Language- and spatially-mediated attention in toddlers

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Abstract

Selective attention involves attending to task-relevant information and inhibiting task-irrelevant information. While spatial priming is known to efficiently shape selective attention, the nature of language-mediated effects on selective attention is not well-understood, particularly in young toddlers. We compare the impact of language-mediated and spatially-mediated attention in an eye-tracking paradigm in which two objects are presented in one of four possible locations and one of the objects is highlighted. The impact of labelling on attention orienting during a *prime* phase was tested in a subsequent *probe* phase, where either the identity, location or both were manipulated, and compared to the impact of spatial priming. To elucidate the role of development on these effects, the study was conducted with 18- and 26-month-old toddlers. The results revealed that both language-mediated and spatially-mediated priming lead to attention orienting during the probe phase: attended information during the prime phase facilitates attention during the probe phase while ignored features are inhibited. However, in contrast to spatially-mediated attention during the prime phase, language-mediated attention can override these inhibitory effects. The impact of language on overcoming inhibitory effects is particularly noteworthy in the older age group.

Keywords: selective attention; attention orienting; language-mediated attention; inhibition; negative priming; spatially mediated attention

Introduction

Selective attention plays a key role in determining what information from the available sensory input will be processed. It involves filtering of the available sensory information: while the relevant information is attended, interference from the remaining alternatives is filtered out (Amso & Scerif, 2015).

Some form of facilitation-based orienting is present even in newborns. In contrast, selective attention orienting which involves inhibition is observed in 4–6-month-old infants (Amso & Scerif, 2015). Inhibition of irrelevant information is considered crucial for development, since attentional selection without inhibition would be random (Amso & Johnson, 2005). A recent study found that selective attention orienting is related to better learning and memory as compared to facilitation-based orienting in 4-month-old infants, suggesting that inhibition plays an important role in cognitive development (Markant & Amso, 2016).

Two experimental paradigms commonly used to study the development of selective attention are negative priming (hereafter NP) and inhibition of return (hereafter IOR). The negative priming paradigm reveals an impaired response to a target that was previously ignored (Frings, Schneider, & Fox, 2015). Furthermore, variations of this paradigm engaging either location- or identity-NP have different effects suggesting that object location is processed in a different way than object identity (Frings et al., 2015). One study found evidence of negative priming even in 9-month-old infants, suggesting that inhibitory mechanisms emerge late in the first year of life (Amso & Johnson, 2005).

While NP paradigms focus on the ability to inhibit previously ignored information, IOR paradigms typically involve a spatial cueing task, where, following brief exposure to a cue, a target appears either in the cued or opposite location. IOR studies tend to yield a crossover pattern: if the delay between cue and target is very short ($< 250ms$), there is a facilitation effect. If the delay is longer ($> 250ms$), the response is faster to targets in the non-cued location as compared to the cued location, revealing the operation of an inhibitory mechanism or selective attention (Klein, 2000).

Studies using paradigms such as NP and IOR have demonstrated the development of selective attention mechanisms during infancy and early childhood. While these studies clearly show how spatial cueing can drive attention orienting and consequent inhibition of the unattended information, it is not clear whether such orienting effects can be driven by non-spatial means.

One non-spatial mean of attention orienting is language. When hearing a name of an object present in her visual field, a toddler will spontaneously shift her gaze towards the named object (e.g. Chow, Aimola Davies, & Plunkett, 2017). While it is clear that language orients attention towards the named objects, the nature of the attentional processes driven by the linguistic input is not fully understood. The present study aims to fill this gap and examine how language directs attention and how this in turn affects visual orienting. More specifically, we explore how language-mediated attention affects the encoding of identity and location information.

To elucidate the role of vocabulary development in language-mediated attention orienting, in the present study we tested 18- and 26-month-old toddlers, i.e., just before and after notable developments in language skills (e.g., the vocabulary spurt typically observed towards the end of the second year). A recent study demonstrated that the emergence of inhibition of attention to no-longer relevant stimuli is associated with vocabulary development: inhibitory effects were only observed in toddlers with larger vocabulary sizes (Chow,

Aimola Davies, Fuentes, & Plunkett, 2018). Therefore, we expected that comparing attentional effects in pre- and post-vocabulary spurt toddlers has the potential to provide a better insight into the development of language-mediated selective attention.

As attention orienting can involve different mechanisms, some of which elicit inhibition and some not (Posner & Cohen, 1984), the present study aims to identify the nature of language-mediated attention in encoding object identity and location, and determine whether it engages *both* facilitatory (enhancement of attended information) *and* inhibitory processes (suppression of the ignored information) in toddlers. To test this, we developed a novel eye-tracking task in which two objects are presented each in one of four possible locations and one object is highlighted during a prime phase. Then, in a probe phase, either the previously attended, ignored or novel object is named and the objects reappear. The objects appear in the same or in different locations as in the prime phase. In the prime phase, we use labelling events (language-mediated condition) or spatial highlighting (spatial condition) to motivate attention to a specific object-location binding.

If processing of the attended identity and location is enhanced during the prime phase, we expect that identification of the previously attended target will be more efficient as compared to identifying a previously ignored object. However, if there is negative priming, we expect that a response to the previously ignored location will be impaired. A contrasting set of predictions derives from the literature on inhibition of return. IOR predicts that responses to previously attended objects will be inhibited in the present study.

To summarise, while it is established that visual spatial priming efficiently drives visual selective attention in infants (Markant & Amso, 2016; Amso & Johnson, 2005), the nature of language-mediated effects on visual selective attention is not well-understood. The aim of the present study was to investigate the impact of language on visual selective attention, and compare the effects of language-mediated and spatial attentional orienting. To determine the role of emerging language abilities in attentional orienting, we tested 18- and 26-month-old toddlers, aiming to capture the language-attention interface before and after the vocabulary spurt.

Method

Participants

Eighty-six participants took part in this study, out of which 71 in the language-mediated condition, and 15 in the spatial condition (data collection paused because of the pandemic). Participants were recruited at the local maternity ward and all were full-term babies with no known health conditions. All participants came from homes where English was the only language spoken. The study was approved by the University of Oxford Ethics Committee. Eight participants were excluded (5 in the spatial condition), due to accumulating fewer than half of the valid trials or equipment failure. Thus, the final sample consisted of 68 participants in the language-mediated condition (38 18-month-old and 30 26-month-old toddlers) and 10 in the spatial condition (5 18-month-old and 5 26-month-old toddlers).

Stimuli

Visual stimuli were photographs of familiar, everyday objects. A total of 72 items were selected based on data from the Oxford Communicative Development Inventory (Hamilton, Plunkett, & Schafer, 2000). For each item, more than 70% of 18-month-old infants understood the names for these objects according to OCDI norms. The objects belonged to four broad categories (animals, food, vehicles and everyday objects). Objects were edited from the original background and placed on a grey background (5% grey, size: 410 x 410 pixels). Audio stimuli were recorded by a native Southern British English female speaker, in infant-directed speech.

Experimental Design

A novel eye-tracking task was developed for the purposes of this study. Each trial consisted of a prime and a probe phase. In the language-mediated condition, the **prime phase** began with a centrally presented attention getter accompanied by an audio phrase (e.g. "Look at the teddy!"). Two pictures then appeared on the screen, one of which was the named target and the other the distractor (see Figure 1). In the spatial condition, instead of being named, the target was spatially highlighted by a looming effect (the target picture changing size every 300ms during the same interval as the naming event in the language-mediated condition). Locations of the targets and the distractors were carefully controlled. The target appeared equally frequently in each of the four possible locations. Phonological, semantic and visual similarity were controlled for target and distractor pairings.

The following **probe phase** was identical across conditions. The attention getter was displayed again whilst either the previously attended picture (e.g., "Teddy!"), the previously unattended picture or an entirely novel object was named (e.g., "Brush!"). Then, the named picture (i.e., target) and a distractor appeared on the screen (see Figure 1). Between each trial a short 2 seconds video was played to serve as a memory flush between trials (e.g. dots of different colours accompanied by a chimming sound).

To investigate how language- and spatially-mediated attention modulate identity-location bindings, the location and the identity of the objects presented in the probe phase were systematically manipulated: attended, ignored and novel identity were presented in old, conflicting or neutral locations. Location of the target, distractor and neutral locations were counterbalanced, and each location was equally likely to contain targets and distractors.

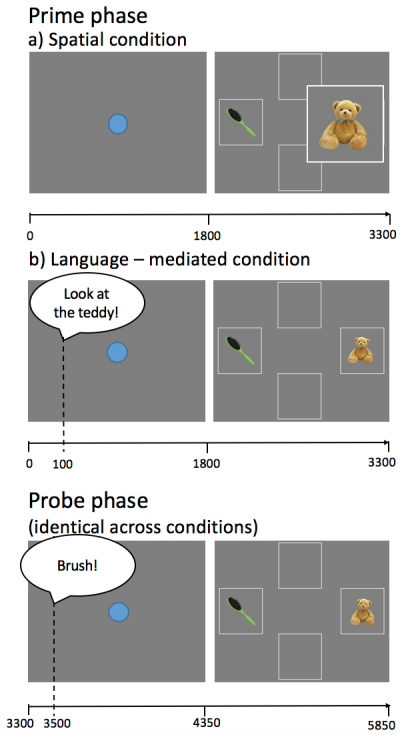

Figure 1: Experimental design. Each trial consisted of a prime and a probe phase. During the prime phase, the target was either spatially highlighted or labelled. The probe phase was identical across conditions: a target was labelled, and presented either in the old, conflicting or a neutral location.

Experimental procedure and data processing

After written consent was obtained from the carer, the infant was seated on their carer's lap approximately 60 cm from a 1920x1080 inch monitor screen in a sound-attenuated experimental booth. The carer was asked to keep their eyes closed for the duration of the experiment. Gaze data was recorded using a Tobii TX300 Eye Tracker with a 120 Hz sampling frequency. The study was run with PresentMate, a custom Matlab stimulus presentation software based on the Psychophysics Toolbox. The session started with a six point calibration procedure. Infants' behaviour was monitored via a centrally-located camera above the screen. In case infants became distracted, between trials the experimenter talked to them via a microphone in order to attract infants' attention back to the screen.

Fixations were calculated from raw gaze data using custom Matlab routines. A second-order Savitsky-Golay filter with a length of seven samples was used for data filtering (Nyström & Holmqvist, 2010). Minimum fixation duration was 100 ms. Eye-tracking data was considered valid if the eye-tracker validation flag indicated that at least one of the eyes was detected and the recorded gaze was within the screen area.

Blinks were detected as sections of the data with an instantaneous rate of change of pupil diameter greater than 0.1 mm for both eyes and the corresponding samples were flagged as invalid. If the invalid data span was shorter than 100ms, it was replaced with the last valid value. Data analysis and visualisation were performed in R (R Core Team, 2013).

Time-course data was modelled using growth-curve analysis (thereafter GCA), (Mirman, 2014) using the lme4 (Bates, Mächler, Bolker, & Walker, 2015) and lmerTest packages (Kuznetsova, Brockhoff, & Christensen, 2017). Fixation proportion was modelled using a linear and quadratic orthogonal growth model with fixed effects of *Age* (18- and 26-mo), *Location* (old, neutral and novel) and *Target Status* (previously attended and previously ignored), and a random effect of *Participant* on the intercept term. The fixed effects were added to the base model and the effects were evaluated using model comparisons (Mirman, 2014).

Given the small sample size in the spatial condition, statistical analysis was restricted to language-mediated condition.

Results

Prime phase

In the prime phase, participants were presented with 2 pictures, and one of of them was highlighted (labelled or spatially primed). To determine whether the highlighting event resulted in orienting of attention towards the highlighted picture (target), we examined the time course of target looking. As shown in Figure 2, participants systematically fixated the target picture more than the other picture (*chance* $= 0.5$), revealing that both language-mediated and spatial priming events direct attention to the target. In the language-mediated condition, there was no difference in the time course of target-looking between 18- and 26-month-old participants. This was confirmed by a GCA which revealed no effect of *Age* ($\chi 2(1) = 2.29, p = 0.13$), i.e., 18- and 26-month-olds were equally fast in fixating the target in the prime phase (average proportion of target fixation was significantly above chance, $t(67) = 16.75, p < .001$).

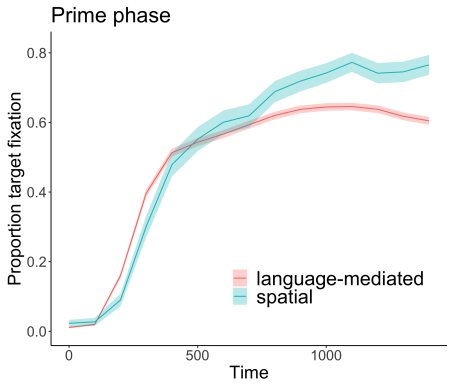

Figure 2: Time course of target fixation in the prime phase: both language-mediated and spatial priming result in orienting attention to the target.

In sum, this result confirms that the highlighting events di-

rected attention towards the target picture equally for the two age groups. Hence, any potential age-differences in looking patterns during the probe phase cannot be attributed to a difference in the speed of target-fixation due to age.

Probe phase

Looking patterns in the prime phase also revealed that participants tend to fixate the target more than the distractor. In the following set of analyses, we examine the impact of the location and identity of the target named in the probe phase once the pictures reappear.

Negative Priming. First, we tested for the presence of negative priming effects. We compared attention to the previously attended and previously ignored objects when they remain in the same locations as in the prime phase. In case of negative priming, we would expect suppression of the previously ignored object-location combination relative to the previously attended object-location combination.

As shown in Figure 3, the pattern of results suggests that language-mediated attention affects the ability to detect the probe target in a way different than spatial priming. In the spatial condition, there seems to be a substantial impact on attention to the previously ignored identity/location in the probe phase. In contrast, the language-mediated condition suggests that language helps overcome inhibition of the previously ignored location.

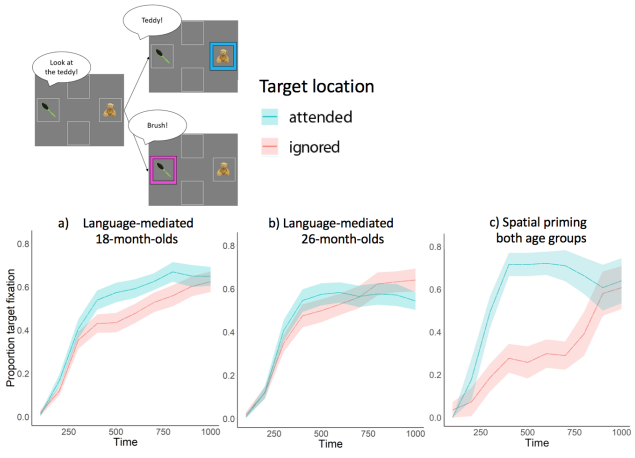

Figure 3: Negative priming: time course of the target fixations to the previously attended and previously ignored identity (display remains the same as in the prime phase). Looking patterns suggest the presence of NP.

Focusing on the language-mediated condition, both 18- and 26-month-old toddlers identified the previously-attended identity/location faster than the previously-ignored identity/location and there was no difference between the two groups (Figure 3). This was confirmed by a GCA which revealed that adding *Target Status* (previously attended vs. ignored) to the base model significantly improved model fit ($\chi 2(3) = 16.73, p < 0.001$), whereas *Age* did not. These results demonstrate that there is a suppression of the previously ignored event (identity-location), providing support for the negative priming hypothesis.

Inhibition of Return. Next, we explored whether there was evidence of IOR by comparing attention to the previously attended identity when presented in its old location, a neutral location and a conflicting location. If there is IOR, we would expect suppression of the previously attended location relative to other locations on the display.

As shown in Figure 4, participants in both conditions are very robust in identifying the target when it is presented in the old or a neutral location. However, they are poor at identifying the target when it is presented in the previously ignored location.

In the language-mediated condition, both 18- and 26-month-old toddlers identified the previously-attended identity faster when it appeared in the old or neutral locations relative to the conflicting location. This was confirmed in a GCA where adding the effect of *Location* (Old vs. Ignored vs. Neutral) significantly improved the model fit ($\chi 2(6) = 122.41, p < 0.001$). The model fit did not improve when *Age* was included.

In sum, this pattern of results provides no support for IOR. At the same time, it provides a further evidence of the inhibition of the previously ignored location.

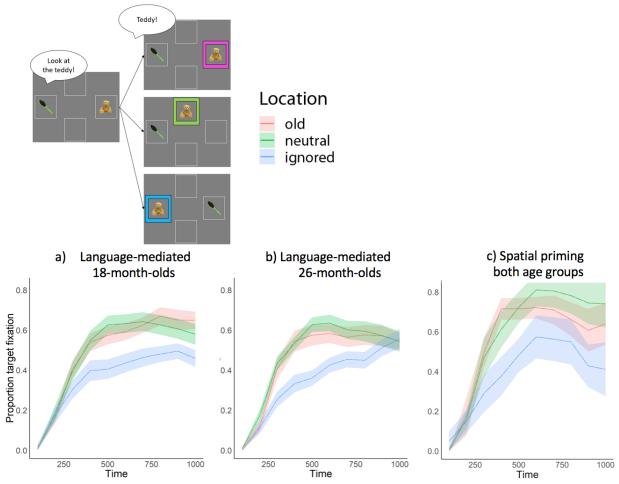

Figure 4: Inhibition of return: time course of the target fixations to the attended identity in an old, neutral or ignored locations. Looking patterns provide no evidence for IOR.

Taken together, the analyses thus far clearly show that language- and spatially-mediated attention orienting lead to enhanced processing of the attended information and inhibition of the ignored location. The following analyses aim to elucidate which components of the attended information, i.e., identity-location binding, are affected by language-mediated attention. We explore whether using language to direct attention affects primarily identity or also location of the ref-

erent. To test this, we examine how violation of location affects attention to the ignored identity and a novel identity. If language primarily indexes a referent (i.e., identity), we would expect that identification of an ignored identity will be delayed regardless of the location, while identification of a novel identity should not be affected by the location.

Ignored Identity. To test the extent to which location of the ignored event was suppressed we compared attention to the previously ignored identity when it remains in the same location as in the prime phase or moves to a neutral location. If the location is suppressed, we would expect faster target detection when a previously ignored object is presented in a neutral location.

As shown in Figure 5, 26-month-olds in the language-mediated condition and participants in the spatial condition were faster to identify the target when it is in a neutral location. In contrast, 18-month-olds are more efficient when the previously-ignored target remains in the old location. GCA of the fixation patterns in the language-mediated condition revealed that including the *Location x Age* interaction significantly improved the model fit ($\chi 2(5) = 23.49, p < 0.001$).

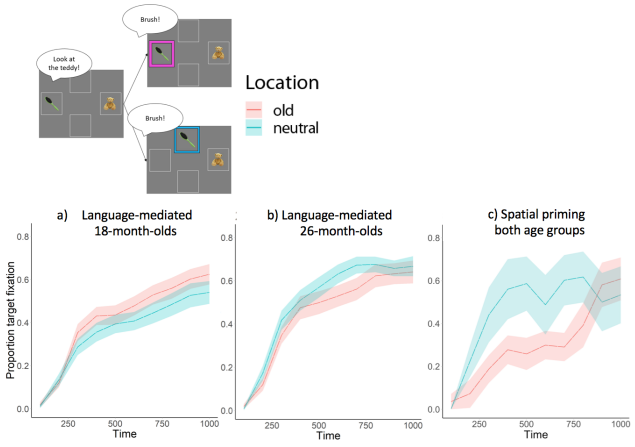

Figure 5: Detecting previously ignored identity: time course of the target fixations to the previously ignored identity presented either in the old or a neutral location.

Novel Identity. To test to whether the previously ignored location is suppressed irrespective of identity, we compared attention to a novel identity in the previously ignored location relative to the novel neutral location. Looking patterns revealed that the previously ignored location is inhibited in both language-mediated and the spatial conditions, and that inhibition seems to be stronger in the spatial condition (see Figure 6). Analysis of the looking patterns in the language-mediated condition revealed a significant effect of *Location* (Ignored and Neutral) and *Age* (18 and 26) and an interaction *Target Status x Age* ($\chi 2(5) = 21.52, p < 0.001$). The observed interaction suggests that 26-month-olds are faster in overcoming the inhibition of the previously ignored location as compared to the 18-month-olds.

These results demonstrate that 18- and 26-month-olds identified a novel identity faster when the novel identity was presented in a neutral location, as compared to when presented in a conflicting location, suggesting that the previously ignored location has been inhibited. Taken together, this suggests that language is targeting, not only identity, but also the location of the binding

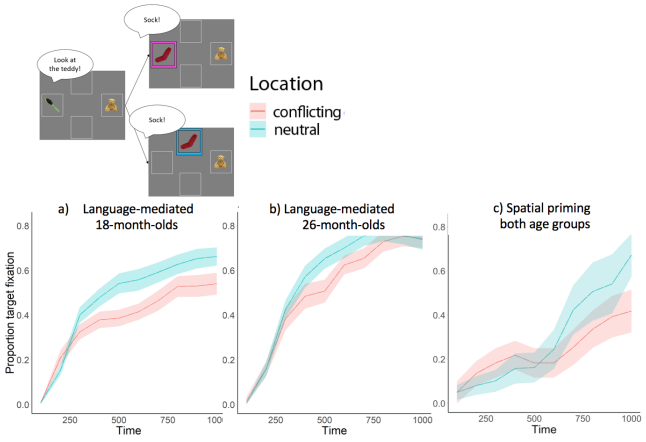

Figure 6: Detecting a novel identity: time course of the target fixations to the novel identity presented either in a previously ignored (conflicting) or a neutral location.

General Discussion

The present study investigated the impact of language on attention. In a novel eye-tracking paradigm, participants were presented with two pictures, one of which was named or spatially highlighted. In the following probe phase, one picture was named and then a display with two pictures appeared. The named object was either the previously attended target, the previously ignored object or a novel one. At the same time, location was systematically manipulated so that the target appeared in the old, conflicting or a neutral location. The results revealed that both language and spatial cues orient attention and shape the strength of encoding of the identity and location in 18- and 26-month-old toddlers.

Comparison of the looking patterns in the language-mediated and spatially-mediated conditions seem to suggest that language-mediated attention affects the probe phase in a way different from spatial priming. In particular, language helps overcome inhibition of the previously ignored object. Although the observed effects are stark, due to the small sample size in the spatial condition, these are only tentative proposals and further data collection for participants in the spatial condition will provide a better understanding of these effects.

Language input mediates attention processes

In this section, we focus on the effects of language on attention. The present study revealed that linguistic input shapes visual processing by orienting of visual attention. When the identity-location information is repeated, the previously at-

tended information is identified faster as compared to the previously ignored information.

The findings suggest that language-mediated attention results in specific inhibitory effects. There is clear evidence of negative priming, where detection of the previously ignored information was significantly hindered. At the same time, there was no support for inhibition of return (IOR), as both age groups were faster to identify the previously attended identity in old and neutral locations relative to conflicting locations. As IOR is sensitive to timing parameters, i.e., delay between the prime and the probe phase, it is possible that manipulating the timing used in the present study might produce IOR-like effects. However, the present set of results supports the hypothesis that language-mediated attention during the prime phase enables/facilitates identification of the same object-location combination in the subsequent probe phase.

Manipulating the location of the previously attended identity revealed that both 18- and 26-month-old toddlers express an inhibition of response when the target is presented in the previously ignored location, whereas they were equally fast to shift attention when the object was presented in the old or neutral location. These results suggests that there is a negative priming effect and inhibition of the previously ignored location for the previously attended object, rather than the identify of the object itself.

Furthermore, 18-month-old toddlers were faster to identify a previously ignored identity when presented in its old location than in the neutral location. In contrast, 26-month-olds show the opposite pattern of results. In the latter case, target identification was faster when the previously ignored identity is presented in a neutral location. These results suggest that both 18-month-olds and 26-month-olds are successful in forming identity-location binding of the ignored event, but the stronger inhibition of location in the older group points to the development of robust suppression of the previously ignored location. This is further supported by the pattern of results observed for the novel identity where both 18- and 26-month-olds showed evidence of inhibition of the previously ignored location.

The observed differences in the 18- and 26-month-old toddlers' performance suggest that vocabulary development plays a role in the impact of language on attention. Although there was no difference in the speed of target identification in the prime phase, looking patterns in the probe phase suggest that with development language becomes increasingly effective in overriding inhibitory effects. This highlights the role language plays in determining which information from the environment will be selected and processed.

Lastly, preliminary insights into the effects of spatially-mediated attention in this task suggest that spatial priming seems to be very effective in directing attention, but, in contrast to language, not so effective in overcoming inhibition. However, these are only speculations and further data collection will provide a clearer insight into these effects.

To summarise, the present study demonstrated that language-mediated attention facilitates encoding of the attended information, while suppressing the ignored. This inhibition effect is not absolute, as toddlers are still able to encode information, and language seems to serve as a flexible orienting system as compared to spatially-mediated orienting.

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References

Amso, D., & Johnson, S. P. (2005). Selection and inhibition in infancy: Evidence from the spatial negative priming paradigm. *Cognition*, *95*(2). doi: 10.1016/j.cognition.2004.08.006

Amso, D., & Scerif, G. (2015). The attentive brain: Insights from developmental cognitive neuroscience. , *16*(10), 606–619. doi: 10.1038/nrn4025

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48.

Chow, J., Aimola Davies, A. M., Fuentes, L. J., & Plunkett, K. (2018). The vocabulary spurt predicts the emergence of backward semantic inhibition in 18-month-old toddlers. *Developmental Science*, e12754. doi: 10.1111/desc.12754

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. doi: 10.1016/j.jml.2016.08.004

Frings, C., Schneider, K. K., & Fox, E. (2015). The negative priming paradigm: An update and implications for selective attention. *Psychonomic Bulletin and Review*, *22*(6), 1577–1597. doi: 10.3758/s13423-015-0841-4

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. doi: 10.1017/S0305000900004414

Klein, R. M. (2000). Inhibition of return. *Trends in Cognitive Sciences*(4), 138–147. doi: 10.1016/S1364-6613(00)01452-2

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software*, *82*(13), 1–26.

Markant, J., & Amso, D. (2016). The Development of Selective Attention Orienting is an Agent of Change in Learning and Memory Efficacy. *Infancy*, *21*(2), 154–176. doi: 10.1111/infa.12100

Mirman, D. (2014). *Growth curve analysis and visualization using r*. CRC Press.

Nyström, M., & Holmqvist, K. (2010). An adaptive algorithm for fixation, saccade, and glissade detection in eyetracking data. *Behavior Research Methods*, *42*(1), 188–204.

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. Bouwhuis (Eds.), *Attention and performance* (p. 531 - 556). Hillsdale, NJ: Lawrence Erlbaum Associates.

R Core Team. (2013). R: A language and environment for statistical computing [Computer software manual]. Vienna, Austria. Retrieved from `http://www.R-project.org/`