Lexical Priming as Evidence for Language-Nonselective Access in the Simultaneous Bilingual Child's Lexicon

Elly Koutamanis, Gerrit Jan Kootstra, Ton Dijkstra, and Sharon Unsworth

1. Introduction

It is well known that bilingual language processing cannot simply be equated to monolingual language processing (Grosjean, 1989). However, compared to the extensive adult bilingualism literature, bilingual language processing in children remains relatively unexplored. More specifically, how two languages are represented in the bilingual child's lexicon and how they interact with each other has only recently started to gain attention. As child bilingualism research has traditionally focused more on morphosyntax (see e.g., Serratrice, 2013), our knowledge of the bilingual lexicon is mostly based on adult research. In this paper, we examine whether insights from the literature on the adult bilingual lexicon apply to bilingual children as well.

In adults, the organization of the lexicon is often studied using lexical priming techniques: Participants are presented with a sequence of two related words and their processing is monitored, for instance in a lexical decision task. A priming effect ensues when the properties of the first word (i.e., the prime) affect the processing of the second word (i.e., the target). These properties include semantics, orthography, and phonology: Semantically related words can prime each other (e.g., *doctor* is processed faster after *nurse* than after the unrelated *bread* [e.g., Meyer & Schvaneveldt, 1971]), as well as orthographically and/or phonologically related words (such as *candle* and *candy,* [see e.g., Hamburger & Slowiaczek, 1996]). Such priming effects are evidence for models of the mental lexicon with connections between related form and meaning representations, and activation spreading through these connections.

Adult bilingualism studies have found priming effects between words from different languages: at the semantic level (e.g., Dimitropoulou et al., 2011a), the orthographic level (e.g., Dijkstra et al., 2010), and the phonological level (e.g., Dimitropoulou et al., 2011b). These between-language priming effects support the view that both languages are represented in one shared lexicon, with connections between form and meaning representations of words from both

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languages. During processing, access to the lexicon is language-nonselective, which means that words from both languages are activated.

It is important to investigate between-language priming in children because of two key differences between bilingual children and bilingual adults: their age of onset and their chronological age. First, most research on adult bilingualism has focused on second language (L2) speakers, whereas in bilingual children both languages develop more or less simultaneously. In simultaneous language development research, the emphasis has so far been on separation between the two language systems, particularly regarding morphosyntax (see e.g., Meisel, 1989; De Houwer, 1990). The question is whether this extends to the lexicon. Second, research on monolingual children and adults has suggested that children show more lexical priming effects due to less efficient processing. This has been demonstrated with mediated priming, where prime and target are not directly related to each other but are both related to another word. Specifically, phonological priming through semantics, where *cat* primes *doll* via its relation with *dog*, was found in monolingual children but not in adults (Jescheniak et al., 2006). According to Jescheniak et al., this suggests that children activate more related words than adults. If this extends to between-language priming as well, we might expect even stronger evidence for language-nonselective access in children than in adults.

Some recent studies have investigated between-language priming in toddlers. Von Holzen and Mani (2012) conducted a preferential looking study with German-English bilingual toddlers. The children heard English primes and German target words, followed by two images: the target image and an unrelated distractor. In the phonological priming condition, where prime and target rhymed with each other (e.g., *slide* – *Kleid* ‘dress’), the children’s looks to the target increased compared to the control condition, resulting in a facilitatory priming effect. In addition, an inhibitory effect of mediated priming in the form of phonological priming through translation was found: If the German translation of the English prime rhymed with the German target word (e.g., *leg* – *Stein* ‘stone’, related via *Bein* ‘leg’), target image looks decreased. These priming effects, both facilitatory and inhibitory, suggest that both the phonological and the semantic representations of words from both languages are accessed during bilingual toddlers’ language processing.

Similar methods have been used to reveal other types of within- and between-language priming in bilingual toddlers. Singh (2014) found between-language and within-language semantic priming (e.g., *table* – *chair*) effects in English-Mandarin Chinese simultaneous bilingual toddlers. Both types of effects were influenced by language dominance: Within-language priming was found only within children’s dominant language, and between-language priming was only found from the dominant to the non-dominant language. Jardak and Byers-Heinlein (2019) partly replicated these findings with French-English early and simultaneous bilingual toddlers. They revealed both within- and between-language semantic priming, but unaffected by language dominance. Finally, Floccia et al. (2020) found translation priming effects (e.g., *cheese* – *fromage* ‘cheese’) and between-language semantic priming (e.g., *dog* – *chat* ‘cat’) effects in bilingual toddlers from diverse language backgrounds. These effects were not influenced by direction, language dominance, or language distance between the toddlers' two languages (as measured by phono-lexical overlap), and translation priming and between-language semantic priming effects did not differ from each other.

Taken together, these studies suggest that, like bilingual adults, young simultaneous bilinguals have an integrated lexicon with language-nonselective access. However, these studies all tested the same age group, providing no evidence for how the bilingual lexicon develops throughout childhood. In addition, as it is difficult to conduct systematic investigations of multiple forms of priming in such young children, most studies have focused on only one level of lexical representation.

1.1. Present study

In the present study, we aim to uncover to what extent and at which levels of lexical representation language-nonselective access take place in school-aged simultaneous bilinguals. To this end, we investigated between-language lexical priming effects in older Dutch-Greek bilingual children, using an eye-tracking task similar to the primed preferential looking tasks described above, combined with picture selection (illustrated in Figure 1).

First, to investigate the levels at which language-nonselective access takes place, we tested for between-language phonological priming and translation priming. We expected to find priming effects at both levels. Second, to explore the extent of language-nonselective access, we tested for phonological priming through translation. We expect to find such mediated priming effects, which would suggest that words do not only activate their translation equivalents, but that activation continues to spread to phonologically related words from both languages. As a control for our paradigm, we included within-language priming conditions, which were tested in bilingual as well as in monolingual children: within-language phonological priming, semantic priming, and – tested in monolinguals only – phonological priming through semantics, as a within-language counterpart to phonological priming through translation (see Table 1).

2. Method

2.1. Participants

The participants were 26 bilingual Dutch-Greek children, aged between 4;7 and 9;2 (*M* = 6;9, *SD* = 1;7), and 26 monolingual Dutch children, aged between 4;5 and 9;2 (*M* = 6;9 *SD* = 1;5), all living in the Netherlands. All bilingual children had received substantial input in both Greek and Dutch, defined as minimally half a day per week, since before the age of four, although most (*n* = 20) had started learning both languages from birth. The majority of bilingual children (*n* = 22) received more Dutch than Greek input, but generally (*n* = 18) neither language accounted for more than 70% of their input. No participants had received substantial input in any other languages than Dutch and/or Greek for minimally

3.5 years prior to testing, but monolingual and bilingual children who were receiving up to an hour of English education per week were included.

There were no significant differences between monolinguals and bilinguals in age ($t(48.865) = 0.024$, p = .98) or whether both parents had obtained a university degree ($\chi^2(1) = 0.18$, p = .67). Taking parental education as a proxy for socio-economic status (SES), most monolingual (n = 23) and bilingual (n = 21) children came from a higher SES background.

2.2. Materials

The stimuli consisted of prime and target words, presented auditorily, and target and distractor images. The target words were 28 Dutch nouns. Each target word was matched to nine different prime words, five Dutch and four Greek nouns, based on semantic and/or phonological overlap (see Sections 2.2.1 and 2.2.2 for details). Matching each target word with multiple primes allowed the same targets to be used in different between- and within-language priming conditions. Each target image was matched to a semantically and phonologically unrelated distractor image.

2.2.1. Design

The bilingual children were tested twice, once in a Dutch-to-Dutch (D-D) priming session and once in a Greek-to-Dutch (G-D) priming session, and the monolingual children were tested once in a Dutch-to-Dutch (D-D) priming session. The same Dutch target words were used in all sessions and in all conditions, but in the D-D sessions they were paired with Dutch primes and in the G-D session with Greek primes.

Table 1. Priming conditions per session, with examples

	Monolingual children	Bilingual children	
Overlap	Dutch-to-Dutch session	Dutch-to-Dutch session	Greek-to-Dutch session
None (control)	Unrelated priming$_a$ *vis* 'fish' – *rok* 'skirt'	Unrelated priming$_a$ *vis* 'fish' – *rok*	Unrelated priming *psari* 'fish' – *rok*
Phonological	Phonological priming$_b$ *rots* 'rock' – *rok*	Phonological priming$_b$ *rots* 'rock' – *rok*	Phonological priming *roda* 'wheel' – *rok*
Semantic	Semantic priming$_c$ *jurk* 'dress' – *rok*	Semantic priming$_c$ *jurk* 'dress' – *rok*	Translation priming *fousta* 'skirt' – *rok*
Phonological and semantic	Phonological priming through semantics *steen* 'stone' – (*rots*) – *rok*	Phonological priming through translation *wiel* 'wheel' – (*roda*) – *rok*	Phonological priming through translation *vrachos* 'rock' – (*rots*) – *rok*

Note: Identical conditions are marked with identical subscripts.

Each session consisted of four conditions (see Table 1 for examples): i) a control condition, in which prime and target, as well as their translations, were phonologically and semantically unrelated; ii) a phonological condition, in which prime and target had word-initial phonological overlap; iii) a (within-language) semantic or (between-language) translation condition; and iv) a mediated condition, which differed per session. In the G-D session, the Dutch translation of the Greek prime overlapped phonologically with the Dutch target (Greek-through-Dutch-to-Dutch phonological overlap through translation [G-D-D], equivalent to phonological priming through translation in Von Holzen & Mani, 2012). In the D-D session for bilingual children, the Greek translation of the Dutch prime overlapped phonologically with the Dutch target (Dutch-through-Greek-to-Dutch phonological overlap through translation [D-G-D]). For the monolingual children, the (Dutch) prime was semantically related to a (Dutch) word that overlapped phonologically with the Dutch target (phonological priming through semantics). Apart from this condition, the D-D sessions for monolingual and for bilingual children were identical.

2.2.2. Stimulus selection and matching criteria

As primes, targets, and distractors, we selected noncognate nouns from word lists expected to be known by young (monolingual Dutch) children, and the Greek translations of these lists: N-CDI (Zink & Lejaegere, 2002), Lexilijst (Schlichting & Lutje Spelberg, 2002), BAK (Mulder et al., 2009), and first half of the PPVT-III-NL (Dunn et al., 2005). To further decrease the likelihood of participants not knowing the prime and target words, we only selected words with an age of acquisition (AoA) below 8;0 according to Brysbaert et al. (2014).

Semantic relations between primes and targets were defined based on the CELEX database (Baayen et al., 1993) and our own intuitions. Phonological relations were defined based on, minimally, the phonemes in the onset and nucleus of the first syllable of each word.[1] Overall, we aimed to minimize differences in frequency (based on SUBTLEX-NL [Keuleers et al., 2010] and SUBTLEX-GR [Dimitropoulou et al., 2010]), AoA (Brysbaert et al., 2014), and length (in syllables) between the sets of primes and targets. In the phonological conditions, all but two (Greek) primes differed no more than one syllable in length from their corresponding target.

The 28 target images and 28 distractor images were full-color clip-art images, on a dark gray background, sized 512 x 512 pixels. The distractor images were similar to the target images to which they were matched in terms of color and visual complexity, based on our own intuitions. The distractor images were semantically and phonologically (in both Dutch and Greek) unrelated to the prime and target words to which they were matched.

The 28 Dutch target words and the 140 and 112 Greek prime words were recorded by a female bilingual native speaker of Dutch and Greek.

2.2.3. Background tests

In addition to the main experiment, we assessed the children's non-linguistic working memory span using the Forward and Backward Digit Span Test

[1] For pairs of Dutch words, these phonemes had to be identical, but for pairs of Greek and Dutch words we made some exceptions for phonemes that were similar, such as /ɑ/ and /a/.

(Alloway, 2012) in Dutch as well as its Greek translation. We also assessed the children's proficiency in Dutch and Greek and their exposure to and use of both languages, using several proficiency tasks as well as a parental questionnaire, although these results are not discussed in this paper.

2.3. Apparatus and procedure

All children were tested individually in quiet rooms in their homes. A laptop with a Tobii Pro X3-120 eye tracker was placed on a table, as well as two response buttons. The child was seated 60-70 cm from the laptop, which had a 15.6 inch screen with a 1366 x 768 pixel resolution. To regulate light and/or block potential distractions, two 50 x 30 cm black PVC screens were used. Audio was played to the children through headphones. The main task was programmed in OpenSesame 3.2.5 (Mathôt et al., 2012), using the PyGaze plugin (Dalmaijer et al., 2014) to program the eye tracking component of the experiment.

The monolingual children were tested once. The bilingual children were tested twice, starting with the D-D priming session and the Dutch background tests, and, one to three weeks later, followed by the G-D session and the Greek background tests. On both occasions, the bilingual children were tested by the same Dutch-Greek bilingual experimenter (the first author), who spoke Dutch in the first session and Greek in the second session. A testing session lasted 60-70 minutes.

The main task, which was embedded in a scavenger-hunt-themed game, consisted of 112 trials. These were divided over four blocks of 28 trials, with each block containing each target word in a different condition and containing seven items per condition. The order between the blocks was rotated over participants using a Latin square. The order of the items within the blocks was randomized per participant, with no more than two subsequent trials in the same condition, and with minimized semantic and phonological overlap between subsequent trials.

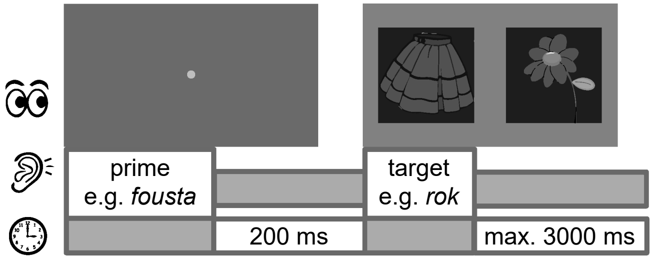

Figure 1. Timeline of a trial, with visual and auditory stimuli

An experimental trial started by showing a yellow fixation symbol on a grey background. After 800 ms, the prime word was played. After a 200 ms pause, the target word was played and, simultaneously, the fixation symbol was replaced by the target image and the distractor image side by side (see Figure 1). Whether the target image appeared on the left or on the right side of the screen was counterbalanced per target between blocks. Participants had up to 3000 ms from the onset of the target word to select a picture and press the corresponding response button – the left button indicated selecting the left picture, and the right button the right picture. Accuracy and response time (RT) data were obtained through these button presses. Eye movements were recorded throughout the trial.

Before the experimental trials, each block started with a recalibration of the eye-tracker and with practice trials. Two to five practice trials were conducted (five in the first block, increasingly fewer in the subsequent blocks).

3. Results

3.1. Analysis

Data were excluded when high error rates and late responses indicated that children did not understand that particular part (e.g., block) of the task. This was the case for five bilingual children and one monolingual child. The remaining responses were coded as correct if the child pressed the correct button within 2500 ms after the offset of the (spoken) target word, and only correct responses within 2.5 SD above or below participant average were included in RT analysis. Of the eye-tracking data, only data within 2000 ms after image onset in correct trials were analyzed.

To answer our research questions, we performed separate RT and eye-tracking analyses for the monolinguals and bilinguals for 1) between-language phonological and translation priming; 2) mediated priming (phonological priming through semantics for the monolinguals, and both forms of phonological priming through translation for the bilinguals); and 3) within-language phonological and semantic priming.

3.1.1. Response time analyses

The RT data were analyzed in linear mixed effects regression models with the lmer function from the lme4 package (Bates et al., 2015). The RTs were log-transformed, approaching a normal distribution (cf. Baayen & Milin, 2010). All continuous variables except logRT and Trial number[2] were scaled and mean-centered. Orthogonal sum-to-zero contrast coding was applied to categorical variables with two levels (i.e., Sex, SES, and, in certain analyses, Condition). In the analyses with more than two conditions, treatment coding was applied to Condition, with the unrelated condition as the reference level. Where data from both sessions were combined (i.e., the mediated priming analyses), the unrelated condition from the D-D session was the reference level.

All models included Condition as a predictor for logRT, and random intercepts for participant and target word. Next, item variables (Prime and Target Frequency, AoA, and Duration [in ms]), task variables (Trial number, Previous

[2] When data from two sessions were combined, Cumulative trial number was used.

trial accuracy, Previous trial RT), and participant variables (Age, Sex, Socio-economic status (SES), and Working memory[3]) were added to the model in a stepwise manner. Of the item, task, and participant variables, only those predictors that significantly improved the model were included, as was established through Likelihood Ratio Tests using the anova function in the base package (R Core Team, 2020). For Age, Trial number and Working memory, we also tested for interactions with Condition. In the final models, p-values were obtained using Type 2 conditional F-tests with Kenward-Roger approximation for degrees of freedom as implemented in the Anova function of the package car (Fox & Weisberg, 2019). Post-hoc tests were carried out using the emmeans and emtrends functions of the package emmeans (Lenth, 2020).

3.1.2. Eye-tracking analyses

The eye-tracking data were analyzed with bootstrapped cluster-based permutation analyses (Maris & Oostenveld, 2007) using the eyetrackingR package (Dink & Ferguson, 2018). The only predictor in these analyses was Condition, which was coded in the same way as in the RT analyses. The dependent variable was proportion of gaze towards the target, averaged over bins of 30 ms, from the onset of the target word and images until the end of the trial.

A linear regression model testing for the effect of Condition was run on each time bin. For each cluster consisting of one or more adjacent bins with a t-value of at least 2, the sum of the t-values was calculated. We then performed 1000 simulations, in which we randomly shuffled the data and performed the same procedure, and saved the largest summed t-value of each simulation. The p-value of our original cluster was then obtained by comparing its summed t-value with the distribution of the simulated t-values: The effect of Condition in a cluster was considered significant if the summed t-value of that cluster was larger than 95% of simulated t-values, corresponding to a p-value of .05. In the analyses where more than two conditions were compared, we performed the bootstrapping cluster-based permutation procedure separately for each condition against the others.

3.2. Between-language priming

To investigate at which levels we could find between-language priming, we performed RT and eye-tracking analyses on the control condition, phonological condition, and translation condition from the G-D priming session. Our final RT model of between-language priming in bilingual children is presented in Table 2. Most importantly, we found a main effect of Condition. Post-hoc pairwise comparisons revealed a significant difference between the control condition and the translation priming condition ($t(1781) = 3.394$, $p = .002$) and between the

[3] The mean of the forward and backward digit span tests; for the bilingual children also averaged over both languages.

control condition and the phonological priming condition ($t(1771) = 4.155$, $p < .001$), but not between the two priming conditions ($t(1790) = 0.679$, $p = .776$. As is illustrated in Figure 2, both priming effects were facilitatory, resulting in shorter RTs.

Table 2. Parameter estimates and results from significance tests of the final model of between-language priming in bilingual children

	Parameter estimates		Significance tests		
Predictor	Beta	SE	F-value	Df/residuals	p-value
(Intercept)	7.040	0.032			
Target length	0.027	0.009	8.140	1/29.84	.008 **
Prime length	-0.013	0.007	3.798	1/500.64	.052
Trial number	-0.00001	0.0003	8.608	1/1769.46	.004 **
Previous trial RT	0.043	0.006	49.203	1/1800.41	< .001 ***
Age	-0.147	0.020	55.951	1/21.79	< .001 ***
SES	0.132	0.053	6.299	1/21.15	.020 *
Translation condition	-0.033	0.026	9.886	2/1780.21	< .001 ***
Phonological condition	0.012	0.026			
Transl. cond. x trial num.	-0.0002	0.0004	4.934	2/1771.59	.007 **
Phon. cond. x trial num.	-0.001	0.0004			

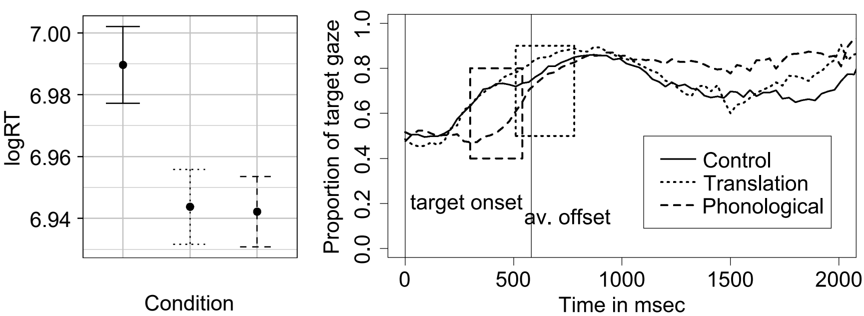

Figure 2. Left: LogRT per condition for between-language priming in bilingual children. Right: proportion of target gaze over time per condition

The eye-tracking analysis revealed that the phonological condition differed from the other conditions between 300 and 540 ms after the onset of the target word and images ($p = .021$). In addition, the translation condition differed from the other conditions between 510 and 780 ms ($p = .039$). Visual inspection of Figure 2 reveals that gaze towards the target image decreased during the significant time cluster in the phonological condition, indicating inhibitory phonological priming. The translation effect was facilitatory, with increased target looks compared to the other conditions.

3.3. Mediated priming
3.3.1. Bilinguals

To investigate the extent of between-language priming effects, we investigated mediated priming in the bilingual children. We performed RT and eye-tracking analyses on the control conditions and phonological priming through translation conditions from both the D-D priming session and the G-D priming session. Our final RT model of mediated priming in bilingual children is presented in Table 3. There was a significant effect of Condition, but post-hoc pairwise comparisons revealed no significant differences between any two individual conditions. Post-hoc pairwise comparisons for the interaction between Condition and Age revealed no significant differences between any two conditions. Post-hoc pairwise comparisons for the interaction between Condition and Cumulative trial number revealed a significant difference between the effect of Cumulative trial number on the two control conditions ($t(2303) = -3.125$, $p = .010$) and between the G-D control condition and the D-G-D mediated condition ($t(2303) = -3.239$, $p = .007$). As can be seen in Figure 3, in the first (D-D) session, children's RTs decreased over time, regardless of whether they were being primed, whereas this was not (or less so) the case in the second (G-D) session.

Table 3. Parameter estimates and results from significance tests of the final model of mediated priming in bilingual children

	Parameter estimates		Significance tests		
Predictor	Beta	SE	F-value	Df/residuals	p-value
(Intercept)	7.120	0.030			
G-D-D condition	-0.015	0.050	4.043	3/2301.83	.007 **
D-G-D condition	0.008	0.027			
G-D control condition	-0.090	0.050			
Age	-0.126	0.019	67.794	1/21.91	< .001 ***
Previous trial RT	0.044	0.005	69.652	1/2328.62	< .001 ***
Cumul. trial number	-0.001	0.0003	31.806	1/2304.18	< .001 ***
SES	0.091	0.045	4.103	1/20.86	.056
G-D-D condition x Age	-0.0005	0.013	3.026	3/2305.13	.028 *
D-G-D condition x Age	-0.023	0.013			
G-D control cond. x Age	-0.030	0.013			
G-D-D condition x Cumul. trial number	0.0006	0.0004	4.693	3/2302.84	.003 **
D-G-D condition x Cumul. trial number	-0.00004	0.0004			
G-D control condition x Cumul. trial number	0.001	0.0004			

The eye-tracking analysis revealed that the D-G-D phonological priming through translation condition differed from the other conditions between 300 and 720 ms after the onset of the target word and images ($p < .001$), and that the G D-D mediated condition differed from the other conditions between 270 and 630 ms after the onset of the target word and images ($p < .001$). Visual inspection of Figure 3 reveals that both effects were inhibitory.

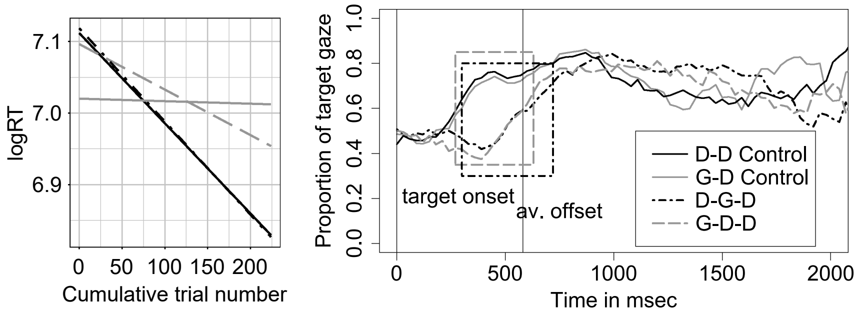

Figure 3. Left: The interaction between logRT and Cumulative trial number for mediated priming in bilingual children. Right: proportion of target gaze over time per condition

3.3.2. Monolinguals

Table 4. Parameter estimates and results from significance tests of the final model of mediated priming in monolingual children

	Parameter estimates		Significance tests		
Predictor	Beta	SE	F-value	Df/residuals	p-value
(Intercept)	7.120	0.023			
Trial number	-0.002	0.0002	107.599	1/1266.07	< .001 ***
Previous trial RT	0.036	0.006	33.725	1/1290.74	< .001 ***
Age	-0.116	0.019	36.793	1/23.93	< .001 ***
Phon. through sem. cond.	-0.001	0.010	0.0172	1/1262.04	.896

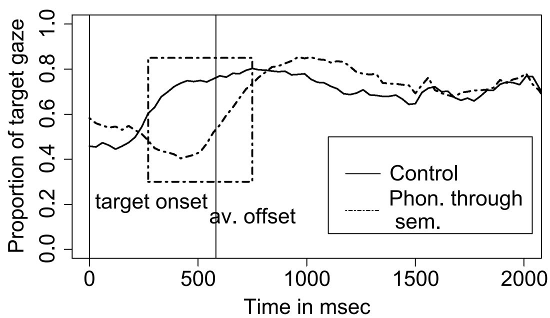

Figure 4. Proportion of target gaze over time per condition for mediated priming in monolingual children

As a control for the phonological priming through translation analyses, we analyzed phonological priming through semantics in the monolingual children.

We performed RT and eye-tracking analyses on the control condition and the phonological priming through semantics condition. Our final RT model is presented in Table 4. There was no significant effect of Condition. The eye-tracking analysis revealed that the conditions differed from each other between 270 and 750 ms after the onset of the target word and images ($p < .001$). Visual inspection of Figure 4 reveals that the phonological priming through semantics effect in this time cluster was inhibitory.

3.4. Within-language priming

Table 5. Parameter estimates and results from significance tests of the final model of within-language priming in bilingual children

	Parameter estimates		Significance tests		
Predictor	Beta	SE	F-value	Df/residuals	p-value
(Intercept)	7.170	0.036			
Prime length	-0.011	0.005	3.762	1/1141.81	.053
Trial number	-0.002	0.0002	108.471	1/1662.43	< .001***
Previous trial RT	0.036	0.006	40.155	1/1680.49	< .001***
Prev. trial accuracy	-0.066	0.027	6.121	1/1668.11	.013 *
Age	-0.120	0.031	15.277	1/20.17	< .001***
Semantic condition	0.008	0.011	0.179	2/1656.61	.836
Phon. condition	0.006	0.011			
Control condition x working memory	0.011	0.031	2.346	3/94.86	.078
Sem. condition x working memory	-0.015	0.031			
Phon. condition x working memory	-0.014	0.031			

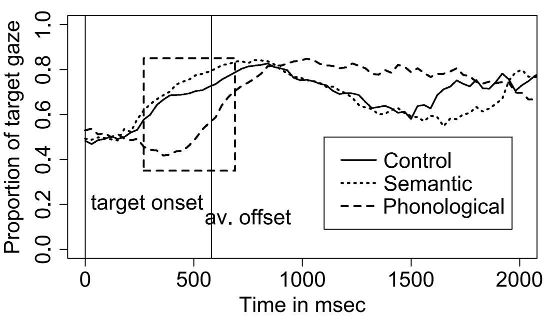

Figure 5. Proportion of target gaze over time per condition for within-language priming in bilingual children

As a further control for our paradigm, we investigated within-language priming in bilinguals and monolinguals. The RT and eye-tracking analyses for both groups included the control condition, phonological condition, and semantic condition from the D-D session. Our final RT model of within-language priming in bilingual children is presented in Table 5. There was no significant effect of Condition. The eye-tracking analysis revealed that the phonological condition differed from the other conditions between 270 and 690 ms after the onset of the target word and images (p = .001). Visual inspection of Figure 5 reveals the phonological priming effect in this time cluster was inhibitory.

Our final RT model of within-language priming in monolingual children is presented in Table 6. There was a significant effect of Condition. Post-hoc pairwise comparisons revealed a significant difference between the control condition and the semantic condition (t(1904) = 2.364, p = .048), but not between the semantic condition and the phonological condition (t(1904) = -2.310, p = .055) or the control condition and the phonological condition (t(1904) = 0.045, p = .999). As can be seen in Figure 6, the semantic priming effect was facilitatory. The eye-tracking analysis revealed that the phonological condition differed from the other conditions between 270 and 720 ms after the onset of the target word and images (p = .007). Visual inspection of Figure 6 reveals the phonological priming effect in this time cluster was inhibitory.

Table 6. Parameter estimates and results from significance tests of the final model of within-language priming in monolingual children

	Parameter estimates		Significance tests		
Predictor	Beta	SE	F-value	Df/residuals	p-value
(Intercept)	7.177	0.035			
Prime frequency	-0.011	0.005	4.422	1/1109.50	.034 *
Trial number	-0.001	0.0001	109.922	1/1908.44	< .001 ***
Prev. trial RT	0.045	0.005	70.566	1/1936.90	< .001 ***
Prev. trial accuracy	-0.001	0.0001	5.706	1/1916.97	< .001 ***
Age	-0.110	0.018	37.433	1/23.73	< .001 ***
Semantic condition	-0.024	0.010	3.646	2/1904.20	.026 *
Phon. condition	-0.0005	0.010			

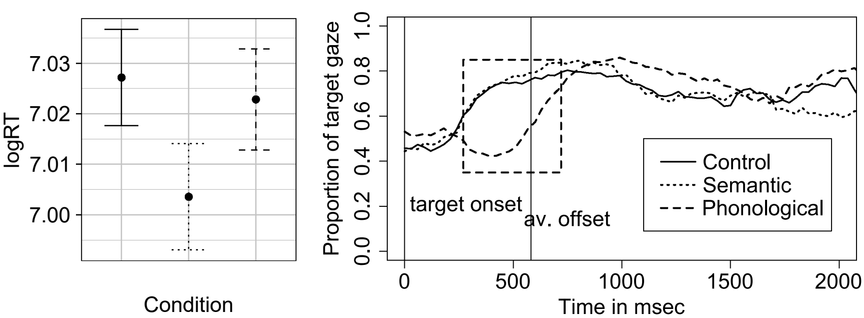

Figure 6. Left: LogRT per condition for within-language priming in monolingual children. Right: proportion of target gaze over time per condition

4. Discussion

This study aimed to uncover to what extent and at which levels of lexical representation there is language-nonselective access in school-aged simultaneous Dutch-Greek bilinguals. The children performed a primed picture selection task in which their eye movements were tracked. Between-language phonological and translation priming were tested, as well as two forms of phonological priming through translation, and within-language phonological and semantic priming. A monolingual Dutch control group was tested on the same within-language conditions, as well as phonological priming through semantics.

4.1. The levels of between-language priming

As predicted, we found between-language priming effects at both the semantic level (i.e., translation priming) and the phonological level in children's response times and eye movements. This indicates that these bilinguals have one fully integrated lexicon, with interactive connections between form and meaning representations of words from both languages, and language-nonselective access to the lexicon during processing. The translation priming effects in RTs and eye-tracking were facilitatory, whereas the phonological priming effect was facilitatory in the RTs but inhibitory in the eye-tracking results. Both inhibitory and facilitatory phonological priming effects have been found in the (monolingual and bilingual) literature, where facilitatory effects are generally associated with longer stimulus onset asynchronies (SOAs), and inhibitory effects with short SOAs, especially when words have word-initial form overlap (see e.g., Dufour, 2008). As explained by, for instance, Lupker and Colombo (1994), during processing, words with the same onset phonemes are co-activated and compete with each other for selection. If phonologically related words are presented with a short SOA, the competition leads to inhibitory priming. With longer SOAs, competition will have faded. As our eye-tracking analysis revealed, the inhibitory effect took place early in the trial, while the target word was, on average, still being played. At that moment, prime and target were likely still in competition. By the time participants selected the target image, this competition had faded. Because a trial ended as soon as a button was pressed, we had fewer eye-tracking data points later in the trial, which may explain why no late facilitation effect appeared in participants' gaze. Regardless, the finding that words from both languages competed with each other also suggests language-nonselective access.

The effects of language-nonselective access that we found at the phonological level and the semantic level are in line with previous studies on bilingual toddlers and adult L2-speakers, as discussed in the Introduction. To our knowledge, we were the first to thoroughly investigate between-language priming in older simultaneous bilingual children. Future research, especially longitudinal or cross-sectional, should focus on the question if and how effects of language-nonselective access change during development and differ between children and adults.

4.2. The extent of between-language priming

We explored the extent of language-nonselective access by testing for phonological priming through translation effects. Our predictions were partly borne out, as we found these priming effects in the eye-tracking data, while the RT results were inconclusive. Phonological priming through translation suggests that words from one language do not only activate their translation equivalents, but that activation continues to spread to phonologically related words. The eye-tracking effects were early inhibition effects (as in Von Holzen & Mani, 2012), similar to what we found in between-language phonological priming. These similar patterns suggest similar processes: A prime word's translation equivalent is automatically activated and subsequently competes with phonologically related words from both languages. In this indirect form of priming, the spreading of activation is possibly weaker than in other forms of priming and may have had already faded by the time the competition effect disappeared, which may be why no clear RT effects were found, in contrast to phonological priming.

Two forms of phonological priming through translation were included in this study, one in which prime and target were in the same language, and one in which they were in different languages. We found no differences between these two forms of priming: The language of the prime did not affect the degree to which translation equivalents were activated and activated phonologically related words. The interaction between condition and trial number likely had little to do with the language of the prime, but rather signaled a learning effect over time, where children's RTs decreased more during the first session than during the second session.

The results of previous toddler studies, as discussed in the Introduction, are inconclusive with regards to directionality and dominance. In the future, we will explore these issues by including participants' language proficiency, exposure, and use of both languages as predictors in our RT and eye-tracking analyses.

4.3. Control: within-language priming and phonological priming through semantics

Although we included within-language priming conditions as a control for our paradigm, we did not find effects in all conditions. This was unexpected, as previous adult and toddler studies (e.g., Perea et al., 2008; Singh, 2014) have found within-language priming to be equal or stronger than between-language priming. In our study, within-language phonological priming and phonological priming through semantics showed the same effects in eye-tracking as their between-language counterparts, but a semantic priming effect only emerged in the monolinguals' RTs, not in the bilinguals and not in the eye-tracking data.

One possible explanation comes from the strength of semantic relations. Translation equivalents share the same meaning, whereas semantically related words do not, so translation priming could be stronger than semantic priming (although this was not found by Floccia et al., 2020). This explanation is supported by the finding of a translation priming effect in both the bilingual children's RTs and eye-tracking, but a semantic effect only in the monolingual children's RTs, not in eye-tracking. The different findings in monolinguals and bilinguals may also indicate that certain semantic connections are stronger in monolingual children than in bilingual children. Our future analyses of the children's proficiency, exposure, and use may reveal if this is indeed a plausible explanation.

Another explanation is that the lack of certain within-language priming effects was a consequence of our experimental design, as within-language priming was always tested before between-language priming (although Singh [2014] found no order effects). By the second session the children had already been exposed to the specific target words and images multiple times, and to some extent even to the primes: the within-language phonological prime played a role in G-D-D mediated priming, and the between-language prime had already played a role in the D-G-D prime. In other words, the strong between-language priming effects we found might have been a combination of long-term priming from the first testing session and short-term priming from within the trials. This session effect would also explain why between-language phonological priming emerged in eye-tracking and the RTs, whereas within-language phonological priming only emerged in eye-tracking. Future studies in which the order of test sessions is counterbalanced, or monolingual children are tested in two sessions as well, could provide evidence for or against this explanation.

Finally, the weaker within-language effects may be explained by differences in processing strategies. Specifically, the Greek-to-Dutch priming session may have been more challenging and therefore engaging for the children, as both languages had to be explicitly activated, causing deeper processing (cf. Bjork & Kroll, 2015).

4.4. Conclusion

In conclusion, we found between-language priming in auditory lexical processing by four-to-nine-year-old simultaneous bilinguals. By combining different measures for language processing, we further found within- and between-language priming at both the semantic and the phonological level of lexical representation, as well as mediated priming through both these levels. Altogether, our results provide evidence for an integrated bilingual lexicon, fully shared at the phonological and semantic level with a high degree of connectivity within and between these levels, and with language-nonselective access. These findings in school-aged bilingual children corroborate earlier findings in bilingual toddlers. Future steps include analyzing the effects of the participants' proficiency, exposure, and use of both languages to get a better understanding of the factors influencing language-nonselective access and between-language priming effects.

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