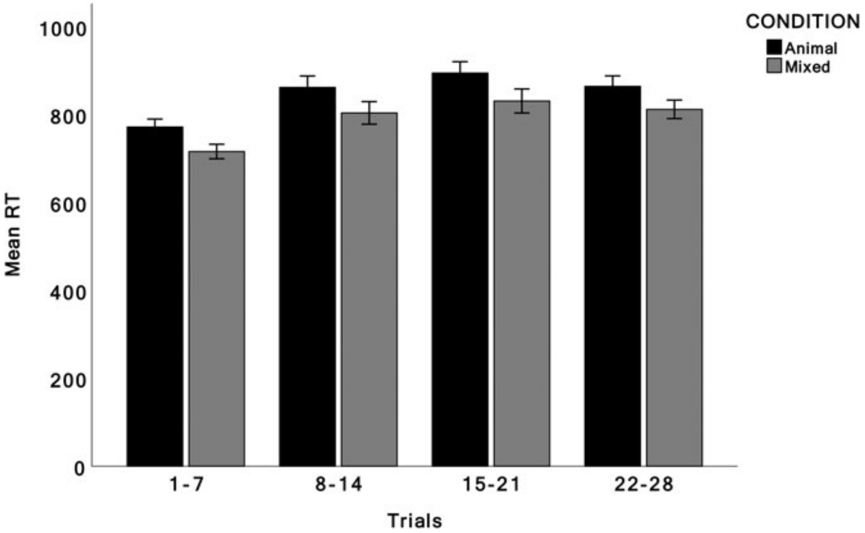

Figure 1. Mean observed picture naming reaction times across trials, animal and mixed conditions, Study 1. Error bars represent +/1 *SE.*

interaction on response latencies. The random effects structure retained the intercepts for participant and items as well as the random slope by participants for the interaction between condition and trial.

The interaction between condition and trial (1.13, $SE = 2.17$) was not significant, $p = .61$. The main effects also did not reach significance: there was a predicted intercept adjustment of -69.6 ms (faster naming) for the Mixed condition ($SE = 38.26$), and a predicted 4.1 ms slowing in response time by trial ($SE = 2.15$), both $ps = .08$. Figure 1 presents the observed mean latencies for the Animal and Mixed conditions, averaged for each block of 7 trials.

Discussion

This study failed to replicate Charest's (2017) finding of cumulative semantic interference effects, operationalized as significantly greater growth over trials in the semantically-homogenous Animal condition than in the control Mixed condition. There are likely several potential reasons for the difference in results between the present study and those of Charest (2017). One possibility is that the method, developed to be accessible to the very young children studied by Charest (2017), was not well-suited to reveal CSI effects in older children. Indeed, Howard et al. (2006) noted that, to observe cumulative semantic interference effects, related items should ideally be separated by unrelated items in order to minimize potential confounds from explicit awareness of relationships and confounds from potential short term facilitatory priming. While these confounds did not prevent observation of cumulative interference effects with very young children (Charest, 2017), older children are arguably more likely to engage in explicit strategic processing and so these potential confounds may have been of greater concern. Thus, in Study 2, we investigated whether cumulative semantic interference effects are present in school-age children when multiple categories are intermixed within the stimulus list and related items are separated by unrelated items.

Study 2

Method

Participants

Twenty-five children (9 male) participated. The children spoke English as their first and primary language and had no known or suspected language development concerns, according to parent report. The mean age of the participants was 8;4 (range: 7;6 to 9;0). Maternal education was obtained as a proxy for socioeconomic status. One mother had less than high school completion, 13 reported some or all of a college/ university degree completed, 10 reported some or all of an advanced degree completed and 1 did not report their education level.

Stimuli

The stimuli consisted of 90 child-appropriate, colored images purchased from Shutterstock.com. Images were sized between 350 and 450 pixels at a resolution of 72 pixels/inch. These images were presented centrally on a white background on the computer screen. The stimulus set consisted of six exemplars from 12 semantic categories (*4-legged animals, fruit and vegetables, clothing, tableware, insects, vehicles, body parts, weather and celestial, nature, professions, buildings, musical instruments)* and 18 filler objects. The full stimulus list is presented in the Appendix. Where objective data are available, the average age of acquisition for the anticipated labels (age in months at which 75% of children are reported to produce the word on the MCDI (Dale & Fenson, 1996; Jørgensen et al., 2010), or as reported by Morrison et al. (1997) for 75% correct picture naming) was 32.9 months.

We constructed a 90-item list containing 72 slots for experimental items and 18 filler slots. Each of the 72 experimental slots was designated as corresponding to a combination of semantic category and ordinal position (e.g., Category 1, Word 1). We created 4 list orders that varied the assignment of semantic category to category position. The "Animals" category, for example, was assigned to the Category 1, 5, 7, and 11 slots across the four lists. The stimulus list was further structured to control for the number of unrelated, intervening items (2, 4, 6 or 8) between related target items. Across the list, each lag occurred with near-equal frequency (Lag2 = 15, Lag4 = 15, Lag6 = 16, Lag8 = 14), and the lags were presented in a different combination and order for each of the 12 categories. Turning to ordinal position within the semantic sets (i.e., Words 1 to 6), the construction of the stimulus lists minimized, but did not completely remove, a relationship between trial and ordinal position ($r = .46$). Potential effects of general fatigue or loss of attention across trials were accounted for in the analytic approach.

Procedure

Participants were seen at either the University of Alberta or in a quiet space within their child care centre for a single session, and were familiarized to the labels for the target stimuli before the naming task. The experimenter presented and named the images, with 6 per page, and the child identified them by pointing. The naming task began with two demonstration trials and three practice trials. Within each semantic category, the order of presentation of the exemplars was randomized by the E-Prime software (Schneider, Eschman & Zuccolotto, 2002). Pictures were presented for naming one at a time, each preceded by an orienting cue lasting 1 s. An auditory tone marked the beginning of the trial as the image appeared on the screen. The picture appeared on the computer screen for up to 5 s. The experimenter advanced the trial manually after the participant's response, at which point the picture disappeared and the next trial began immediately. The stimulus list was presented in 6 blocks of 15 images, with children receiving positive reinforcement (a happy face with the message "Great Job!!") after every block of 15. Sessions were audio and video recorded for later transcription and scoring. The average RSI between trials was 1.9 s ($SD = 316$ ms; range: 1.6-4.2 s); between blocks of 15 trials, the average pause duration was 9.6 s (range: 3.2-63.5 s).

Transcription, scoring and reliability

Naming responses and RTs were recorded by two research assistants. Three trials were discarded as unusable due to distractions in the environment at the time of the participant's response. Responses were scored as correct if they provided the correct label for the image or a reasonable synonym (e.g., *lips/mouth*). Responses were scored as incorrect if there were: (1) naming errors (e.g., *apple/cherry*); (2) hesitations (responses preceded by 'uh' or 'umm'); (3) revisions of part-words (e.g., *s… fork*) or whole words (e.g., *violin… wait no… flute*) 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.

Five (20%) randomly selected sessions were transcribed by both research assistants, recording the content and timing of the responses. Those same sessions were scored by both authors for whether or not trials were usable, as well as whether the response was correct or contained an error. RT reliability was computed as the number of trials with less than 10 ms difference divided by the total number of RTs. RT reliability was 94% with an average difference of 3 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. Reliability for content of the response was 99%. For judgment of a trial as usable or unusable, reliability was 100% and for judgment of a response as correct or in error it was also 100%.

Results

Accuracy

Naming accuracy was high overall. After discarding unusable trials and filler trials, 1669 trials remained for analysis. Of these, 127 were scored as errors (5.7%). There were 28 naming errors (22.1% of errors), 48 hesitations (37.8%), 36 revisions (28.3%), and 15 non-responses (11.8%). Overall accuracy was 94.4%. Given the overall high rates of accuracy and the low total number of naming errors, we did not further analyze accuracy.

Response latencies

The remaining 1669 experimental trials were examined for potential outliers. 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 54 (3.2%) RTs

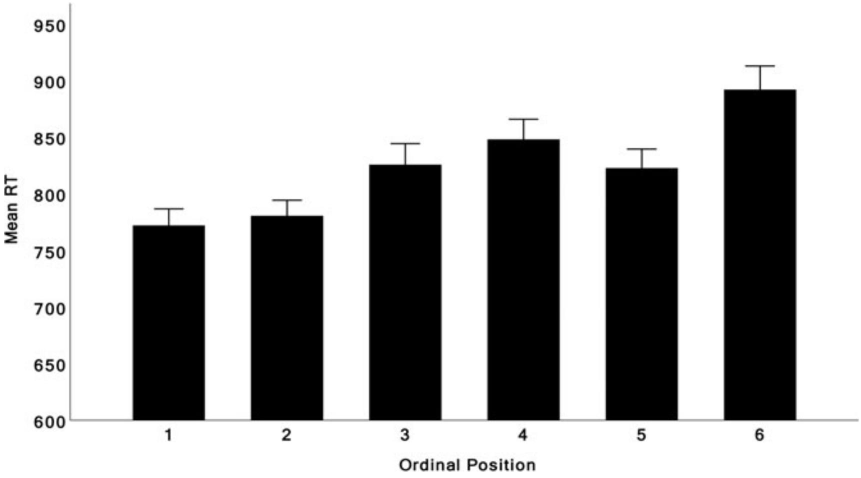

Figure 2. Mean observed picture naming reaction times by ordinal position within semantic set (Words 1–6), Study 2. Error bars represent +/- 1 *SE*.

were removed. Figure 2 presents the observed mean response latencies by ordinal position.

We examined the effects of trial and ordinal position on response latencies, using linear mixed effects models and following a model comparison approach beginning with the most complex model motivated by the research question and testing the removal of predictors. For these analyses, trial was centered with Trial 1 as the intercept, and ordinal position was centered with Word 1 as the intercept. Table 1 presents the model outcomes. We first determined the random structure of the model. The first model contained the fixed main effects of trial and ordinal position within the semantic set. The random effects structure contained the intercepts for participants and items, as well as random slopes for trial by participant and ordinal position by participant. We then tested the removal of the random slopes for trial and ordinal position in successive models. As Table 1 demonstrates, the inclusion of random slopes did not improve model fits, and thus, only the random intercepts for participant and trial (m2) were retained.

To test the fixed effects, we began with the model containing the fixed main effects of trial and ordinal position (m2) and then tested successive models removing first trial and then ordinal position. As can be seen in Table 1, the removal of either of these fixed predictors resulted in a significantly worse model fit, and both were thus retained. The final preferred model (m2) contained fixed main effects of both trial and ordinal position. Coefficients for this model indicated a predicted response latency of 741.75 ms ($SE = 28.49$) at Trial 1. There was a predicted slowing of 1.2 ms per trial ($SE = .31$, $p < .001$). Importantly, the estimate for ordinal position within the semantic set indicated a predicted slowing of 15.2 ms for each additional word within the set ($SE = 4.06$, $p < 0.001$).

Finally, we examined the effect of lag on response latencies, and whether the cumulative interference effect varied with distance between related words, via the interaction between lag and ordinal position. Trials with ordinal position 1 were excluded by necessity. We adopted the same general approach as in the previous

Table 1. Model Comparison Outcomes Testing the Effects of Trial and Ordinal Position within Semantic Set on Picture Naming Reaction Times, Study 2

Model	Fixed Effects	Random Slope Effects	AIC	Comparison	X^2*(df)*	*p*
Random Effects Model Comparisons (fit with REML)						
m0	Trial + Ordinal Position	Trial | Participant Ordinal Position | Participant	22512			
m1	Trial + Ordinal Position	Ordinal Position | Participant	22511	m0	4.95 (3)	.18
m2	Trial + Ordinal Position	Random intercepts only	22510	m1	2.91 (2)	.23
Fixed Effects Model Comparisons ((fit with ML)						
m2	Trial + Ordinal Position	Random intercepts only	22522			
m3	Ordinal Position	Random intercepts only	22536	m2	16.20 (1)	< .001
m4	Trial	Random intercepts only	22534	m2	14.05 (1)	< .001

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

analysis, first testing and trimming back the random structure and then testing the fixed effects. Ordinal position was centered with Word 2 as the intercept. Table 2 presents the outcomes of the model comparisons. The first model contained the fixed main effects of ordinal position and trial, as well as the interaction between ordinal position and lag. The random effects structure contained the random intercepts for participant and item, as well as the random slope of ordinal position by lag for participant. We then tested successively simpler random structures. As can be seen in Table 2, none of the simplifications of the random structure caused significant decrements in model fit, and thus only the random intercepts (m3) for participant and item were retained. In particular, the comparisons between m1 and m0 and between m2 and m1 indicate that none of the random slopes for lag were warranted.

For the tests of the fixed effects, we began with m3, containing random intercepts for participant and item, and fixed main effects of ordinal position and trial, as well as the interaction between ordinal position and lag. We first tested the removal of the interaction term, followed by the main effects of trial and ordinal position. The comparison between m4 and m3 indicates that removing the interaction term for lag did not have a detrimental effect on the model ($p = .35$); neither did the removal of lag as a main effect ($p = .73$). The lag between semantically-related items did not contribute to predicting onset latencies. Finally, the comparisons of models 6 and 7 with m5 indicate that, as with the full data set, neither the main effect of trial nor that of ordinal position could be removed, as doing so resulted in significant decrements in model fit. Thus the final, preferred model (m5) contained random intercepts for participants and items, and fixed main effects for trial and ordinal position, but no effects for lag. In this model, containing only data from Words 2 through 6, the estimated increase in response latency by trial was .88 ms ($SE = .35$, $p = .01$), and the estimated increase in latency by ordinal position was 20.6 ms ($SE = 5.38$, $p < .001$).

General discussion

Study 2 demonstrated a linear increase in RT as a function of ordinal position within semantic set, that was additional to any general slowing effects accounted for by the main effect of trial. This increase was unaffected by the lag, or number of intervening, unrelated items between related items. Thus, Study 2 demonstrated cumulative semantic interference in young, school-age children. The findings are consistent with prior reports of interference effects obtained for children in blocked cyclic naming contexts (Ladányi & Lukács, 2016; Snyder & Munakata, 2013; Boelens & La Heij, 2017), but they extend these findings to more clearly demonstrate cumulative effects. To our knowledge, this is the first study to demonstrate CSI effects in children across lags of unrelated responses. This finding is consistent with adult-focused studies showing CSI across two to eight trials (Howard et al., 2006; Schnur, 2014), and supports the view that children, like adults, experience cumulative semantic interference effects that can be construed as reflecting relatively durable changes in connection strengths for recently produced words. The results point to continuity of lexical processes from childhood to adulthood and are consistent with prior findings to suggest that models of lexical access and methods of investigation derived from the adult literature can be fruitfully applied to children (e.g., Budd et al., 2011; Gershkoff-Stowe, Connell & Smith, 2006; Jerger, Martin & Damian, 2002; McKee, McDaniel & Garrett, 2018).

Table 2. Model Comparison Outcomes Testing the Effect of Lag on Picture Naming Reaction Times, Study 2

Model	Fixed Effects	Random Slope Effects	AIC	Comparison	$X^2(df)$	*p*
Random Effects Model Comparisons (fit with REML)						
m0	Ordinal Position * Lag + Trial	Ordinal Position * Lag | Participant	18750			
m1	Ordinal Position * Lag + Trial	Ordinal Position | Participant Lag | Participant	18743	m0	1.27 (4)	.87
m2	Ordinal Position * Lag + Trial	Ordinal Position | Participant	18738	m1	.485 (2)	.92
m3	Ordinal Position * Lag + Trial	Random intercepts only	18735	m2	1.49 (2)	.47
Fixed Effects Model Comparisons ((fit with ML)						
m3	Ordinal Position * Lag + Trial	Random intercepts only	18756			
m4	Ordinal Position, Lag + Trial	Random intercepts only	18755	m3	.881 (1)	.35
m5	Ordinal Position + Trial	Random intercepts only	18753	m4	.117 (2)	.73
m6	Ordinal position	Random intercepts only	18757	m5	6.27 (1)	.01
m7	Trial	Random intercepts only	18765	m5	14.51 (1)	< .001

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

The continuous-list naming task used in CSI studies is simple and easy for even very young children to understand. The method is designed to minimize explicit awareness of relevant categories, and does not require explicit reflection on relationships between words or responses to judgment questions. These features of the method make it ideally suited to work with children of different ages. Research using this method has the potential to provide novel insights into a number of developmentally important questions. Of note, given that CSI requires shared activation pathways and competition among items with shared semantic relationships, its manifestation can provide insight into the nature of the relationships that are relevant in young children's lexical-semantic systems. CSI effects, if observed, can provide evidence that the relationships within the stimulus sets index some aspect of shared representation in children's lexicons. For example, in categorization tasks examining conceptual preferences, early research indicated a reliance on thematic relations in young children (Smiley & Brown, 1979). Later research demonstrated that children could categorize items according to both thematic and categorical relationships, and that choices were sensitive to the wording of the questions or instructions given to children (Waxman & Namy, 1997). Other research using spoken responses has emphasized the limited nature of categorical relationships in children's lexical associations. Lucariello, Kyratzis and Nelson (1992), for example, argued from category production (semantic verbal fluency) and word association tasks that four-year-olds rely more on thematic-based relationships than seven-years-olds, and that four-year-olds' categorical structures or knowledge are limited to categorical relations that also share event structure or spatiotemporal proximity, while seven-year-olds are sensitive to categorical relations more broadly. With careful construction of categories, CSI effects offer the potential to contribute further insight into these apparent developmental changes. Moreover, given that the magnitude of interference effects can vary across the categories that are embedded within a list, such variations may provide additional insight into the dimensions or categories that characterize robust semantic relationships in young children (Alario & del Prado Martín, 2010).

In our view, a particularly powerful contribution of the CSI phenomenon for the study of language development is that cumulative effects tap into incremental, experience-dependent changes in the strength or integrity of connections within the lexicon and can thus provide insight into how production experiences affect processing and representation in less robust or mature language systems. Researchers have noted that lexical retrieval in children appears to be particularly susceptible to disruption (see McKee et al., 2018). Evidence of cumulative semantic interference challenges us, when working with children, to distinguish between interference effects that suggest difficulties or immaturity in knowledge or processing, and interference effects that suggest robust learning mechanisms.

In referring to learning mechanisms, we are referring to experience-driven changes in connection strengths, acknowledging that different models of these changes have been proposed: namely, strengthening of targets following the naming response (coupled with competition during lexical access, Howard et al., 2006), and a competitive learning mechanism that pairs strengthening of connections to the target with weakening of connections to competitors (Oppenheim et al., 2010). The present research was not designed to adjudicate between these two possibilities. Having established that CSI effects are observed in children, in a continuous list context and across unrelated trials, a direction for future work would be to investigate more closely where the competition within the CSI effect occurs. This question is central to our understanding of the mechanisms responsible for lexical processing. There are a number of additional avenues for future research. For example, studies of interference at the item level have demonstrated greater interference in younger children than older (Booth & Vitkovitch, 2008; Gershkoff-Stowe, 2002). The research by Booth and Vitkovitch provided the suggestion that there may be different temporal dynamics of interference with age. Data from Gershkoff-Stowe (2002) indicate that, in toddlers, interference effects are observed among unrelated as well as semantically-related items. And, finally, CSI research with adults has demonstrated that effects are not observed at very long lags (e.g., lags of 8 to 50 unrelated items, Schnur; 2014) without early reinforcement. All of these findings invite further investigation in children with methods that look beyond individual trial-to-trial interference. We can ask if the magnitude or temporal dynamics of cumulative, learning-based interference effects vary with age, language ability, the relationships under investigation, or the relative familiarity of the items under study.

The present data also revealed some unexpected patterns that will require future investigation. Most notably, the interference effects in Study 2 appeared to grow in magnitude from Word 2 to Word 3. And, as can be seen in Figure 2 in the observed data there was a departure from the overall growth pattern for Word 5. Given the robustness of the predicted linear effects, we suspect that this departure reflects non-systematic noise. Further evaluation of this expectation will require observations of the shape of CSI effects with other groups of children and other stimulus sets. We note that despite care taken in the construction of the stimulus list, there is the potential for noise to arise out of unintended relationships within the stimulus set, such as potential associations to filler items, or potential thematic relationships among items from different semantic categories.

The null finding in Study 1 was also unexpected. With respect to the outcomes of Study 1 and Study 2, the methods and materials differed in several ways, and thus we cannot comment with certainty on the basis for the different findings. Study 2 was better suited to avoiding potential confounds of explicit awareness of categories and facilitative priming (Howard et al., 2006), and, being more closely matched to the methods previously used with adults, provides the better test of the phenomenon. Despite the null finding of Study 1, Study 2 allows confidence in the conclusion that school-age children show CSI effects. Given the differences in findings between Study 1 and Charest (2017), more research is needed before drawing conclusions about continuity in CSI effects (or lack thereof) from early to later childhood. In particular, the 3-year-old children studied by Charest (2017) demonstrated the CSI effects using a single semantic category with 28 exemplars and no intervening trials; the extent to which the findings fully mirror the CSI effect as understood in the adult literature is not known. It will be important in future work to examine whether CSI effects are observed in younger children with broader representation of semantic categories and across lags of different lengths.

Conclusion

To conclude, in this study, school-age children demonstrated cumulative semantic interference effects when measured using intermixed semantic categories, with two to eight unrelated items intervening between related items. The fact that the interference effects were cumulative and robust against the time delay imposed by the unrelated items is consistent with the view that they arose from experience-driven changes in the semantic-to-lexical connection weights that drive activation and access in the moment of speaking. This finding points to continuity with adult lexical processing. It invites further investigation of how lexical representation and processing is shaped in small ways by speaking experiences, and how these incremental effects relate to broader changes or differences in language ability within and between children.

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Appendix

Study 2 Stimuli
Animals: *bear, cow, dog, horse, lion, pig*
Fruits and vegetables: *apple, banana, carot, cherry, corn, pear*
Clothing: *coat, dress, hat, scarf, shirt, shoe*
Tableware: *bowl, cup, fork, knife, plate, spoon*
Insects: *ant, bee, butterfly, ladybug, spider, worm*
Vehicles: *airplane, boat, bus, car, tractor, train*
Body parts: *ear, eye, foot, hand, mouth, nose*
Weather and celestial: *cloud, lightning, moon, rainbow, star, sun*
Nature: *bush, flower, leaf, rock, tree, stick*
Professions: *astronaut, clown, cook, cowboy, farmer, fireman*
Buildings: *barn, castle, church, hospital, house, library*
Instruments: d*rum, flute, guitar, piano, trumpet, violin*
Fillers: *balloon, bed, bell, book, box, broom, cake, hammer, heart, kite, ladder, pen, present, slide, tent, baby, puzzle, lamp*

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