

The vocabulary spurt predicts the emergence of backward semantic inhibition in 18-month-old  
toddlers

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## Vocabulary Spurt and Backward Semantic Inhibition

### Author Note

JC designed and performed the experiment, analysed the data and wrote the manuscript. AAD, LJF and KP designed the experiment, wrote and critically reviewed the manuscript.

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### Research Significance

- We demonstrate that 18-month-olds can inhibit attention to a previously-attended but no longer relevant semantic category, but only if they have a relatively large vocabulary.
- Inhibitory processes are not only relatively late emerging in development, but are also relatively delayed in their online effects compared to facilitatory processes.
- A denser mental lexicon likely results in the formation of inhibitory links between lexical concepts, which allow toddlers to select and deselect concepts more efficiently.

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### Abstract

The current study examines the relationship between 18-month-old toddlers' vocabulary size and their ability to inhibit attention to no-longer relevant information using the backward semantic inhibition (BSI) paradigm. When adults switch attention from one semantic category to another, the former and no-longer-relevant semantic category becomes inhibited, and subsequent attention to an item that belongs to the inhibited semantic category is impaired. Here we demonstrate that 18-month-olds can inhibit attention to no-longer relevant semantic categories, but only if they have a relatively large vocabulary. These findings suggest that an increased number of items (word knowledge) in the toddler lexical-semantic system during the 'vocabulary spurt' at 18-months may be an important driving force behind the emergence of a semantic inhibitory mechanism. Possessing more words in the mental lexicon likely results in the formation of inhibitory links between words, which allow toddlers to select and deselect words and concepts more efficiently. Our findings highlight the role of vocabulary growth in the development of inhibitory processes in the emerging lexical-semantic system.

*Keywords:* attention; toddler; vocabulary; inhibition; lexical-semantics

### The vocabulary spurt predicts the emergence of backward semantic inhibition in 18-month-old toddlers

The organized storage of word forms and their meanings in the human mind constitute the lexical-semantic system. One of the hallmarks of the adult lexical-semantic system is that items are not stored in isolation, but in relation to each other. More specifically, lexical-semantic items can be connected by both facilitatory and inhibitory links, which allow flexible selection of word form and meaning during word recognition and selective attention. For example, items that belong to the same semantic category can activate (Huettig & Altmann, 2005; Huettig & McQueen, 2007; Meyer & Schvaneveldt, 1971) each other based on demand and context. The classical example is semantic priming, which shows that the prime word ‘doctor’ primes our response (faster reaction time) to the word ‘nurse’, as these two words belong to the same semantic category of medical practitioners (Meyer & Schvaneveldt, 1971).

There is overwhelming evidence that the adult lexical-semantic system is connected by inhibitory links. In the context of spoken-word recognition, inhibitory links allow lexical items to compete for selection. Word recognition is thereby accelerated since more plausible word candidates can suppress weaker candidates (e.g., Dahan, Magnuson, Tanenhaus, & Hogan, 2001; McClelland & Elman, 1986). Word recognition can also be slowed down when there are a large number of similar sounding (same onset and neighbour) words in the lexicon (e.g., Allopenna, Magnuson, & Tanenhaus, 1998; Goldinger, Luce, & Pisoni, 1989; Luce & Pisoni, 1998; Zwitserlood, 1989).

Inhibitory links have also been observed between and within semantic categories (e.g., Glaser & Döngelhoff, 1984; Schriefers, Meyer, & Levelt, 1990; Tipper, 1985; Wheeldon &

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Monsell, 1994), and most often when selective attention is required. For example, backward semantic inhibition (BSI) engages an inhibitory mechanism that allows adults to efficiently select a relevant item over a previously-relevant and attended item in a ‘backward’ fashion (Fuentes, Vivas, & Humphreys, 1999a, 1999b; Weger & Inhoff, 2006): Adult participants’ responses in a modified lexical decision task were impaired when attending to words that belonged to a previously attended semantic category (e.g., Category A: Furniture → Category B: Animal → Category A: Furniture), compared to a previously unattended semantic category (e.g., Category C: Clothing → Category B: Animal → Category A: Furniture). The term BSI originated from the widely-replicated effect of backward inhibition (BI) in the context of task-switching in adults (Mayr & Keele, 2000, see Kiesel et al., 2010 for review). In a typical task-switching experiment, adult participants attend to relevant tasks based on written cues on a screen (e.g., participants select an object based on colour, orientation or movement). BI refers to the finding that participants’ responses are typically impaired when they have to return to a previously attended task (e.g., Task A: Colour → Task B: Orientation → Task A: Colour), compared to a new task (e.g., Task C: Movement → Task B: Orientation → Task A: Colour).

Recent evidence suggests that the formation of facilitatory and inhibitory links in the infant lexical-semantic system may undergo different developmental trajectories. Facilitatory links in the lexical-semantic system have been demonstrated as early as 18-months: 18-month-old toddlers listen to a list of words (no visual stimuli at all) for longer if the words belong to the same taxonomic category (Delle Luche, Durrant, Floccia, & Plunkett, 2014; see also Willits, Wojcik, Seidenberg, & Saffran, 2013 for comparable findings with 2 year olds). Adult-like facilitatory links between semantically-related concepts are evident in 24- and 30-month-old toddlers who, upon hearing the label ‘dog’, show increased attention to the picture of a bee (taxonomically-related)

and a bone (thematically-related) despite their perceptual dissimilarity with ‘dog’ (Chow, Aimola Davies, & Plunkett, 2017). Note that the words used in these studies were deliberately chosen to be phonologically unrelated to their semantically related referents, highlighting the lexical-semantic character of the facilitatory priming effects observed.

In comparison to the many studies on facilitatory links, only a handful of studies have examined the formation of adult-like lexical inhibitory links in infants and toddlers (e.g., Mani & Plunkett, 2011; Swingley & Aslin, 2007). Specifically, semantic inhibition has only been reported in toddlers from the age of 21–24 months using two infant preferential looking paradigms: forward semantic inhibition (FSI) (Arias-Trejo & Plunkett, 2009, 2013; Styles & Plunkett, 2009) and backward semantic inhibition (BSI) (Chow, Aimola Davies, Fuentes, & Plunkett, 2016). In a typical preferential-looking study, toddlers are shown a pair of target and distractor pictures and they hear the target label. Toddlers’ eye-movements are taken as an index of on-going perceptual and cognitive processing of auditory and visual stimuli. Spoken-word recognition is manifest as significantly longer looking at the target picture than the distractor picture (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987). To examine whether links have been formed in the lexical-semantic system, experimenters in the FSI studies presented a prime label prior to the target label (e.g., ‘Yesterday, I saw a dog [prime]. Cat [target]!’). Twenty-one month-olds showed an inhibitory priming effect in the unrelated condition: hearing a semantically-unrelated prime label disrupted the toddlers’ tendency to preferentially fixate the target picture in response to the target label, suggesting that hearing the unrelated prime inhibited subsequent processing of the target in a ‘forward’ fashion (Arias-Trejo & Plunkett, 2009, 2013; Styles & Plunkett, 2009). No such inhibition was observed in 18-month olds who successfully identified target referents in both related and unrelated conditions.

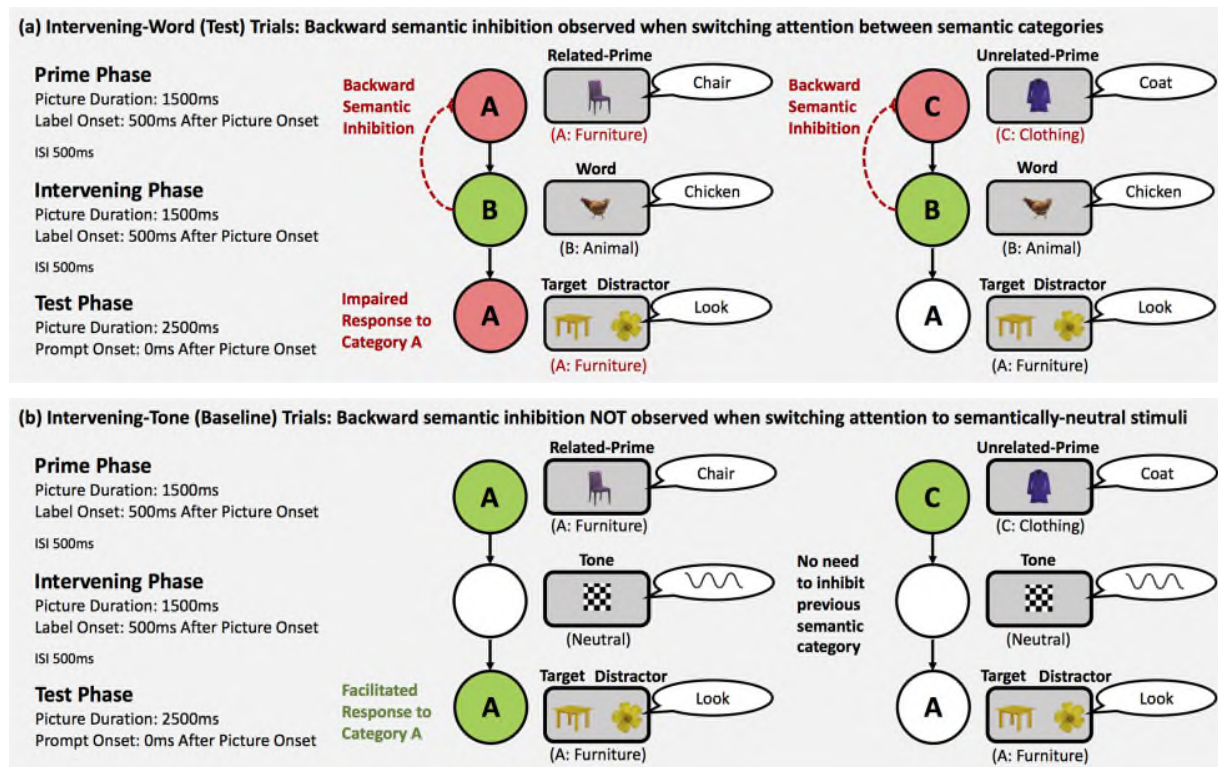
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One study has explored BSI using an attention-switching paradigm in 24-month-old toddlers (Chow et al., 2016) that mimics the logic of adult BSI studies. As seen in Figure 1a, there were two types of test trials: ABA and CBA. An example of an ABA trial would be Chair (Related-Prime) → Chicken (Intervening-Word) → Table (Target) vs. Flower (Distractor). BSI of the prime category was inferred when 24-month-olds showed a reduced preference for the target picture in the ABA trials in comparison to the CBA trials (Figure 1a). In contrast, no inhibition was observed in the baseline trials (Figure 1b): A\_A and C\_A, when the semantic category B was replaced with a semantically-neutral intervening stimulus (a checkerboard and sinewave tone). In fact, A\_A lead to a facilitatory effect in comparison to C\_A. In other words, BSI did not take place when there was no shift of attention within semantic space. BSI is likely to be supported by a lateral inhibitory mechanism (see discussion in Chow et al., 2016).

In sum, the above findings suggest that inhibitory semantic links, operating in a forward and backward fashion, are in place by the end of the second year of life. This is in stark contrast to evidence for the development of facilitatory lexical-semantic links where multiple studies have reported evidence for facilitatory priming at least as early as 18-months of age, suggesting distinct development trajectories for the two forms of priming. This leaves open the questions as to whether inhibitory priming effects can be observed in the lexical-semantic system at an earlier age, and if so what drives the emergence of these inhibitory processes.



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*Figure 1.* The backward semantic inhibition (BSI) paradigm used in 24-month-old toddlers (Chow et al., 2016) and in 18-month-old toddlers in the current study. There were in total four types of trials: a) Two intervening-word (test) trials, including Related Prime with Intervening Word (ABA) and Unrelated Prime with Intervening Word (CBA); b) Two intervening-tone (baseline) trials, including Related Prime with Intervening Tone (A\_A) and Unrelated Prime with Intervening Tone (C\_A).

A possible driving force behind the emergence of inhibitory links is a quantitative change in the toddlers' lexical-semantic system. Often referred to as the 'vocabulary spurt', the number of words toddlers can understand and say increases dramatically from around 18-months onwards. With an increase in the number of lexical items, there is an increase in the pressure to develop an efficient, adult-like word recognition system that is driven not only by activation, but also by inhibition. Since previous studies have only found forward inhibitory effects in 21- and 24-month-olds, but not in 18-month-olds, we predicted that 18-month-olds as a group would not demonstrate BSI. However, if the emergence of inhibitory processes in the lexical-semantic system is driven

by vocabulary size, then given the large variability in vocabulary growth at this age, we predict that 18-month-olds with a larger vocabulary size should behave more similarly to 24-month-olds.

In the current study, we conducted a large-scale BSI study with 72 18-month-old toddlers to detect the presence/absence of inhibitory semantic processes, and determine the manner in which any observed inhibitory processes are modulated by vocabulary size. The study's design is identical to the BSI paradigm conducted by Chow et al (2016) and described above (see Figure 1).

### Methods

#### Participants

A total of 86 toddlers were recruited from British English monolingual households, 72 of which were included in the analysis ( $M_{\text{age}} = 18.25$ , age range = 17.58-18.92, Male = 37, Female = 35). We targeted a sample size of approximately 35 toddlers for the high and low vocabulary size groups based on previous BSI findings in 24-month-olds (Chow et al., 2016). Each toddler's parent filled in the Oxford Communicative Development Inventory (OCDI) (Hamilton, Plunkett, & Schafer, 2000). Five toddlers were excluded due to the parents' failure to fill in the OCDI. Nine toddlers were excluded because they did not complete the experiment due to fussiness.

#### Design

Each toddler saw a total of 16 trials, which were presented in a random order generated by the eye-tracking software. As seen in Figure 1, there were in total four types of trials. The two intervening-word (test) trials were: Related Prime with Intervening Word (ABA) and Unrelated Prime with Intervening Word (CBA). The two intervening-tone (baseline) trials were: Related Prime with Intervening Tone (A\_A) and Unrelated Prime with Intervening Tone (C\_A). Each trial consists of a 1500 ms prime phase, in which toddlers saw either a related- or unrelated-prime picture (chair or coat) accompanied by the picture's auditory label (label onset at 500 ms after

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prime picture onset). This was followed by the intervening phase, which consisted of one of two intervening stimulus types. In the intervening-word (test) trials, toddlers saw either a picture of a chicken or a car accompanied by the picture's auditory label (label onset at 500 ms after picture onset). In the intervening-tone (baseline) trials, toddlers saw a checkerboard (diamond or square) accompanied by a sine-wave tone. Finally, in the test phase, toddlers saw a pair of pictures – target (table or hat) and distractor (flower or balloon) pictures for 2500 ms, accompanied by an attention-getting word ('look' or 'wow'). An example of an 'ABA' trial would be Chair (Related-Prime) → Chicken (Intervening-Word) → Table (Target) vs. Flower (Distractor). There was a 1000 ms audio-visual attention getter at the beginning of each trial to grab the toddler's attention, and an inter-stimulus interval of 500 ms between each of the three phases. Toddlers were randomly assigned to one of four lists that were counterbalanced for picture location and target and distractor combinations (see Table S1 as an example). The prime and target pairs were chosen because they belong to the same taxonomic category and were semantically-associated based on the Edinburgh Associative Thesaurus (Kiss, Armstrong, & Milroy, 1972). The intervening stimuli were semantically-unrelated to the primes, targets and distractors.

**Visual Stimuli.** The prime objects were either a chair or a coat. The intervening stimulus was either a chicken or a car in the intervening-word trials, or either a square checkerboard (checkerboard 1) or a diamond checkerboard (checkerboard 2) in the intervening-tone trials. The test target was either a table or a hat, while the test distractor was either a flower or a balloon. Objects were represented by realistic photographs. Each object was edited out of its original background and placed in the centre of a 19.59 cm x 19.59 cm 50% gray background (16.8° x 16.8°) using Adobe Photoshop. To maintain the toddlers' interest in the stimuli, we used four different photographs (each in a different colour) to represent each prime, intervening stimulus,

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target and distractor. During the test phase, the target and distractor images were controlled to have the same colour and luminance (in parentheses) in each trial: red (120), blue (121), yellow (126) or white (140). Within each trial, objects in the prime, intervening and test phases were always in different colours to avoid colour-cuing. The prime and intervening stimulus were always positioned in the centre of the screen. The target and distractor images in the test phase were positioned on the left and right side of the screen and separated by a visual angle of 19.8°; these images were counterbalanced for position and combination across four lists (see Table S1).

**Auditory Stimuli.** A female Southern British English speaker recorded the auditory labels in a child-directed manner. Duration of the prime labels was 683 ms (chair) and 739 ms (coat). Duration of the intervening labels was 700 ms (chicken/tone 1) and 679 ms (car/tone 2). Tone 1, accompanying the square checkerboard was a sine wave tone in C. Tone 2 accompanying the diamond checkerboard was a sine wave tone in D.

### Apparatus and Procedure

Toddlers sat on their caregiver's lap, approximately 65 cm from a Tobii TX 300 eye-tracker running at 120 Hz and a 23-in. computer screen (1920 x 1080 resolution). A 9-point calibration was performed. After calibration, toddlers were shown the 16 trials. The experimenter initiated all trials, by pressing a computer key when the toddler's attention was on the screen. The caregiver was instructed to keep their eyes closed and to refrain from talking or interacting with their child during the study. The study was run using 'Presentmate', a custom Matlab stimuli presentation framework based on Psychophysics Toolbox extensions.

### Results

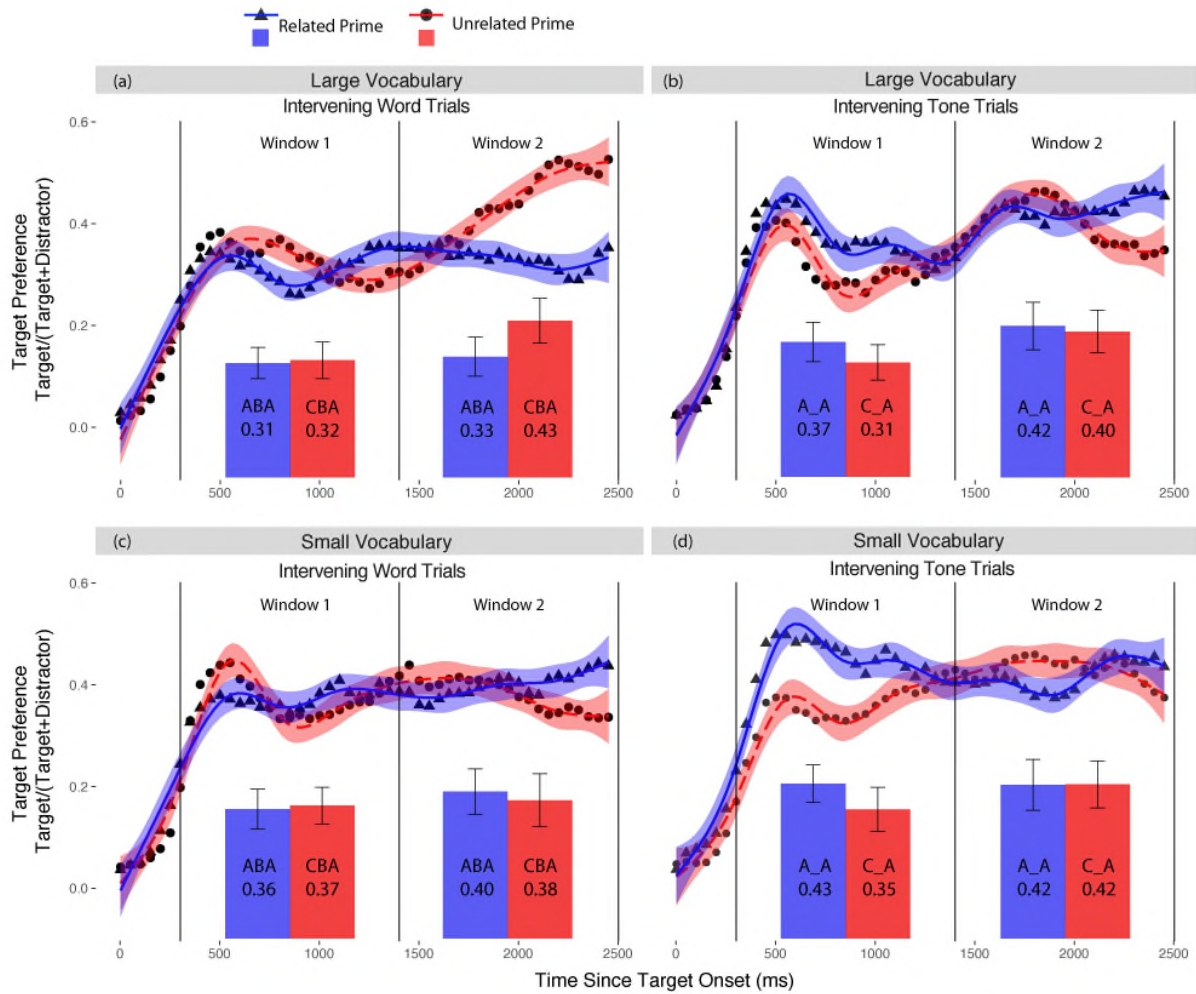
As planned, toddlers were split into large and small vocabulary size groups based on their Oxford Communicative Development Inventory (OCDI) (Hamilton et al., 2000) receptive scores

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(*median* = 215). The large vocabulary size group was reported to understand 285 out of 416 words (*range* = 216-416), while the small vocabulary size group was reported to understand an average of 140 out of 416 words on the OCDI (*range* = 24-213). A Welch unequal variance t-test indicated that the small vocabulary size group had a significantly lower OCDI receptive score than the large vocabulary size group ( $t(66.29) = -10.90, p < .001$ ). The large vocabulary size group was reported to understand on average 7.5 out of 8 test words. The small vocabulary size group was reported to understand on average 5.1 out of 8 test words.

Toddlers' preference for the target in the test phase was measured ( $\text{Target Preference} = \frac{\text{Looking Time}_{\text{Target}}}{(\text{Looking Time}_{\text{Target}} + \text{Looking Time}_{\text{Distractor}})}$ ). To allow for data comparison with the 24-month-old BSI data (Chow et al., 2016), the time course data in Figure 2 was aggregated into two equal windows for analysis: early looking period (Window 1) from 300-1400 ms and late looking period (Window 2) from 1401-2500 ms. For each window, the averaged target fixation data was entered into a binomial logistic mixed-effects model (R version 3.5.0, package lme4 version 1.1-17: function glmer) with three fixed effects: Intervening Stimulus (Word vs. Tone), Prime (Related vs. Unrelated) and Vocabulary Size (Large vs. Small), and random effects of toddlers on the intercept.

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**Figure 2.** Toddler's fixation data presented in time course (points and lines) and in aggregation (bars). The time course is divided into two equal windows: Window 1 (early looking period) and Window 2 (late looking period). Error bars indicate 95% confidence interval.

Table 1 shows the results of the Window 1 model. There was no significant effect of intervening stimulus but there was a significant effect of prime type, indicating that across both intervening stimulus types, toddlers fixated the target picture more in the related-prime trials than in the unrelated-prime trials. There was a significant interaction of intervening stimulus x prime. Post-hoc model contrasts with Bonferroni-corrected *p*-values indicate that when the intervening stimulus was a word, toddlers showed a similar amount of preference in the related-prime and

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unrelated-prime trials ( $Estimates = -0.07 (0.08)$ ,  $z = -0.84$ ,  $p = 1$ ). In contrast, when the intervening stimulus was a tone, toddlers showed a significantly greater target preference in the related-prime trials than in the unrelated-prime trials ( $Estimates = 0.39 (0.08)$ ,  $z = 4.81$ ,  $p < .001$ ). There was no significant effect of vocabulary size or interaction of intervening stimulus x vocabulary size, but there was a significant prime x vocabulary size interaction, indicating that across both intervening stimulus types, toddlers with a smaller vocabulary showed greater target preference in the related-prime trials than in the unrelated-prime trials. However, there was no significant 3-way interaction of intervening stimulus x prime x vocabulary size. In sum, toddlers, regardless of vocabulary size, showed a facilitatory semantic priming effect in the intervening-tone (baseline) trials in Window 1.

Table 1. *Results of Window 1 (Early Looking Period: 300 – 1400 ms)*

Fixed Effects	Estimates	SE	z	p
Intercept	-0.67	0.09	-7.11	< .001*
<b>Intervening Stimulus:</b> Word (baseline: Tone)	0.08	0.05	1.54	.122
<b>Prime:</b> Related (baseline: Unrelated)	0.41	0.05	8.16	< .001*
<b>Vocabulary Size:</b> Large (baseline: Small)	-0.14	0.13	-1.05	.294
<b>Intervening Stimulus:</b> Word x <b>Prime:</b> Related	-0.41	0.07	-5.73	< .001*
<b>Intervening Stimulus:</b> Word x <b>Vocabulary Size:</b> Large	-0.05	0.07	-0.71	.480
<b>Prime:</b> Related x <b>Vocabulary Size:</b> Large	-0.18	0.07	-2.48	.013*
<b>Intervening Stimulus:</b> Word x <b>Prime:</b> Related x <b>Vocabulary Size:</b> Large	0.13	0.10	1.26	.210

Table 2 shows the results of the Window 2 model. There was a significant effect of intervening stimulus. Across both prime types, toddlers showed a significant reduction in target preference when the intervening stimulus was a word than when it was a tone. There was no significant effect of prime type, nor of vocabulary size. There was a marginally significant interaction of intervening stimulus x prime type ( $p = .056$ ), and two significant interactions of intervening stimulus x vocabulary size and prime type x vocabulary size; all three of these two-

way interactions were driven by the significant 3-way interaction of intervening stimulus x prime type x vocabulary size (see last row of Table 2). Post-hoc model contrasts with Bonferroni-corrected  $p$ -values indicate that, when the intervening stimulus was a word, toddlers with a large vocabulary had a significantly smaller target preference in the related-prime trials than in the unrelated-prime trials ( $Estimates = -0.43$  (0.05),  $z = -8.63$ ,  $p < .001$ ), while toddlers with a small vocabulary showed a similar amount of target preference in the related- and unrelated-prime trials ( $Estimates = 0.07$  (0.05),  $z = 1.43$ ,  $p = .607$ ). When the intervening stimulus was a tone, similar levels of target preference were observed in the related- and unrelated-prime trials for both large ( $Estimates = 0.10$  (0.05),  $z = 2.01$ ,  $p = .178$ ) and small vocabulary toddlers ( $Estimates = -0.06$  (0.05),  $z = -1.27$ ,  $p = .816$ ). In sum, BSI was observed in Window 2 in the intervening-word trials, but only amongst toddlers with a large vocabulary.

Table 2. *Results of Window 2 (Late Looking Period: 1401 – 2500 ms)*

Fixed Effects	Estimates	SE	$z$	$p$
Intercept	-0.30	0.08	-3.59	< .001*
<b>Intervening Stimulus:</b> Word (baseline: Tone)	-0.20	0.05	-4.10	< .001*
<b>Prime Type:</b> Related (baseline: Unrelated)	-0.06	0.05	-1.27	.204
<b>Vocabulary Size:</b> Large (baseline: Small)	-0.14	0.12	-1.18	.237
<b>Intervening Stimulus:</b> Word x <b>Prime Type:</b> Related	0.13	0.07	1.91	.056
<b>Intervening Stimulus:</b> Word x <b>Vocabulary Size:</b> Large	0.34	0.07	4.84	< .001*
<b>Prime Type:</b> Related x <b>Vocabulary Size:</b> Large	0.16	0.07	2.32	.020*
<b>Intervening Stimulus:</b> Word x <b>Prime Type:</b> Related x <b>Vocabulary Size:</b> Large	-0.66	0.10	-6.71	< .001*

## Discussion

The current study has two main findings. First, 18-month-olds showed a facilitatory semantic priming effect in the intervening-tone (baseline) trials during the early looking period (Window 1), i.e., a larger target preference in the A\_A (related-prime) trials than in the C\_A (unrelated-prime) trials. This effect was equivalent for both the large and small vocabulary size



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groups, suggesting that both groups had similar understanding of the semantic categories used in the current study. Second, 18-month-olds showed the BSI effect in the intervening-word (test) trials. As predicted, the BSI effect was modulated by vocabulary size: BSI was observed during the late looking period (Window 2) only in 18-month-olds with a relatively large vocabulary, replicating that previously reported for 24-month-olds in Chow et al., 2016 (see Figure 2a). No BSI effect was found in 18-month-olds with a small vocabulary (see Figure 2c). Specifically, toddlers with a large vocabulary had a significantly smaller target preference in the ABA (related-prime) trials than in the CBA (unrelated-prime) trials, while toddlers with a small vocabulary showed a similar amount of target preference in the ABA and CBA trials. These findings demonstrate that backward semantic inhibition emerges between the age of 18-months and 24-months, and suggests that an increased number of items (word knowledge) in the toddlers' lexical-semantic system may be an important driving force behind the emergence of backward semantic inhibition (i.e., the formation of inhibitory links between items), thus allowing efficient selective attention to currently relevant words and concepts.

In our study, we predicted that vocabulary size would play a fundamental role for semantic inhibition processes to emerge. Inhibitory mechanisms usually serve a selective function. Organisms develop attention-based inhibitory mechanisms to deal with a busy environment. When task-relevant stimuli are presented alongside other distracting stimuli, an inhibitory mechanism can be of great help for target selection. However, inhibition would be of little help if the organism has to deal with a simple environment. In our case, the environment is the lexicon and the objects are the words in the lexicon. As the environment (lexicon) becomes more complex, inhibition becomes increasingly important. The busy environment recruits the inhibition needed to deal with

it. This is a strong rationale in favour of the interpretation that it is an increasing vocabulary that promotes semantic inhibition in young children.

Toddlers with smaller vocabularies showed larger facilitatory priming with the tone as the intervening stimulus than toddlers with larger vocabularies. This result is in line with Yap, Tse, and Balota's (2009) results in which undergraduates with different vocabulary knowledge were compared according to their priming effects as a function of target difficulty. For high-vocabulary participants, both high- and low-frequency target words were fluently processed due to their relatively strong representations in the lexical system (similar high-integrity representations), and hence priming was not modulated by the frequency of the target words. However, for low-vocabulary participants, low-frequency target words were less fluently processed (low-integrity representations) than high-frequency ones, and participants showed greater reliance on primes for resolving these difficult targets, producing larger priming effects. In the current study, toddlers with smaller vocabularies might have similarly benefited more from related primes than toddlers with larger vocabularies because the targets were less robustly represented in these small vocabularies.

A striking finding in the time course of the observed effects is that BSI is observed only in the late looking period (Window 2), not in the early looking period (Window 1). One explanation for why the effect emerges later in time relates to the time course of other inhibitory mechanisms reported in the adult literature. For instance, inhibition of return is usually observed at cue-target intervals longer than 300 ms in simple detection tasks and even later in discrimination tasks (Lupiañez, Milán, Tornay, Madrid, & Tudela, 1997; Posner & Cohen, 1984). It is a common view that inhibitory processes take time to manifest. The large vocabulary toddlers in the current study

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who manifest BSI also do so at a delayed interval, demonstrating a striking convergence between our more precocious young participants and adults.

### **Locus of Backward Semantic Inhibition**

Did BSI take place at the lexical or conceptual level in the mental lexicon? With the current design, we cannot determine whether BSI took place at the lexical level, conceptual level or both. We speculate that it is likely to be both. We included a target label in the experimental paradigm to ensure that the targeted concepts are activated since we know that labels automatically activate their associated concepts. Future research should look into teasing apart the two possibilities, such as by removing the target label from the prime and intervening phases of the trial. Regardless of whether BSI operates at the lexical and/or conceptual level, our findings indicate that the inhibitory connections underpinning BSI are not present until the second half of the second year. This finding parallels the findings for forward semantic inhibition (FSI), which is present at 21-months but not 18-months of age. It seems that a semantic inhibitory mechanism emerges to deal with a greater need for a more structured organisation of the mental lexicon that allows more efficient selection and deselection of items. Given the similar timeframe of the emergence of BSI and FSI, and that both BSI and FSI likely serve to increase efficiency of semantic item selection and deselection, it is possible that both inhibitory effects share the same underlying mechanism.

### **Conclusion**

Our current findings highlight the potential role of vocabulary growth for the emergence of inhibitory processes in the developing lexical-semantic system. In contrast to facilitatory priming effects which can be detected at least as early as 18-months of age<sup>1</sup>, inhibitory processes emerge later in development and appear to be closely related to vocabulary growth. The link

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<sup>1</sup> Recent research, using the same methods as Delle Luche et al. (2014), have reported facilitatory lexical-semantic priming in 15-month olds (Floccia, Delle Luche, Goslin, Hills, & Plunkett, 2016).

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between vocabulary growth and the emergence of inhibitory processing makes sense: as the number of lexical items increases, the pressure to develop an efficient, adult-like word recognition system driven by activation *and* by inhibition also increases.

Inhibitory processes are not only relatively late emerging in development, but are also relatively delayed in their online effects compared to facilitatory processes: Inhibition was observed in the large vocabulary 18-month olds only in the later second time window of analysis, whereas facilitation effects were found in the early time window of analysis. The slower acting processes of inhibition observed in the infant lexical-semantic system are consistent with a top-down role for language in mediating attention to referents in a complex environment.

References

- Allopenna, P. D., Magnuson, J. S., & Tanenhaus, M. K. (1998). Tracking the Time Course of Spoken Word Recognition Using Eye Movements: Evidence for Continuous Mapping Models. *Journal of Memory and Language*, 38(4), 419–439.  
<https://doi.org/10.1006/jmla.1997.2558>
- Arias-Trejo, N., & Plunkett, K. (2009). Lexical-semantic priming effects during infancy. *Philosophical Transactions of the Royal Society of London*, 364(1536), 3633–3647.  
<https://doi.org/10.1098/rstb.2009.0146>
- Arias-Trejo, N., & Plunkett, K. (2013). What's in a link: Associative and taxonomic priming effects in the infant lexicon. *Cognition*, 128(2), 214–227.  
<https://doi.org/10.1016/j.cognition.2013.03.008>
- Chow, J., Aimola Davies, A. M., Fuentes, L. J., & Plunkett, K. (2016). Backward Semantic Inhibition in Toddlers. *Psychological Science*, 27(10).  
<https://doi.org/10.1177/0956797616659766>
- Chow, J., Aimola Davies, A. M., & Plunkett, K. (2017). Spoken-word recognition in 2-year-olds: The tug of war between phonological and semantic activation. *Journal of Memory and Language*, 93, 104–134. <https://doi.org/10.1016/j.jml.2016.08.004>
- Dahan, D., Magnuson, J. S., Tanenhaus, M. K., & Hogan, E. M. (2001). Subcategorical mismatches and the time course of lexical access: Evidence for lexical competition. *Language and Cognitive Processes*, 16(5–6), 507–534.  
<https://doi.org/10.1080/01690960143000074>
- Delle Luche, C., Durrant, S., Floccia, C., & Plunkett, K. (2014). Implicit meaning in 18-month-old toddlers. *Developmental Science*, 1–8. <https://doi.org/10.1111/desc.12164>
- Floccia, C., Delle Luche, C., Goslin, J., Hills, T., & Plunkett, K. (2016). The organisation of the early lexicon: Evidence from auditory priming in 15- and 18-month-olds. *Oral Communication Presented at the 2016 Biennial International Conference on Infant Studies, New Orleans*.
- Fuentes, L. J., Vivas, A. B., & Humphreys, G. W. (1999a). Inhibitory Mechanisms of Attentional Networks : Spatial and Semantic Inhibitory Processing. *Journal of Experimental Psychology: Human Perception and Performance*, 25(4), 1114–1126.  
<https://doi.org/10.1037/0096-1523.25.4.1114>

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- Fuentes, L. J., Vivas, A. B., & Humphreys, G. W. (1999b). Inhibitory Tagging of Stimulus Properties in Inhibition of Return: Effects on Semantic Priming and Flanker Interference. *The Quarterly Journal of Experimental Psychology Section A*, 52(1), 149–164. <https://doi.org/10.1080/713755797>
- Glaser, W. R., & Dünghoff, F.-J. (1984). The time course of picture-word interference. *Journal of Experimental Psychology: Human Perception and Performance*, 10(5), 640–654. <https://doi.org/10.1037/0096-1523.10.5.640>
- Goldinger, S. D., Luce, P. A., & Pisoni, D. B. (1989). Priming Lexical Neighbors of Spoken Words: Effects of Competition and Inhibition. *Journal of Memory and Language*, 28(5), 501–518.
- Golinkoff, R. M., Hirsh-Pasek, K., Cauley, K. M., & Gordon, L. (1987). The eyes have it: lexical and syntactic comprehension in a new paradigm. *Journal of Child Language*, 14(01), 23–45. <https://doi.org/10.1017/S030500090001271X>
- Hamilton, a, Plunkett, K., & Schafer, G. (2000). Infant vocabulary development assessed with a British communicative development inventory. *Journal of Child Language*, 27(3), 689–705. <https://doi.org/10.1017/S0305000900004414>
- Huettig, F., & Altmann, G. T. M. (2005). Word meaning and the control of eye fixation: Semantic competitor effects and the visual world paradigm. *Cognition*, 96(1), 23–32. <https://doi.org/10.1016/j.cognition.2004.10.003>
- Huettig, F., & McQueen, J. M. (2007). The tug of war between phonological, semantic and shape information in language-mediated visual search. *Journal of Memory and Language*, 57(4), 460–482. <https://doi.org/10.1016/j.jml.2007.02.001>
- Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., & Koch, I. (2010). Control and interference in task switching—A review. *Psychological Bulletin*, 136(5), 849–874. <https://doi.org/10.1037/a0019842>
- Kiss, G. R., Armstrong, C. A., & Milroy, R. (1972). *An associative thesaurus of English*. Medical Research Council. Speech and Communication Unit, University of Edinburgh, Scotland.
- Luce, P. A., & Pisoni, D. B. (1998). Recognizing Spoken Words: The Neighborhood Activation Model. *Ear and Hearing*, 19(1), 1–36. <https://doi.org/10.1097/MPG.0b013e3181a15ae8>.Screening

- Lupiáñez, J., Milán, E. G., Tornay, F. J., Madrid, E., & Tudela, P. (1997). Does IOR occur in discrimination tasks? Yes, it does, but later. *Perception & Psychophysics*, 59(8), 1241–1254. <https://doi.org/10.3758/BF03214211>
- Mani, N., & Plunkett, K. (2011). Phonological priming and cohort effects in toddlers. *Cognition*, 121(2), 196–206. <https://doi.org/10.1016/j.cognition.2011.06.013>
- Mayr, U., & Keele, S. W. (2000). Changing internal constraints on action: the role of backward inhibition. *Journal of Experimental Psychology. General*, 129(1), 4–26. <https://doi.org/10.1037/0096-3445.129.1.4>
- McClelland, J. L., & Elman, J. L. (1986). The TRACE model of speech perception. *Cognitive Psychology*, 18(1), 1–86. [https://doi.org/10.1016/0010-0285\(86\)90015-0](https://doi.org/10.1016/0010-0285(86)90015-0)
- Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: evidence of a dependence between retrieval operations. *Journal of Experimental Psychology*, 90(2), 227–234. <https://doi.org/10.1037/h0031564>
- Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. *Attention and Performance: Control of Language Processes*, 531–556. <https://doi.org/10.1162/jocn.1991.3.4.335>
- Schriefers, H., Meyer, A. S., & Levelt, W. J. M. (1990). Exploring the time course of lexical access in language production: Picture-word interference studies. *Journal of Memory and Language*, 29(1), 86–102. [https://doi.org/10.1016/0749-596X\(90\)90011-N](https://doi.org/10.1016/0749-596X(90)90011-N)
- Styles, S. J., & Plunkett, K. (2009). How do infants build a semantic system? *Language and Cognition*, 1(1), 1–24. <https://doi.org/10.1515/LANGCOG.2009.001>
- Swingle, D., & Aslin, R. N. (2007). Lexical competition in young children's word learning. *Cognitive Psychology*, 54(2), 99–132. <https://doi.org/10.1016/j.cogpsych.2006.05.001>
- Tipper, S. P. (1985). The negative priming effect: inhibitory priming by ignored objects. *The Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology*, 37(4), 571–590. <https://doi.org/10.1080/14640748508400920>
- Weger, U. W., & Inhoff, A. W. (2006). Semantic inhibition of return is the exception rather than the rule. *Perception & Psychophysics*, 68(2), 244–253.
- Wheeldon, L. R., & Monsell, S. (1994). Inhibition of spoken word production by priming a semantic competitor. *Journal of Memory and Language*. <https://doi.org/10.1006/jmla.1994.1016>
- Willits, J. A., Wojcik, E. H., Seidenberg, M. S., & Saffran, J. R. (2013). Toddlers Activate

Lexical Semantic Knowledge in the Absence of Visual Referents: Evidence from Auditory Priming. *Infancy*, 18(6), 1053–1075. <https://doi.org/10.1111/infa.12026>

Yap, M. J., Tse, C. S., & Balota, D. A. (2009). Individual differences in the joint effects of semantic priming and word frequency revealed by RT distributional analyses: The role of lexical integrity. *Journal of Memory and Language*, 61(3), 303–325. <https://doi.org/10.1016/j.jml.2009.07.001>

Zwitserslood, P. (1989). The locus of the effects of sentential-semantic context in spoken-word processing. *Cognition*, 32(1), 25–64. [https://doi.org/10.1016/0010-0277\(89\)90013-9](https://doi.org/10.1016/0010-0277(89)90013-9)



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*Figure 1.* The backward semantic inhibition (BSI) paradigm used in 24-month-old toddlers (Chow et al., 2016) and in 18-month-old toddlers in the current study. There were in total four types of trials: a) Two intervening-word (test) trials, including Related Prime with Intervening Word (ABA) and Unrelated Prime with Intervening Word (CBA); b) Two intervening-tone (baseline) trials, including Related Prime with Intervening Tone (A\_A) and Unrelated Prime with Intervening Tone (C\_A).

*Figure 2.* Toddler's fixation data presented in time course (points and lines) and in aggregation (bars). The time course is divided into two equal windows: Window 1 (early looking period) and Window 2 (late looking period). Error bars indicate 95% confidence interval.

## Supplementary Materials

Table S1. *Example of the Stimuli Presented in Each Trial*

Trial*	Condition			Visual (and Audio) Stimuli Presented in Each Trial				
	Categories	Prime	Intervening	Prime	Intervening	Test <sup>+</sup>		
1	ABA	Related	Word	Chair (Chair)	Chicken (Chicken)	Balloon	<b><u>Table</u></b>	(Look)
2	ABA	Related	Word	Chair (Chair)	Chicken (Chicken)	<b><u>Table</u></b>	Balloon	(Wow)
3	ABA	Related	Word	Coat (Coat)	Car (Car)	Flower	<b><u>Hat</u></b>	(Look)
4	ABA	Related	Word	Coat (Coat)	Car (Car)	<b><u>Hat</u></b>	Flower	(Wow)
5	CBA	Unrelated	Word	Coat (Coat)	Chicken (Chicken)	Balloon	<b><u>Table</u></b>	(Look)
6	CBA	Unrelated	Word	Coat (Coat)	Chicken (Chicken)	<b><u>Table</u></b>	Balloon	(Wow)
7	CBA	Unrelated	Word	Chair (Chair)	Car (Car)	Flower	<b><u>Hat</u></b>	(Look)
8	CBA	Unrelated	Word	Chair (Chair)	Car (Car)	<b><u>Hat</u></b>	Flower	(Wow)
9	A_A	Related	Tone	Chair (Chair)	Checkerboard 1 (Tone 1)	Balloon	<b><u>Table</u></b>	(Look)
10	A_A	Related	Tone	Chair (Chair)	Checkerboard 1 (Tone 1)	<b><u>Table</u></b>	Balloon	(Wow)
11	A_A	Related	Tone	Coat (Coat)	Checkerboard 2 (Tone 2)	Flower	<b><u>Hat</u></b>	(Look)
12	A_A	Related	Tone	Coat (Coat)	Checkerboard 2 (Tone 2)	<b><u>Hat</u></b>	Flower	(Wow)
13	C_A	Unrelated	Tone	Coat (Coat)	Checkerboard 1 (Tone 1)	Balloon	<b><u>Table</u></b>	(Look)
14	C_A	Unrelated	Tone	Coat (Coat)	Checkerboard 1 (Tone 1)	<b><u>Table</u></b>	Balloon	(Wow)
15	C_A	Unrelated	Tone	Chair (Chair)	Checkerboard 2 (Tone 2)	Flower	<b><u>Hat</u></b>	(Look)
16	C_A	Unrelated	Tone	Chair (Chair)	Checkerboard 2 (Tone 2)	<b><u>Hat</u></b>	Flower	(Wow)

\* Actual trial order was randomised by the eye-tracking software

<sup>+</sup>Test target is in bold and underlined