Semantic prediction in monolingual and bilingual children

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Semantic prediction in monolingual and bilingual children

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One of the mechanisms responsible for the fast recognition of spoken language is prediction. This study examined whether 4–5 year old monolingual children differ from bilingual children in predicting the upcoming noun on the basis of the lexical semantics of the verb. In an eye-tracking task, we presented visual displays with two objects (e.g. cake, tree) while presenting semantically constraining (e.g. The boy eats the big cake) or neutral sentences (e.g. The boy sees the big cake). Results showed that both groups are able to predict but that 4-year-old bilinguals are faster than their monolingual peers. Moreover, sentence prediction ability in bilinguals is associated with performance on the forward digit recall task. These results extend views on bilingual sentence processing.

Keywords: bilingualism, eye-tracking, prediction, working memory

Introduction

A wealth of research has shown that monolingual children and adults have an impressive capacity to understand their native language (L1) with great ease and rapidity as it unfolds (Allopenna, Magnuson, & Tanenhaus, 1998; Swingley, Pinto, & Fernald, 1999). This capacity is at least partly derived from generating predictions on the basis of the incoming input which allows them to proactively construct interpretations before the speaker has completed the word or the utterance (e.g. Altmann & Kamide, 1999; Borovsky et al., 2012; Federmeier, 2007; Mani & Huettig, 2012). Contrary to monolinguals, bilingual children and adults often experience difficulties in processing their second language (L2). Several explanations have been given for why L2 comprehenders are overall slower and less accurate than natives (e.g. Bialystok, Luk, Peets, & Yang, 2010; Frenck-Mestre & Pynte, 1997; Hahne, 2001). In this study, we examine whether the language processing difficulties in
the L2 are due to a lack of predictive abilities. Are monolingual children better able to use cues in a sentence to predict words that are likely to follow than bilingual children? Moreover, we investigate which linguistic and/or cognitive factors are involved in sentence prediction ability.

Prediction plays an important role in current approaches of sentence comprehension (e.g. Chang, Dell, & Bock, 2006; Federmeier & Kutas, 1999; Pickering & Garrod, 2013) and it has been described as a central ingredient of efficient communication and incremental processing (Altmann & Mirković, 2009; Jaeger & Snider, 2013). Federmeier (2007) has argued that the language comprehension system is able to make detailed, multi-faceted predictions about specific aspects of upcoming words. Kaan (2014) has suggested that predictive processing in L2 is not inherently different from predictive processing in L1, but it may be modulated by factors associated with L2 comprehension. Native speakers of a language have learned to associate certain words, word categories, syntactic frames and rules, building a database of relative frequencies of occurrence and associations. From this it follows that prediction ability can be seen as a product of strong associations between forms and/or (abstract) concepts. Prediction is thus the result of learning to form such associations.

Prediction has predominantly been investigated in electrophysiological and visual-world paradigm eye-tracking studies, which have shown that different types of cues are used to anticipate upcoming words. The cues that have been studied frequently in monolinguals, and to some extent in bilinguals, are semantic (e.g. Altmann & Kamide, 1999; Borovsky et al., 2012; Nation, Marshall, & Altmann, 2003; Mani & Huettig, 2012) or morphosyntactic in nature (e.g. Dussias, Valdés Kroff, Guzzardo Tamargo, & Gerfen, 2013; Foucart, Moreno, Martin, & Costa, 2014; Grüter, Lew-Williams, & Fernald, 2012; Hopp, 2013; Lew-Williams & Fernald, 2007, 2010; Martin, Thierry, Kuipers, Boutonnet, Foucart, & Costa, 2013).

Semantic cues have, for example, been investigated by Mani and Huettig (2012). They examined whether monolingual 2-year old children could use the semantics of the verb that was predictive of other, upcoming words. In a visual-world eye-tracking paradigm, they presented sentences such as “The boy eats/see the big cake” while displaying two objects on the screen (e.g. a cake and a tree). Results showed that upon hearing the semantically-constraining verb “eat”, children anticipated that the direct object is likely to be something edible (i.e. the cake), whereas no anticipation occurred upon hearing the neutral verb “see”. The same pattern has been found for older monolingual children (e.g. Borovsky et al., 2012; Nation et al., 2003) and adults (e.g. Altmann & Kamide, 1999). However, to our knowledge no studies thus far have looked into the question whether bilingual children use the semantics of the verb for prediction to the same extent as monolingual children do. This question will be central in the present study.
Although there is a lack of semantic prediction studies in bilinguals, there have been neurological and eye-tracking studies on the use of morphosyntactic information to predict upcoming words (e.g. Dussias et al., 2013; Foucart et al., 2014; Grüter et al., 2012; Hopp, 2013; Lew-Williams & Fernald, 2010; Martin et al., 2013). These studies focused on languages with a grammatical gender system. The rules of such a system could constrain the upcoming words that listeners ultimately arrive at. The work on monolingual children has shown that they are able to use gender information on the preceding article to predict the upcoming noun (e.g. Johnson, 2005; Lew-Williams & Fernald, 2007). For example, Lew-Williams and Fernald (2007) tested monolingual Spanish 3-year-olds using an eye-tracking procedure. Their results showed that if the visual display depicted objects that corresponded to nouns with different grammatical gender (e.g. la pelota “ball” and el zapato “shoe”), children actively made use of gender (la) to predict the noun (pelota). However, when both objects corresponded to nouns with the same grammatical gender (e.g. la pelota and la galleta “cookie”), participants had no preference for the target pelota before the corresponding noun appeared in the sentence.

The studies on the use of grammatical gender in bilinguals have only been conducted with adults and revealed differential patterns (e.g. Dussias et al., 2013; Foucart et al., 2014; Grüter et al. 2012; Hopp, 2013; Lew-Williams & Fernald, 2010; Martin et al., 2013). On the one hand, researchers have found that L2 adults have difficulty using gender as a predictive cue and that they anticipate words to a weaker extent than L1 adults (e.g. Grüter et al., 2012; Lew-Williams & Fernald, 2010; Martin et al., 2013). On the other hand, studies have demonstrated that the presence of an anticipation effect is not modulated by being bilingual (e.g. Dussias et al., 2013; Foucart et al., 2014). Several factors appear to be involved in the anticipatory use of gender in bilinguals. For example, L2 proficiency level (although Grüter et al. found no sensitivity to gender cues in an advanced group of bilinguals), age of L2 onset, cross-linguistic differences between the L1 and the L2 (Dussias et al., 2013), and/or knowledge of lexical gender marking (Hopp, 2013) might play a role.

In sum, the previous research on the use of semantic information for prediction has only focused on monolinguals. Moreover, the prior work on morphosyntactic information, and in particular gender information, has shown inconclusive results with respect to anticipatory processing in L2 adult listeners. To date, no evidence exists on bilingual children’s verb-based anticipatory abilities during language processing. Here, we focus on the use of semantic cues for prediction. The question is whether and which patterns of behaviour in L2 adults will be similar to our bilingual children.

Besides looking at the use of semantic prediction during language processing, many of those studies also investigated the influence of mediating factors on this process. What makes children good versus bad predictors? It has been found that
vocabulary size plays an important role in semantic prediction (Borovsky et al., 2012; Fernald, Zangl, Portillo, & Marchman, 2008; Mani & Huettig, 2012). This type of work showed diverging results depending on age. For 2-year-olds it was found that productive vocabulary is associated with prediction ability (Mani & Huettig, 2012), whereas for 3-to-10 year olds a large receptive vocabulary size was positively correlated with prediction of upcoming input (Borovsky et al., 2012). However, yet another study reported that comprehension skills have limited effects on 6-year-olds’ prediction skills (Nation et al., 2003). These data show that the results are inconsistent with respect to which types of linguistic knowledge are important for prediction. The current study will therefore, once again, examine the role of receptive vocabulary for semantic prediction in monolingual but also in bilingual children. Receptive vocabulary can be seen as a proxy of how well-developed one’s linguistic system is and thus provides insight into how strong associations are for L2 learners.

In addition to the influence of receptive vocabulary knowledge, we also looked at two cognitive factors that might have an effect on semantic prediction. The two factors that were under investigation in the present study are inhibition and working memory (WM) skills, which both are part of the so-called executive functioning (EF) abilities. EF has been distinguished by Miyake, Freidman, Emerson, Witzki, Howerter, and Wager (2000) into three main components: inhibition, shifting, and updating. Inhibition is the capacity to suppress responses or maintain control over automatic responses. Shifting refers to the ability to switch between different tasks. Updating refers to WM and the continuous monitoring of the WM content. There are two reasons why we were interested in assessing EF abilities. First, previous research has often shown that bilingual children and adults experience an advantage on these skills compared to monolinguals (e.g. Adesope, Lavin, Thompson, & Ungerleider, 2010; Bialystok & Viswanathan, 2009; Barac & Bialystok, 2011). For example, bilinguals have outperformed monolinguals on inhibition tasks (e.g. Martin-Rhee & Bialystok, 2008), and on WM tasks (Blom, Küntay, Messer, Verhagen, & Leseman, 2014; Morales, Calvo, & Bialystok, 2013, but see Engel de Abreu, 2011).

Secondly, it has been claimed that EF plays a role in predictive processing (Fedorenko, 2014). This idea is supported by findings from Federmeier and colleagues who have found that aging monolinguals, i.e. a group with deteriorating EF, have diminished predictive processing abilities in language (Federmeier & Kutas, 1999; Federmeier, McLennan, De Ochoa, & Kutas, 2002; Federmeier, Kutas, & Schul, 2010). Additionally, prior work has shown that WM influences prediction ability in adult monolinguals (Huettig & Janse, 2016; Huettig et al., 2011; Otten & Van Berkum, 2009). The present study therefore assesses whether EF skills support predictive processing in monolingual and bilingual children.
In the present study, we will test 4–5 year old Dutch monolingual and bilingual children. The bilingual children differed in their L1 background and 85% of them learnt Dutch at or before their first year. Following Mani and Huettig’s (2012) visual world eye-tracking set-up, we presented semantically constraining (e.g. *De jongen eet de grote taart* “The boy eats the big cake”) and neutral sentences (e.g. *De jongen ziet de grote taart* “The boy sees the big cake”), while displaying two pictures on the screen (e.g. *taart* “cake” and *boom* “tree”). We tracked children’s eye gaze to examine whether they make use of the semantics of the verb to predict the upcoming noun.

Three possible outcomes are presented. First, it is possible that bilingual children will only process a word once it has been completely uttered. This so-called integrative processing is based on the assumption that bilinguals experience difficulties in processing their L2 because they are less able to use the various cues (e.g. semantic or syntactic) provided by the sentence parts than monolinguals. In other words, their L2 knowledge is weaker and their construction knowledge might be less entrenched. This might lead to delays, less accurate performance, and/or less efficient processing of L2 sentences which, as a result, may interrupt successful prediction in bilinguals. This prediction is in line with previous work that states that bilinguals have weaker prediction mechanisms (Grüter et al., 2012; Grüter, Rohde, & Schafer, 2014; Lew-Williams & Fernald, 2010; Martin et al., 2013). Grüter et al. (2014), for example, proposed the so-called RAGE (Reduced Ability to Generate Expectations) hypothesis for adult L2 learners. This hypothesis holds that L2 adult speakers have a generally limited ability to make predictions in sentence processing, irrespective of whether semantic, lexical or morphosyntactic information cues the prediction.

Secondly, we expect that bilinguals will be able to anticipate information on the basis of the semantics of the verb in a similar way as monolinguals. This result would be consistent with some of the prior work on morphosyntactic prediction in which it was found that bilinguals are able to anticipate in a similar manner as monolinguals (Dussias et al., 2013; Foucart et al., 2014; Hopp, 2013). Although not all previous work on morphosyntactic prediction has shown this pattern, it is also possible that semantic prediction works in another way than morphosyntactic prediction. A difference between the two types of prediction is that for semantic cues conceptual associations rely on world knowledge. Part of this knowledge is shared across languages and might therefore be transferred from one language to the other. However, grammatical gender encoding varies across languages and the same noun might have different gender across languages, which consequently might result in processing difficulties. This difference might make morphosyntactic prediction more difficult than semantic prediction.
Thirdly, it might be possible that bilinguals will be better able to predict upcoming information than monolinguals. This idea is in line with previous findings which have shown that bilinguals’ EF skills are better compared to monolinguals’ due to suppressing the non-relevant language (e.g. Bialystok & Viswanathan, 2009; Martin-Rhee & Bialystok, 2008; Blom et al., 2014; Morales et al., 2013). Bonifacci, Giombini, Bellocchi, and Contento (2011, p. 259) argued that “anticipation skills are improved in bilinguals because they have practice in anticipating the upcoming element of a sentence in two or more languages”. In their study, they used a colour-sequence learning paradigm with 4-and 5-year-old monolingual and bilingual children. In the first part of this task, participants were explicitly informed that they would see colored rectangles in a fixed sequence, and that their task was to find the pattern. After the sequence was learned, participants were presented with the first rectangles of a fixed sequence that was previously learned and were asked to anticipate the color of the upcoming rectangle. Their results demonstrated a prediction advantage for bilingual children compared to monolingual children. Although Bonifacci and colleagues (2011) conducted a non-linguistic anticipation task, it is hypothesized that bilinguals might also develop more efficient linguistic anticipation skills than monolinguals.

Method

Participants

Participants were 4-and 5-year-old monolingual and bilingual children of Dutch (see Table 1). The father or mother of the child filled in a language background questionnaire. This questionnaire showed that the bilingual children were from different language backgrounds (i.e. Arabic (1), Catalan (1), English (5), French (2), German (2), Hindi (1), Italian (3), Cape Verdean (1), Moroccan (17), Papiamento (8), Polish (1), Portuguese (1), Russian (5), Spanish (1), Thai (1), and Turkish (2)) and they all started learning Dutch before the age of 4. There were only 7 children who learnt Dutch after the age of 1 year and their age of onset varied between 16 and 48 months. Moreover, parents rated the proficiency level of their child’s L1 and L2 on a 5-point Likert scale (1-very high to 5-very low). The results revealed that the proficiency level in both languages were assumed to be high to very high ($M_{L1} = 1.46, SD_{L1} = 0.74; M_{L2} = 1.46, SD_{L2} = 0.92$). The mean percentage of L1 and L2 usage during the day was filled out to be 44% and 52% for the 4-year olds and 46% and 53% for the 5-year olds, respectively. Note that these percentages do not add up to 100 as some of the children also spoke a third language. The children were without any hearing problems and with normal or corrected-to-normal vision. Parents gave informed consent and the children were compensated with a toy.
Table 1. Characteristics of the participants

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>M_AGE</th>
<th>SD_AGE</th>
<th>Gender</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Monolinguals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-year-olds</td>
<td>20</td>
<td>4;5</td>
<td>0;3</td>
<td>12 F, 8 M</td>
</tr>
<tr>
<td>5-year-olds</td>
<td>42</td>
<td>5;4</td>
<td>0;4</td>
<td>17 F, 25 M</td>
</tr>
<tr>
<td><strong>Bilinguals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-year-olds</td>
<td>28</td>
<td>4;4</td>
<td>0;3</td>
<td>12 F, 16 M</td>
</tr>
<tr>
<td>5-year-olds</td>
<td>24</td>
<td>5;4</td>
<td>0;3</td>
<td>12 F, 12 M</td>
</tr>
</tbody>
</table>

Material

The eye-tracking experiment consisted of 24 visual displays with two pictures on the screen. These displays were paired either with a semantically constraining sentence as in (1) or with a neutral sentence as in (2). One of the two pictures corresponded to the target word (e.g. *taart*, “cake”); the other was a distractor (e.g. *boom*, “tree”; see the Appendix for an overview of the stimuli).

(1) \textit{De jongen eet de grote taart} [semantic condition]
    The boy eats the big cake

(2) \textit{De jongen ziet de grote taart} [neutral condition]
    The boy sees the big cake

The sentences were produced by a female adult speaker of native-Dutch (16 bits, 44100 Hz). Each sentence consisted of a noun phrase, a verb and a determiner-adjective-noun combination. The timing of the different constituents in each sentence was measured in PRAAT (Boersma & Weenink, 2016). The duration of the region from verb onset until noun onset, which construed the anticipatory time window, was on average 2400 ms. Importantly, this average was held constant across conditions. All sentences were equalized to the same rms level of 65 dB. The target and distractor words were highly familiar to 4–5 year olds (as based on a wordlist for 4-to 6-year-olds by Damhuis, de Glopper, Broers, & Kienstra, 1992). There was no phonological overlap between the target-distractor pairs at word onset.

A further 8 filler items were created through which children were motivated to continue with the task (e.g. “you are doing a great job!”). Four different lists were created in which target position (left vs. right) and sentence (semantic vs. neutral) were counterbalanced. In each list the semantic, neutral, and filler trials were presented pseudorandomly.
Norming task

We administered a norming study to evaluate whether our verbs predictively elicit the nouns to be tested. 24 Dutch adults were asked to judge which would be a likely target when given the sentence beginning of their L1 (e.g. “The boy eats the nice…”). Participants had to choose between two alternatives, which were similar to the target and distractor presented in the eye-tracking experiments (e.g. “cake” and “book”). Performance on the semantic sentences was very high (99% correct), showing that our sentences effectively set up semantically predictable contexts.

Linguistic and cognitive tasks

Receptive vocabulary was assessed using the Dutch version of the Peabody Picture Vocabulary Task (PPVT; Dunn, Dunn, & Schlichting, 2005). The child’s task was to point to one of four pictures in a book that corresponded to the word spoken by the experimenter.

Working memory was assessed through the Digit Span task (DST; Wechsler, 2004). This task consists of two conditions. In the forward condition the child is asked to listen to a sequence of digits and then reproduce them. In the backward condition the child is asked to reproduce the digits in reverse order. This task was presented on a laptop and the digits were prerecorded by a female native Dutch speaker. The child was first presented with two practice trials to be familiarized with the task. In the forward condition the task started with a block of one digit and continued with blocks of increasing length. In the backward condition the first block consisted of two digits and also continued with blocks of increasing length. Each block contained six trials. The AWMA procedure (Alloway, 2007) was applied for scoring. Trials were scored as incorrect if the child recalled the digits incorrectly or if the child omitted one or more of the digits. If a child repeated the first four trials within a block correctly, (s)he automatically received a score of 6 and continued with the next block. Testing stopped after three incorrect trials within one block. The scores could range from 0 to 48 for the forward condition (8 blocks) and from 0 to 36 for the backward condition (6 blocks).

Inhibition skills were assessed using a modified version (Engel de Abreu, Cruz-Santos, Tourinho, Martin, & Bialystok, 2014) of the Flanker task (Rueda, Fan, McCanliss, Halparin, Gruber, Lercari, & Posner, 2004). The task was administered on a laptop and the instructions were prerecorded by a female native Dutch speaker. Each display consists of a horizontal row of five equally spaced yellow fish. The child’s task was to indicate the direction of the fish in the middle (target fish) by pressing the corresponding button (ctrl for fish going to the left
and right arrow for fish going to the right) as quickly as possible. In the congruent condition, the fish flanking the middle fish point in the same direction as the target fish, whereas in the incongruent condition, the flanking fish point in the opposite direction as the target fish. Congruent trials occurred as often as incongruent trials. Each trial started with a 1000 ms fixation cross in the middle of the screen, followed by the five fish for 5000 ms or until a response was made. Each response was followed by feedback (a positive “woohoo” sound or a negative low tone) and a 400 ms blank interval. Two blocks of 20 trials were presented in which congruent and incongruent trials were randomized. Prior to the task, eight practice items were presented.

Procedure

The experimental session took place in the lab at Utrecht University, Utrecht or at a Dutch primary school. The tasks were administered in a fixed order. First, the children sat behind the screen of a Tobii T120 on which stimuli were presented using E-Prime© software. Before the start of the experiment, a 9-point calibration procedure was performed. Before each trial, children were shown a fixation cross in the middle of the screen, which they were instructed to fixate on before every trial (drift correction). Children were told that they would be seeing two pictures on the screen while hearing sentences. Their task was to listen carefully to these sentences and to look at the pictures. The two pictures were shown 2000 ms before sentence onset and the pictures remained on the screen until sentence offset. After completion of the eye-tracking experiment, the Flanker and the DST were administered on a laptop. Finally, the PPVT was conducted. The session lasted about 50 minutes.

Results

Linguistic and cognitive data

On the PPVT, the raw accuracy scores were standardized and compared across Language (monolinguals vs. bilinguals) and Age (4-vs. 5-year olds). Data of two bilingual 4-year olds were missing due to tiredness. A two-way ANOVA revealed a main effect of Language ($F(1, 112) = 26.86, p < 0.001$, partial $\eta^2 = 0.20$), indicating that monolingual children ($M = 112.48; SE = 1.93$) had on average significantly higher vocabulary scores than bilingual children ($M = 98.01; SE = 2.01$). No other effects were significant ($p > 0.1$).
On the Flanker task, response times (RTs) on the congruent and incongruent condition were calculated on correct responses only. RTs below 250 ms and RTs three standard deviations above the mean per language, age and condition were excluded from the analyses. One 4-year-old monolingual child did not perform the Flanker task due to tiredness. The data on the two conditions are illustrated in Table 2 for the 4- and 5-year-old monolingual and bilingual children. This table also reveals the Flanker effect, i.e. the RT difference score between the incongruent minus the congruent condition.

A repeated measures ANOVA with RTs as dependent variable and with Condition (congruent vs. incongruent) as within-subject variable and Language and Age as between-subject variables was performed. Results showed a main effect of Condition \( (F(1, 109) = 71.31, p < 0.0001, \text{partial } \eta^2 = 0.40) \), indicating that both groups performed faster in the congruent than the incongruent condition. The results also revealed a main effect of Age \( (F(1, 109) = 24.92, p < 0.0001, \text{partial } \eta^2 = 0.19) \) and of Language \( (F(1, 109) = 4.07, p < 0.05, \text{partial } \eta^2 = 0.04) \). These effects reveal that 4-year-olds perform overall slower than 5-year-olds and that bilinguals perform overall faster than monolinguals on both conditions, respectively. Finally, the interaction effect between Condition and Language \( (F(1, 109) = 10.16, p < 0.01, \text{partial } \eta^2 = 0.09) \) was significant. This reveals that the interference produced by the incongruent condition in comparison to the congruent condition (i.e. the Flanker effect) was more pronounced for the monolinguals than for the bilinguals. No other effects were significant \( (p > .05) \).

On the DST, accuracy scores were calculated on the forward and the backward condition. The mean raw scores and the percentage correct (added for interpretation and for analysis purposes) are illustrated in Table 3. As the difficulty level and the maximum possible score differed between the forward (48) and the backward (36) condition, we analyzed the data separately for each task. A two-way ANOVA with percentage correct as dependent variable and Language and Age as between-subject variables was conducted for each task. The forward digit span data showed a main effect of Language \( (F(1, 110) = 8.88, p < 0.01, \text{partial } \eta^2 = 0.08) \) and of Age \( (F(1, 110) = 12.30, p < 0.01, \text{partial } \eta^2 = 0.10) \). The backward digit span data also demonstrated a main effect of Language \( (F(1, 110) = 9.39, p < 0.01, \text{partial } \eta^2 = 0.08) \) and of Age \( (F(1, 110) = 5.36, p < 0.05, \text{partial } \eta^2 = 0.05) \). These effects indicate that monolinguals outperformed bilinguals and that 5-year olds performed better than 4-year-olds on forward and on backward recall.
Table 2. Mean reaction times along with standard errors in parentheses for monolingual and bilingual children on the congruent and incongruent condition of the Flanker task. The Flanker effect represents the difference scores between the two conditions (incongruent-congruent).

<table>
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<tr>
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<th>Monolinguals</th>
<th>Bilinguals</th>
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<tbody>
<tr>
<td></td>
<td>4-year olds</td>
<td>5-year olds</td>
</tr>
<tr>
<td>Congruent</td>
<td>2130 (134)</td>
<td>1582 (66)</td>
</tr>
<tr>
<td>Incongruent</td>
<td>2483 (145)</td>
<td>1999 (81)</td>
</tr>
<tr>
<td>Flanker effect</td>
<td>353 (88)</td>
<td>417 (50)</td>
</tr>
</tbody>
</table>

Table 3. Mean raw scores and mean percentage correct along with standard errors in parentheses for monolingual and bilingual children on the forward and backward condition of the Digit Span Task.

<table>
<thead>
<tr>
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<th>Monolinguals</th>
<th>Bilinguals</th>
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<tbody>
<tr>
<td></td>
<td>4-year olds</td>
<td>5-year olds</td>
</tr>
<tr>
<td></td>
<td>raw</td>
<td>%</td>
</tr>
<tr>
<td>Forward</td>
<td>16 (3)</td>
<td>33.54 (2.01)</td>
</tr>
<tr>
<td>Backward</td>
<td>4 (3)</td>
<td>10.00 (2.56)</td>
</tr>
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Eye-tracking data

Figure 1 plots the proportion fixations to targets from verb onset for monolingual and bilingual 4- and 5-year-olds. These figures reveal that all groups look more at targets in the semantic than in the neutral condition. This pattern initiates during the unfolding of the verb. The timing at which fixations to targets in the semantic condition diverge from fixations to targets in the neutral condition varies between groups. To examine whether these patterns are significant, we log-transformed the mean fixation proportions to targets in our analyses. Zeros and ones were replaced by 0.01 and 0.99 (cf. Macmillan & Creelman, 1991). We conducted two types of analyses on our data to measure prediction ability and its time course.
Monolingual 4-year olds

Monolingual 5-year olds

Bilingual 4-year olds

Proportion of target fixations

Time in msec

Semantic condition (eat)
Neutral condition (see)
Prediction ability

The anticipatory window from verb onset until noun onset was selected to measure prediction ability across the child groups. We compared fixations to targets in the semantic vs. the neutral condition over this anticipatory window. A repeated measures ANOVA was performed with log-transformed target fixations as dependent variable, Condition (semantic vs. neutral) as within-group variable, and Language (monolingual vs. bilingual) and Age (4 vs. 5 years) as between-group variables. Results showed a main effect of Condition ($F(1, 110) = 83.48; p < 0.0001$, partial $\eta^2 = 0.43$). No other differences were found ($p > 0.05$).

Time course of prediction ability

Although no group differences were found over the whole anticipatory window, Figure 1 clearly shows that the timing of when the prediction effect initiates differs between groups. We examined these apparent differences in fixation timing between groups by conducting paired t-tests at each 100-ms time bin between the log-transformed target fixations in the semantic vs. the neutral condition (Bonferroni corrected). Following previous work we choose 100-ms time bins to have enough data points in one time bin to draw any conclusions (i.e. 8 data points per bin per participant; e.g. Huettig & McQueen, 2007). However, note that possible
timing differences between groups need to be interpreted with caution as they are dependent on the size of our time bins. To minimize the possibility that differences measured by these multiple t-tests comparisons might have arisen by chance, we consider the earliest time of prediction when the first window of five consecutive time windows are significant at a level of $p < 0.05$ (see Borovsky et al., 2012, for a similar type of analysis). These results are reported in Table 4.

According to these analyses, the time at which the prediction effect initiates differs considerably between groups. There are differences between the 4-year-olds and the 5-year-olds. The younger age group needs on average more time (800 ms) than the older age group (550 ms). Moreover, differences can be observed between 4-year-old monolinguals (900 ms) and bilinguals (700 ms). The 5-year-old monolinguals and bilinguals need about the same amount of time (500 ms vs. 600 ms) for prediction to occur.

Individual differences

Next, we examined the relationship between children’s eye-gaze performance (prediction ability, i.e. fixations to targets in the semantic vs. the neutral condition over the anticipatory window) and their performance on the linguistic and cognitive tasks. Table 5 shows the Pearson correlations between these measures for monolinguals and bilinguals, respectively. The only measure that correlated significantly with prediction ability is the forward condition of the DST in the bilingual group ($r(51) = .358, p < 0.01$), indicating that better prediction ability was related to higher performance on this condition.

We carried out a multiple regression analysis to estimate the independent contribution of each measure to prediction. The eye-gaze to targets in the semantic versus the neutral condition (i.e. difference scores; measured in log-transformed looks converted to z-scores) from verb onset to noun onset was used as dependent variable. The linguistic and cognitive measures were used as predictor variables in the multiple regression models. As a linguistic predictor we entered the standardized scores of the PPVT. As cognitive measures we entered the difference in response time on the incongruent minus the congruent condition (i.e. the Flanker effect) and the raw accuracy scores on the forward and the backward condition of the DST. All predictors were standardized as z-scores and entered stepwise in the regression model. We analyzed the data of the monolinguals and the bilinguals independently but we collapsed across age groups to ascertain a larger number of participants within each model.

The monolingual model showed no significant predictors that explained the eye gaze performance. The bilingual data, however, showed that the forward condition
Table 4. T-scores for difference between target fixations in semantic vs. neutral condition measured from 200 ms after verb onset

<table>
<thead>
<tr>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Monolinguals</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-year</td>
<td>0.44</td>
<td>0.24</td>
<td>−0.03</td>
<td>−0.12</td>
<td>−0.09</td>
<td>−1.09</td>
<td>−1.67</td>
<td>−2.62</td>
<td>−2.21</td>
<td>−2.48</td>
<td>−2.73</td>
<td>−2.57</td>
<td>−2.17</td>
</tr>
<tr>
<td>5-year</td>
<td>0.11</td>
<td>0.58</td>
<td>−0.86</td>
<td>−2.34</td>
<td>−5.48***</td>
<td>−5.52***</td>
<td>−6.41***</td>
<td>−5.33***</td>
<td>−4.58***</td>
<td>−5.30***</td>
<td>−4.88***</td>
<td>−4.98***</td>
<td>−5.48***</td>
</tr>
<tr>
<td><strong>Bilinguals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-year</td>
<td>1.05</td>
<td>0.98</td>
<td>0.65</td>
<td>0.28</td>
<td>−1.72</td>
<td>−3.00*</td>
<td>−3.21*</td>
<td>−3.83**</td>
<td>−2.88</td>
<td>−3.47**</td>
<td>−4.17**</td>
<td>−4.18**</td>
<td>−4.22**</td>
</tr>
<tr>
<td>5-year</td>
<td>0.26</td>
<td>−0.92</td>
<td>−1.33</td>
<td>−1.98</td>
<td>−2.97*</td>
<td>−2.97*</td>
<td>−2.07*</td>
<td>−2.93*</td>
<td>−2.77*</td>
<td>−2.34*</td>
<td>−3.60*</td>
<td>−4.14**</td>
<td>−3.13*</td>
</tr>
</tbody>
</table>

* p < .05;  
** p < .01;  
*** p < .001;  
# p < .0001
of the DST was a significant predictor ($\beta = .37, SE = .13, t = 2.74, p < 0.01$). The other measures did not contribute significantly (all $p > 0.05$). Figure 2 displays this relation between prediction ability and working memory for the bilinguals.

Table 5. Pearson correlations between prediction ability (eye-gaze), linguistic and cognitive measures (transformed to z-scores) in monolinguals (below the diagonal) and bilinguals (above the diagonal)

<table>
<thead>
<tr>
<th></th>
<th>Prediction ability</th>
<th>PPVT</th>
<th>Flanker</th>
<th>DST-forward</th>
<th>DST-backward</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prediction ability</td>
<td>1</td>
<td>.107</td>
<td>−0.31</td>
<td>.358*</td>
<td>.142</td>
</tr>
<tr>
<td>PPVT</td>
<td>.054</td>
<td>1</td>
<td>.031</td>
<td>.429*</td>
<td>.366*</td>
</tr>
<tr>
<td>Flanker</td>
<td>.199</td>
<td>.124</td>
<td>1</td>
<td>.010</td>
<td>−.047</td>
</tr>
<tr>
<td>DST-forward</td>
<td>.095</td>
<td>.345*</td>
<td>.037</td>
<td>1</td>
<td>.577**</td>
</tr>
<tr>
<td>DST-backward</td>
<td>−.011</td>
<td>.173</td>
<td>.081</td>
<td>.364*</td>
<td>1</td>
</tr>
</tbody>
</table>

$PPVT =$ Peabody Picture Vocabulary Task; DST = Digit Span Task; *Correlation is significant at the 0.01 level; **Correlation is significant at 0.001 level

Figure 2. Working memory scores (measured with the forward condition of the Digit Span Task) plotted against prediction ability (difference scores between target fixations in the semantic minus the neutral condition) for the bilingual children.
Discussion

The present study is the first to compare semantic prediction abilities in monolingual and bilingual children. In addition, we investigated which linguistic and/or cognitive factors are associated with sentence prediction ability. In a visual-world eye-tracking experiment, we compared 4–5 year old monolingual and bilingual children’s eye gaze behavior to two pictures (e.g. cake, tree) on the screen while hearing semantically constraining (The boy eats the big cake) and neutral sentences (The boy sees the big cake). We also assessed their receptive vocabulary, inhibition, and working memory skills. Our results showed three main findings, which we will discuss below.

First, we looked at prediction ability across our four groups (4 and 5 year old monolingual vs. bilingual children). Prediction ability was measured by comparing target fixations in the semantic vs. the neutral condition across the anticipatory time window (i.e. from verb onset until noun onset). Our results first showed that all of our four groups made use of prediction, indicating that predictive processes are at play in the course of L2 sentence comprehension. Secondly, prediction ability was equal in each of our four groups, regardless of their age, their language status, and/or whether they performed the task in their L1 or in their L2. If we consider this measure as an index of predictive processing, we can conclude that bilingual children are able to anticipate information on the basis of the semantics of the verb in a similar way as monolingual children. This is consistent with previous research on morphosyntactic prediction (Dussias et al., 2013; Foucart et al., 2014; Hopp, 2013; but see e.g. Grüter et al., 2012; Lew-Williams & Fernald, 2010; Martin et al., 2013). On the basis of these findings, we can conclude that bilingual children have no problems with semantic prediction in their L2.

Two possible explanations can be given for the finding that bilinguals showed the same prediction effect as monolinguals. The first explanation is similar to Foucart et al.’s (2014, p. 8) suggestion as mentioned in their conclusion section “we foresee that highly proficient bilinguals would anticipate upcoming words like monolinguals even when their two languages present cross-linguistic differences”. Although our bilingual children had a significantly lower receptive vocabulary than our monolingual children (as measured with the PPVT), the standardized score of our bilingual children (i.e. 98) still fell within the average range, indicating that this group was reasonably proficient in Dutch. 85% of our bilingual children also started to learn Dutch at the age of one. Moreover, the sentences in our study consisted of mid-to-high frequency verbs and nouns that were most likely known to our bilingual participants. As our bilinguals had different linguistic backgrounds, it might indeed be the case that a certain level of proficiency overcomes any problems with semantic prediction.
A second explanation for the similar pattern for monolingual and bilingual children has to do with the type of predictive cue. Our study examined whether bilinguals use the semantics of the verb to predict the upcoming noun. Most of the previous work on bilinguals, however, focused on the use of morphosyntactic cues for prediction. The main difference between these types of cues is the potential for being “transferred” from one language to the other. Semantic cues can be seen as conceptual associations, which rely more on world knowledge. For example, after hearing the verb ‘eat’ the listener expects something edible (e.g. cake, apple, bread), independent of his or her language. Semantic knowledge is almost always similar across an L1 and an L2, which therefore makes “transfer” from one language to the other less difficult. Or, in other words, the lexical representations of the L1 and the L2 that share the same semantic content are easily merged together. However, morphosyntactic cues may differ across languages (e.g. in Dutch there is a two-way gender system, whereas in German there is a three-way gender system) or may even be present in one language but absent in the other language (e.g. gender exists in Dutch but not in Turkish). As transfer might not always be helpful in certain language combinations, this might make it harder for bilinguals to make use of morphosyntactic than of semantic cues.

Another difference between semantic and morphosyntactic cues, as pointed out by Huettig (2015, p. 129), is that “semantic context effects are likely to build up over the course of the sentence, whereas the cue (in morphosyntactic experiments) is a relatively local one”. In our study, the anticipatory window was 2400 ms long, which confirms Huettig’s reasoning that participants have plenty of time to make predictions when the sentence unfolds. Looking at morphosyntactic studies, and in particular grammatical gender studies, the anticipatory window is typically smaller as this window only contains the length of the determiner (and in some cases also the length of an adjective following the determiner). If the length of the anticipatory window plays an important role, it might be possible that bilinguals can take advantage from the long semantic window but experience disadvantages when the window is short, as in gender studies, and prediction has to occur relatively instantaneously. We will come back to this issue below.

The second main finding of our study relates to the time course of prediction effects. While we found that bilinguals were able to predict like monolinguals, we were also interested to discovering when our bilinguals were able to benefit from the semantics of the verb. In particular, we examined whether there were differences in timing between L1 and L2 predictive processing. Our results demonstrated three important differences between groups. First, we found an effect of age, showing that the 4-year-olds needed on average approximately 250 ms more time than the 5-year-olds for prediction to occur. Secondly, our results revealed that the 4-year-old bilinguals were about 200 ms faster than the monolinguals, whereas the timing
for the 5-year-old monolinguals and bilinguals hardly differed from each other. And thirdly, we observed that bilinguals’ prediction speed hardly changed over time (from 700 (4-year olds) to 600 ms (5-year olds)), whereas the monolinguals’ prediction speed decreased substantially over time (from 900 (4-year olds) to 500 ms (5-year olds)). This indicates that separate developmental processes might be at work for monolinguals’ and bilinguals’ predictive processing skills. Longitudinal data from the same participant (within-participants design) needs to be collected to get more insight into this matter.

Although we observed these timing differences, note that the prediction effect initiated as early as during the unfolding of the verb for each of our four groups. This indicates that even before the verb was fully uttered, monolingual and bilingual children are able to predict the upcoming noun. On average, it took our groups 675 ms to benefit from the semantics of the verb. Comparing this length with the timing of effects in gender studies shows that this is longer than the length of a determiner but is about the same length when the window contains a determiner and an adjective. Thus, although semantic context can be built up over the course of a sentence, it seems like our monolingual and bilingual children hardly made use of this entire duration but predicted as soon as possible, that is, when they more or less knew which verb was uttered by the speaker.

The time course results seem to fit with two of our predictions as described in the Introduction section. The results of the 5-year-olds are mainly in line with the idea that there are no processing differences between monolinguals and bilinguals. The difference between the two groups was only about 100 ms long and the bilinguals showed a marginally significant effect at approximately 500 ms where the monolinguals showed an effect at $p < 0.05$. Also, when the data are not log-transformed, both groups experienced an effect from 500 ms on. These findings therefore seem to fit with the prediction ability effects: no predictive processing differences between 5-year-old monolinguals and bilinguals.

However, the results of the 4-year-olds are more consistent with the idea that bilinguals are better able to predict upcoming information than monolinguals. The 4-year old monolinguals needed on average approximately 200 ms more time to predict than the 4-year old bilinguals. This suggests that bilingual children might have developed anticipation skills earlier than monolingual children. A similar bilingual advantage has been found for 4-and 5-year-olds in a non-linguistic anticipation task (Bonifacci et al., 2011). Bonifacci and colleagues explained their results by comparing them to the enhanced EF skills as found in bilinguals compared to monolinguals (e.g., Adesope et al., 2010; Bialystok & Viswanathan, 2009; Barac & Bialystok, 2011). As bilinguals are used to suppressing the irrelevant language, the authors argued that they also exert continuous practice in predicting upcoming elements (words, sentences, and meaning) in two or more languages, each
characterized by specific semantic, syntactic and pragmatic rules. Even though bilinguals might produce and perceive less utterances in their L2 (due to their concurrent L1 use) compared to monolinguals in their L1, they may have twice as much experience with encountering semantic information in two linguistic systems than monolinguals. Perhaps anticipation skills can therefore be seen as a component of EF abilities.

In the present study, we assessed two EF components, namely inhibition and WM skills, in our monolingual and bilingual children. Our inhibition results, as measured with the Flanker task, replicated previous work with monolingual and bilingual children (Adesope et al., 2010; Bialystok & Viswanathan, 2009; Barac & Bialystok, 2011). Not only were the bilinguals faster overall than the monolinguals but the interference from the incongruent compared to the congruent condition (i.e. the Flanker effect) was also less for the bilinguals. Our inhibition data thus clearly showed a bilingual advantage. The WM data, however, did not show such a bilingual benefit. On the contrary, the results from the Digit Span task showed that monolinguals outperformed our bilinguals, which is consistent with some of the previous work (e.g. Engel de Abreu, 2011). A possible reason for this, as suggested by an anonymous reviewer, may be that these results are a language effect. The monolingual children used their native and best language but this was not necessarily the case for the bilinguals.

The third main finding of the current study is related to the question whether EF skills support predictive processing. A growing body of previous research started to look at individual differences in predictive processing. This work has shown that EF plays an important role for prediction ability in adult monolinguals (Federmeier & Kutas, 1999; Federmeier et al., 2002; Federmeier et al., 2010; Huettig & Janse, 2016; Huettig et al., 2011). In our study, we examined the relationship between predictive processing and receptive vocabulary, inhibition and WM skills in monolingual and bilingual children. For the monolingual children we found no association between prediction ability and our linguistic and cognitive measures. This lack of an association is inconsistent with previous work (e.g. Borovsky et al., 2012; Mani & Huettig, 2012; Huettig & Janse, 2016). This difference might be due to the nature of our monolingual sample. On average, our monolinguals performed very well on all of our linguistic and cognitive measures, which might have caused not enough variation in their scores. However, for the bilingual children, we found that forward digit recall skills contributed to semantic prediction ability. The better the bilingual children were in repeating back digits in a forward fashion, the better their prediction skills were. This result seems to suggest that WM skills are important for predicting spoken language in real time because listeners need to rapidly adjust to novel information and linguistic structures. The language system must
therefore maintain, at least, momentarily, some memory of previously encountered linguistic elements. Alternatively, one could argue that these WM scores express language ability for the bilinguals (and not for the monolinguals).

To conclude, our results suggest that bilingual children use semantic prediction ability to the same extent as monolingual children. This goes against the hypothesis that bilingual children have weak semantic prediction mechanisms. They are as good in thinking ahead in their L2 as monolinguals are in their L1. More specifically, our results showed that 4-year-old bilinguals are faster in predicting than 4-year old monolinguals and that forward recall skills contribute to the bilingual children’s prediction ability. More research needs to be done to see if this holds true for predictive processing in general or only for semantic prediction. Furthermore, it needs to be tested whether bilinguals with different ages, proficiency levels, age of acquisition, amount of exposure, and (homogeneous) language backgrounds will show similar performance on semantic prediction.

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References


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Appendix

Stimuli used in the eye-tracking task. The two versions of each sentence are presented on the same line, with the semantically constraining sentence first. The distractor object of each sentence is between parentheses.

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>Translation</th>
</tr>
</thead>
<tbody>
<tr>
<td>De jongen eet/ziet de grote taart (boom)</td>
<td>The boy eats/sees the big cake (tree)</td>
</tr>
<tr>
<td>De jongen wast/pakt de groene broek (plant)</td>
<td>The boy washes/gets the green trousers (plant)</td>
</tr>
<tr>
<td>De jongen slaapt/staat in het mooie bed (gras)</td>
<td>The boy sleeps in/stands in the nice bed (grass)</td>
</tr>
<tr>
<td>De jongen bouwt/ziet het rode huis (geld)</td>
<td>The boy builds/sees the red house (money)</td>
</tr>
<tr>
<td>De jongen drinkt/krijgt de koude melk (bank)</td>
<td>The boy drinks/gets the cold milk (couch)</td>
</tr>
<tr>
<td>De jongen speelt op/staat op de blauwe fluit (kast)</td>
<td>The boy plays/stands on the blue flute (closet)</td>
</tr>
<tr>
<td>De jongen rijdt op/kijkt naar het bruine paard (schaap)</td>
<td>The boy rides/looks at the brown horse (sheep)</td>
</tr>
<tr>
<td>De jongen schiet op/wacht op de oude beer (kip)</td>
<td>The boy shoots/waits for the old bear (chicken)</td>
</tr>
<tr>
<td>Het meisje rijdt op/kijkt naar de oude fiets (steen)</td>
<td>The girl rides on/looks at the old bike (stone)</td>
</tr>
<tr>
<td>Het meisje leest/brengt het mooie boek (raam)</td>
<td>The girl reads/brings the nice book (window)</td>
</tr>
<tr>
<td>Het meisje gooit/ziet de rode bal (schoen)</td>
<td>The girl throws/sees the red ball (shoe)</td>
</tr>
<tr>
<td>Het meisje draagt/koopt de blauwe jurk (kaars)</td>
<td>The girl wears/buys the blue dress (candle)</td>
</tr>
<tr>
<td>Het meisje melkt/help de grote koe (hond)</td>
<td>The girl milks/helps the big cow (dog)</td>
</tr>
<tr>
<td>De jongen eet/draait de grote kers (hoed)</td>
<td>The boy eats/turns the big cherry (hat)</td>
</tr>
<tr>
<td>De jongen knipt/tekent het bruine haar (dak)</td>
<td>The boy cuts/draws the brown hair (roof)</td>
</tr>
<tr>
<td>De jongen draagt/krijgt de rode bril (kop)</td>
<td>The boy wears/gets the red glasses (cup)</td>
</tr>
<tr>
<td>De jongen draagt/brengt het groene hemd (glas)</td>
<td>The boy wears/brings the green shirt (glass)</td>
</tr>
<tr>
<td>Het meisje drinkt/krijgt de koude thee (muts)</td>
<td>The girl drinks/gets the cold tea (woolen hat)</td>
</tr>
<tr>
<td>Het meisje verft/haalt het mooie hek (brood)</td>
<td>The girl paints/gets the nice fence (bread)</td>
</tr>
<tr>
<td>Het meisje wast/kleurt de blauwe trui (bloem)</td>
<td>The girl washes/colours the blue sweater (flower)</td>
</tr>
<tr>
<td>Het meisje eet/pakt de oude kaas (jas)</td>
<td>The girl eats/gets the old cheese (jacket)</td>
</tr>
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