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OBSERVATION

# Prediction During Language Processing is a Piece of Cake — But Only for Skilled Producers

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Are there individual differences in children's prediction of upcoming linguistic input and what do these differences reflect? Using a variant of the preferential looking paradigm (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987), we found that, upon hearing a sentence like, "The boy eats a big cake," 2-year-olds fixate edible objects in a visual scene (a cake) soon after they hear the semantically constraining verb *eats* and prior to hearing the word *cake*. Importantly, children's prediction skills were significantly correlated with their productive vocabulary size—skilled producers (i.e., children with large production vocabularies) showed evidence of predicting upcoming linguistic input, while low producers did not. Furthermore, we found that children's prediction ability is tied specifically to their production skills and not to their comprehension skills. Prediction is really a piece of cake, but only for skilled producers.

*Keywords:* prediction, production vocabulary, language-mediated visual search, toddlers

Both children and adults display considerable individual differences in the speed and accuracy of their language comprehension. Recent work has attempted to unravel the consequences of, and the factors driving, such individual differences. This work reveals effects of language comprehension skill on adults' suppression of irrelevant linguistic information in language processing (e.g., Gernsbacher & Faust, 1991), children's performance in semantic priming tasks (e.g., Nation & Snowling, 1999), and adults' learning of an artificial language grammar (e.g., Misyak, Christiansen, & Tomblin, 2010).

Interestingly, however, Nation, Marshall, and Altmann (2003) report limited effects of comprehension skill on 6-year-olds' *prediction* of upcoming linguistic input in online language processing. In this study, children were presented with four images at the same time (one of which was the target image, cake, and three unrelated distractor images) and heard either "Jane watched her mother choose a cake" or "Jane watched her mother eat a cake." Previous work finds that hearing *eat* leads adults to predict *cake* as an appropriate thematic fit to the verb, since cakes are edible (Kamide, Altmann, & Haywood, 2003). While 6-year-olds similarly predicted *cake* as an appropriate thematic fit to the verb, children's comprehension abilities had little impact on their prediction abilities.

However, 6-year-olds may already be at ceiling in such tasks. Perhaps, then, we might be able to tap into individual differences in children's abilities at a younger age, where children may not as readily extract information from the verb to predict upcoming input. This would help identify the potential bases for individual differences in language processing. Indeed, recent work finds a significant influence of children's comprehension skills on their prediction abilities in younger children aged between 3 and 10 years of age (Borovsky, Fernald, & Elman, 2012).

While the above studies highlight the influence of language comprehension skill on language processing, recent theoretical and computational models of language processing propose an important role for production-based mechanisms in language comprehension, with particular regard to prediction of upcoming linguistic input in language comprehension tasks (Chang, Dell, & Bock, 2006; Pickering & Garrod, 2007). Furthermore, recent work with infants showed that even 18-month-olds implicitly produce the labels for familiar images and use these implicitly produced labels in comprehension (Mani & Plunkett, 2010). Against this background, we ask whether toddlers are capable of implicitly producing thematic arguments that fit a verb's selectional restrictions and of using this information to orient toward images of thematically appropriate arguments. More importantly, we ask whether toddlers' skill in predicting upcoming linguistic input is correlated with their language production skills (cf. Chang et al., 2006; Pickering & Garrod, 2007). If implicit production of semantically appropriate verb arguments is the basis for toddlers' prediction, then we should find that high producers are better at predicting upcoming linguistic input than low producers.

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# Method

## Participants

The participants were 30 German toddlers at 24 months of age ($M = 23.76$ months; range = 23.1 to 25.43 months). Five additional toddlers were excluded due to their not providing enough trials ($n = 1$) or not completing the experiment ($n = 4$).

## Procedure

Toddlers sat on their caregiver's lap facing a screen. Two cameras mounted above where the pictures would appear on the screen recorded toddlers' eye movements. Auditory stimuli were presented through loudspeakers located above the screen. Speech stimuli were produced by a female native speaker of German.

Each child was presented with 12 test trials. Prior to the test trials, children were shown a cartoon of a boy and a girl, and were told that they were going to hear some stories about them. Each test trial then began with the presentation of two images of familiar objects side-by-side on the screen, followed by a sentence containing either a semantically constraining or semantically neutral verb related to one of the images on the screen. For instance, children saw a picture of a cake (*Kuchen*) and a bird (*Vogel*), and heard either a sentence containing a semantically constraining verb—"The boy eats the big cake"— or a sentence containing a neutral verb—"The boy sees the big cake." Half of the trials presented children with sentences containing semantically constraining verbs, while the other half presented children with sentences containing neutral verbs (see Table 1 for a list of stimuli). The pictures remained on-screen for 8 s. Figure 1 presents a schematic of the trials in the current study.

Table 1
*Images and Auditory Stimuli Presented to Children*

| Target | Sentence |
|---|---|
| Horse (*Pferd*) | The girl rides (sees) the brown horse.<br>*Das Mädchen reitet (sieht) das braune Pferd.* |
| Cake (*Kuchen*) | The boy eats (sees) the big cake.<br>*Der Junge ißt (sieht) den großen Kuchen.* |
| Trousers (*Hosen*) | The boy washes (likes) the new trousers.<br>*Der Junge wäscht (mag) die neuen Hosen.* |
| Bathtub (*Wanne*) | The boy bathes in the (sees the) big bathtub.<br>*Der Junge badet in der (sieht die) grossen Wanne.* |
| Paper (*Papier*) | The girl cuts (loves) the pretty paper.<br>*Das Mädchen schneidet (liebt) das schöne Papier.* |
| Milk (*Milch*) | The girl drinks (likes) milk.<br>*Das Mädchen trinkt (mag) gern Milch.* |
| Pictures (*Bilder*) | The boy paints (loves) many pictures.<br>*Der Junge malt (liebt) viele Bilder.* |
| Books (*Bücher*) | The girl reads (likes) only new books.<br>*Das Mädchen liest (mag) nur neue Bücher.* |
| Car (*Auto*) | The boy drives (has) my old car.<br>*Der Junge fährt mit meinem alten (hat meinen altes) Auto.* |
| Chair (*Stuhl*) | The girl sits on (looks at) the blue chair.<br>*Das Mädchen sitzt auf dem (schaut auf den) blauen Stuhl.* |
| Ball (*Ball*) | The boy throws (loves) the green ball.<br>*Der Junge wirft (liebt) den grünen Ball.* |
| Cat (*Katze*) | The girl strokes (likes) the little cat.<br>*Das Mädchen streichelt (mag) die kleine Katze.* |

*Note.* Across children, we counterbalanced whether the girl or the boy was the subject of the sentence. Furthermore, if the adjective biased children toward the target image in any way, for example, the green ball, then the distractor object shared the same attribute, for example, the green table.

The auditory stimuli were presented such that the onset of the verb was 3000 ms into the trial. Furthermore, we ensured there was at least 1500 ms between the onset of the verb and the onset of the disambiguating noun in each of the sentences. There was no linguistic information interspersed between the verb and the noun that could bias the child toward any one of the pictures on the screen.[1] Labels for the target and distractor images were semantically and associatively unrelated. Toddlers saw each image once during the experiment. Target and distractor pairings were maintained and appeared in the semantically constraining and neutral conditions with equal frequency. Targets appeared equally often to the left and to the right in both conditions.

Vocabulary knowledge was assessed by asking parents if their children understood or produced the words listed in the long form of the vocabulary section of German parental communicative inventory reports (*Fragebogen zur Frühkindlichen Sprachentwicklung* [FRAKIS], Szagun, Stumper, & Schramm, 2009, standardized for children between 1; 6 and 2; 6 years of age, i.e., appropriate for use with children between 1; 6 and 2; 6 years of age). We calculated the number of words that each child understood but did not produce (comprehension vocabulary size) and the number of words that children understood and produced (production vocabulary size).

## Scoring and Analysis

A digital-video scoring system assessed visual events on a frame-by-frame basis (every 40 ms) and the coded video frames were used to determine the amount of time children looked at the target (T) and distractor (D) images. We separately calculated the proportion of time (T/[T + D]) children spent looking at the target across three time-windows. The *prenaming* window analyzed eye movements that took place in the second before the onset of the verb, that is, from 2000 ms to 3000 ms. The *verb* window analyzed eye movements that took place 233 ms from the onset of the verb to the onset of the noun, that is, from 3233 ms to the onset of the noun. Since the onset of the noun varied across the different sentences, the duration of this time-window varied across sentences. The *noun* window analyzed eye movements that took place 233 ms to 2000 ms from the onset of the noun. This follows the standard in infant eye-tracking literature that only considers eye movements launched 233 ms after the onset of a word (Haith, Hazan, & Goodman, 1988; Canfield & Haith, 1991).

Note that we only considered those trials where children were reported to comprehend both the target label and the verbs, as indicated by individual communicative inventory reports. This excluded 19% of trials (73 out of 370 trials). It is crucial that each child was familiar with the words presented to him or her, since the

[1] Indeed, in nine out of 12 sentences, the stimuli were cross-spliced following the verb so that the sentences were identical after semantically constraining and neutral verbs. This was not possible in three of the sentences, as these sentences contained prepositions specific to the verbs.

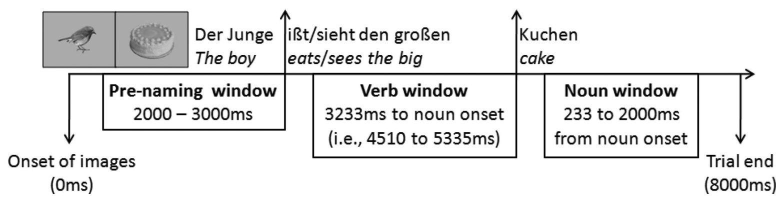


*Figure 1.* Schematic of trials presented to children in the current study.

purpose of the study is to examine the impact of the child's vocabulary knowledge on their ability to predict upcoming linguistic input.

## Results and Discussion

Figure 2 plots the proportion of infants' fixations to the target image during the prenaming, verb, and noun windows. As Figure 2 shows, shortly after the onset of the verb, children fixate the target image (e.g., cake, *Kuchen*) more while listening to sentences containing semantically constraining verbs (eats, *isst*) compared to neutral verbs (sees, *sieht*).

A 3 × 2 repeated measures ANOVA with window (prenaming, verb, noun) and condition (semantically constraining, neutral) as within-subjects factors found a significant main effect of window ($F[2, 28] = 9.17$; $p = .001$) and a significant interaction between condition and window ($F[2, 28] = 3.59$; $p = .04$). There was no significant main effect of condition ($p = .3$). Paired samples $t$ tests further examined these effects.

There was no significant difference in infants' preference for the target image across the two conditions in the prenaming window, $t(29) = .53$, $p = .5$, or the noun window, $t(29) = .4$, $p = .6$. However, in the verb window, children fixated the target image more in semantically constraining trials ($M = .63$, $SE = .03$) compared with neutral trials ($M = .53$, $SE = .03$; $t[29] = 2.09$, $p = .045$). Furthermore, children looked more at the target image in the verb window relative to the prenaming window in semantically constraining trials, $t(29) = 2.26$, $p = .03$, but not in neutral trials, $t(29) = .5$, $p = .6$.[2] Furthermore, children looked more at the target image in the noun window (where children were presented with the target label, e.g., cake, *Kuchen*) relative to the prenaming window in both semantically constraining, $t(29) = 2.56$, $p = .016$, and neutral trials, $t(29) = 3.9$, $p < .001$.

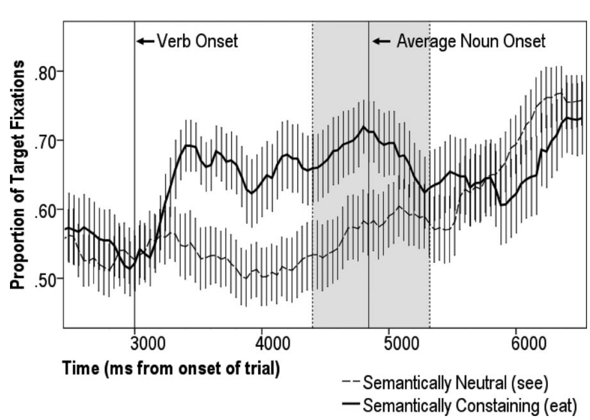


*Figure 2.* Proportion of time spent looking at the target in semantically constraining and semantically neutral trials. Lines indicate onset of verb and average onset of noun. Shaded window covers earliest and latest noun onset.

### Vocabulary Knowledge and Prediction

We correlated children's prediction ability (proportion of fixations to the target in semantically constraining trials − proportion of fixations to the target in neutral trials *in the verb window*) with their comprehension and production vocabulary size. There was no significant correlation between children's comprehension vocabulary size and their prediction abilities ($z = -15$, $p = .4$). However, as Figure 3 shows, children with larger productive vocabularies looked more toward the target in semantically constraining trials relative to neutral trials in the verb window ($z = .38$, $p = .034$). An additional analysis categorized the children as high and low producers, based on the median split of their production vocabulary size (225 words). Only high producers looked more toward the target in the verb window in semantically constraining compared to neutral trials, $t(13) = -2.75$, $p = .016$, while low producers did not, $t(15) = -.6$, $p = .5$.

Note that the results did not vary based on whether we only excluded those words that children were reported to comprehend relative to analyses only including words that children comprehended and produced: There remained a significant difference between children's target looking in semantically constraining trials and nonconstraining trials in the verb window, $t(21) = 2.23$; $p = .037$, and a significant correlation between children's prediction ability and their production vocabulary size alone ($z = .45$, $p = .035$). We suggest that the finding of similar results, irrespective of whether toddlers were able to produce the stimuli used in the experiment, implies that any correlation between production size and prediction ability reflects toddlers' overall production fluency rather than their specific fluency with the words tested.

## General Discussion

The present findings confirm that 2-year-olds, like adults, are successfully able to predict upcoming linguistic input that is a thematic fit to familiar verbs—upon hearing a familiar verb, for

[2] Three of 12 items (*fährt-Auto*, *badet-Wanne*, *sitzt-Stuhl*) included information between the verb and the noun that was not identical across semantically constraining and neutral sentences. A reduced analysis excluding these items found a significant increase in infants' preference for the target image from the prenaming to the verb window in semantically constraining trials ($t[28] = 2.43$, $p = .022$) but not in neutral trials ($t[28] = .8$, $p = .3$).

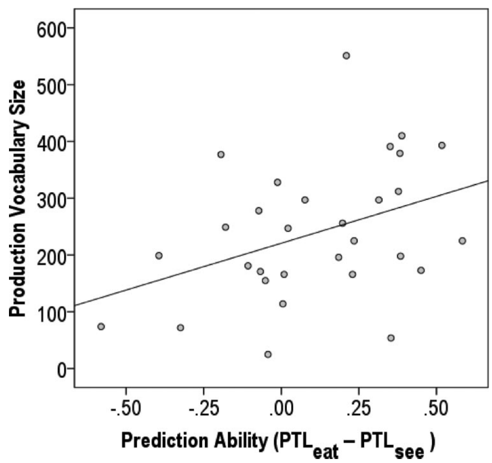


*Figure 3.* Production vocabulary size plotted against children's prediction abilities ($PTL_{eat} - PTL_{see}$ in the verb window).

example, eat, our "average" 2-year-olds anticipated verb arguments that are semantically appropriate, that is, edible objects, and looked more toward these objects than toward unrelated distractor objects in a visual scene. Being able to predict upcoming linguistic input allows comprehenders more time to understand a given discourse and supports the comprehension system in understanding ambiguous speech stimuli. Clearly, by 2 years of age, children can exploit their awareness of the world to speed and improve their language comprehension.

Second, our findings highlight one possible mechanism driving prediction in language comprehension, with a strong suggestion that children's production skills underlie their ability to predict upcoming linguistic input: We found that high producers were better predictors than low producers. Indeed, the possibility of just such an influence of the language production system on language prediction is raised by recent models of language processing (Chang et al., 2006; Pickering & Garrod, 2007), and the current data appear to support such an influence.

We suggest that the developing production system learns to implicitly predict linguistic input that fits incoming speech input. High *explicit* producers are likely to also be high *implicit* producers and may be more used to implicitly producing potential nouns that are semantically appropriate to a verb's selectional restrictions. Therefore, in high explicit producers, the production system is developed enough to take on this additional role. Low producers may not be as adept at implicit or explicit generation of internal or external speech and may be limited in their ability to generate thematic arguments to semantically constraining verbs. Such an account suggests that our language production system is intrinsically involved in the mechanisms underlying prediction in language comprehension.

We note, however, that there might be a simpler mechanism underlying children's prediction abilities. That is, children's ability to predict upcoming linguistic input might stem from their memory of rudimentary associations between words (Bar, 2007, 2009). For instance, it might be that high producers are more experienced language users in general and are therefore equipped with stronger thematic links between verbs and their arguments, making them more likely to preactivate thematically appropriate arguments upon hearing the verb. However, if such an account were correct, one would expect a similar correlation between children's comprehension skills and their ability to predict upcoming linguistic input. Contrary to such a suggestion, there was no significant correlation between the number of words that children only comprehended (but did not produce) and their prediction skills.

Indeed, our results suggest a comprehension-independent influence of children's production abilities in their prediction of upcoming linguistic input that further allows us to potentially differentiate between current production-based models of prediction (i.e., Chang et al., 2006; Pickering & Garrod, 2007). Pickering and Garrod (2007) propose that the language production system acts as an "emulator," predicting upcoming speech input at varying degrees of specificity, that is, phonology, semantics, syntax. Every prediction put forth by the production system is assessed on the basis of subsequent speech input and either further ratified or excluded until the predicted token is unambiguously part of the discourse. Therefore, comprehension uses production resources to predict upcoming linguistic input. However, one implication of this proposal is that once the shared variation between comprehension and production has been partialed out, there should be no correlation between toddlers' production and prediction skills—the shared variation between production and comprehension scores reflects the production resources available to predict upcoming linguistic input. Any remaining variation in production scores should not, therefore, correlate with toddler's prediction skills.

Chang et al. (2006) present an error-based learning model that develops meaning and sequencing representations on the basis of the difference between its production-based predictions and heard input. The model is able to use this error mechanism to explain syntactic preferential looking data and a similar mechanism might explain the preferential looking task used here. In contrast to Pickering and Garrod (2007), the model does not build interpretations or link them to world knowledge, so there are aspects of comprehension that are not explained by its prediction-based mechanism. Therefore, the model allows for a greater separation between comprehension abilities and production-based prediction in toddler word recognition.

To examine the reality of such a comprehension-independent influence of children's production abilities in their prediction abilities, we analyzed whether toddlers' language production skills correlate with their language prediction skills, once the shared variation between production and comprehension scores has been partialed out. The residualized production score refers to the amount of variability in production vocabulary size that is left over after accounting for the variability explained by children's comprehension vocabulary size. Using the residuals output, by regressing production vocabulary size with comprehension vocabulary size, we found a correlation between residualized production scores and children's prediction ability ($z = .37$; $p = .044$). This finding suggests that there is a component to children's prediction ability that is specifically tied to children's production skills and not to their comprehension skills. This might be taken to suggest that prediction using production is not a general feature of language comprehension but may be more specific to the learning of production representations. Prediction is really a piece of cake, but only for skilled producers.

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